RPWG
R

1700 SOUTH SHORES RD, SAN DIEGO, CA 92109 · HUBBS-SEA WORLD RESEARCH INSTITUTE · TEL: 619-226-3870 · FAX: 619-226-3944

Mr. Stanley E. Senner
Co-Chairman
Restoration Planning Work Group
EXXON Valdez Oil Spill Office
645 "G" Street
Anchorage, Alaska 99501

30 June 1992

Dear Stan,

Enclosed is the revised final report **REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: HARBOR SEALS AND KILLER WHALES** which incorporates comments and suggestions that you and John Strand offered in late April. We have not made changes to the annotated bibliography which you accepted earlier. We noted in the introduction of the text the reason for using pronouns in abstracts (i.e., when an abstract was included in the original reference we cited it as written), an editorial point raised by John Strand. If you need additional copies of the annotated bibliography or the final report printed on recycled paper please let us know.

Sincerely,

Brent S. Stewart, Ph.D.
Senior Staff Scientist

cc: Jehl
Yochem
Wright

encl. Final Report (35 pp) – 2 copies

RPWG
R

1700 South Shores Rd, San Diego, CA 92109 · Hubbs-Sea World Research Institute · Tel: 619-226-3870 · Fax: 619-226-3944

Mr. Stanley E. Senner
Co-Chairman
Restoration Planning Work Group
EXXON Valdez Oil Spill Office
645 "G" Street
Anchorage, Alaska 99501

30 June 1992

Dear Stan,

Enclosed is the revised final report **REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: HARBOR SEALS AND KILLER WHALES** which incorporates comments and suggestions that you and John Strand offered in late April. We have not made changes to the annotated bibliography which you accepted earlier. We noted in the introduction of the text the reason for using pronouns in abstracts (i.e., when an abstract was included in the original reference we cited it as written), an editorial point raised by John Strand. If you need additional copies of the annotated bibliography or the final report printed on recycled paper please let us know.

Sincerely,

Brent S. Stewart, Ph.D.
Senior Staff Scientist

cc: Jehl
Yochem
Wright

encl. Final Report (35 pp) — 2 copies

RPWG
R

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
**National Marine Fisheries Service**
**Office of Oil Spill Damage**
**Assessment and Restoration**
**P.O. Box 210029**
**Auke Bay, Alaska 99821**

December 14, 1992

Dr. Thomas E. Sibley
School of Fisheries (WH-10)
University of Washington
Seattle, WA 98195

Dear Tom:

Enclosed please find copies of three reviews that I asked Bob Spies and fellow peer reviewers to conduct on your report, "Comprehensive Review and Critical Synthesis of the Literature of Ecosystems From Disturbance (Fish and Shellfish)."

I would suggest that you take a few days to interpret the comments, determine how you will revise your report, then give me a call so that we might discuss and adopt a mutually agreeable course of action. Perhaps you would also be prepared to discuss the status of your budget. I trust that you will provide a copy of the reviews to Ahmad. Thank you.

Yours very truly,

John A. Strand,
Restoration Manager

Enclosures (3)

cc: John Armstrong
Byron Morris
RPWG

General Comments:

A strength of this approach is the systematic treatment of economically significant bony fishes, crustaceans, and molluscs. It is very useful to have statements based on literature records about the likelihood of recovery for these species. A further potential strength is the tilt toward literature that supports the time-heals-all-ecosystems hypothesis. This would become an actual strength if balanced by literature supporting the alternative hypothesis, "Ecological succession is a chaotic process leading to many possible equilibrium states."

Principal weaknesses lie in ignorance of some primary literature, a narrowness of the literature cited, and in confusion of correlative measures with conclusive evidence. Symptomatic of the confusion is the statement, "Shellfish populations typically recover more rapidly from other types of disturbance than from overfishing." (Page 2, Executive Summary). The authors do not present any data or literature to substantiate this assertion, the citations to papers contained in Caddy (1989) notwithstanding, nor am I aware that any exist.

The treatment of the key concept of ecological succession was not well balanced. The authors presume, without so stating, that any ecosystem will tend to return to its original state after perturbation, if the source of the perturbation is removed. They proceed to cite literature supporting this point of view, emphasizing findings that coincide with the steady-state hypothesis, and missing the aspects of the cites that are contradictory. I suggest that if they are willing to be hoist on this petard, they should state the equilibrium assumption up front. Maybe they do not realize they are functioning under an outdated hypothesis that has been absorbed into more recent thinking about ecosystem structure and function, for example that of Robert May, or see Sherman and Alexander (1986).

I do not necessarily disagree with the central conclusion they are laboring so mightily to reach, " ... do not recommend any intervention to enhance the finfish populations ... ", but the next part of this sentence, " ... since the most important commercial species have had record catches since the spill.", is most definitely a <u>non sequitur</u> that displays substantial ignorance of the specifics of the stock structure of the species involved. Why sully the other reasonably sound conclusions (e.g. " ... fishery statistics ... should be used to monitor the recovery of finfish populations." p. 2) of this report with such potentially inflammatory, and unfounded, statements? I present more specifics on this point below.

I also point out that the types of fishery statistics presently collected will probably have to be evaluated within the context of the roles they have to play as part of a comprehensive monitoring and evaluation program for the Prince William Sound ecosystem before one can make a blanket statement on their utility for gauging finfish recovery. In the old days, fishery folk and other autecologists concentrated on describing the behavior of the single species in isolation from their ecosystems, however it is now generally recognized that it may be necessary to characterize species assemblages in order to properly understand the behavior of the single species.

It is not clear to me whether any one person or group now has the information necessary to specify the types of data necessary to monitor the status of any component of the PWS ecosystem, including shellfish and finfish. Such monitoring and evaluation designs will have to be developed through experience in an adaptive framework (see Holling 1978).

This paper needs to be substantially revised and strengthened before release. The tense of verbs needs to be carefully examined to see whether data and literature actually support the use of the definite, as opposed to the conditional. Primary literature needs to be found and cited. An explanation of the motivation for exploring "overfishing" within the context of perturbation needs to be given, particularly since the impacts of fishing on crustaceans are so obscure. And most of all, the basic hypotheses need to be stated at the beginning, so the reader does not have to guess about the philosophical origin of the arguments presented.

Specific comments

"However, recovery may be more dependent upon physical oceanographic and climatic conditions that are variable and unpredictable than upon biological processes." (first page of Executive Summary) Statement contradicted by data, analysis, and literature cited in (MacCall 1986). The reference to Francis and Sibley (1991) in this regard on page 9 of the manuscript is not primary literature. I believe they have completely missed the point regarding the impact of physical oceanographic factors on the processes surrounding ecological succession, made by so many of the authors and references in Sherman and Alexander (1986).

" ... disturbances that significantly alter habitat such as channelization of streams, or flood damage." (Second page of Executive Summary) Where is the discussion of the Toutle River, Washington State, and citations to literature on recovery from volcanic eruption of Mt. St. Helens volcano in 1980?

" In all cases the rate of recovery depend (sic) upon the availability of colonizing individuals to reoccupy the area after disturbance." (Third page of Executive Summary) This statement is contradicted by data, analysis, and literature cited in

(MacCall 1986). The statement is not supported by Olmstead and Clout (1974) as implied on p. 16 of the manuscript.

In section 3.1.1 what happened to the salmon? A number of very well documented salmon populations in Alaska experienced unlimited commercial fishing for at least fifty years prior to any attempt at regulation (e.g. Bristol Bay sockeye salmon, reference Fried, ADFG, Div. Comm. Fish., Anchorage). These populations have recovered to unprecedented levels of abundance. Since one of the principal species of concern in EVOS is a salmon, why are they spending so much time on less well documented demersal finfish species such as cod and plaice, where the data refer directly primarily to catch at age? Compared to the quality and extent of data available for salmon, the cod and plaice data, although very old, are merely anecdotal.

" ... the loss of pelagic eggs and fish larvae has no immediate impact on the fish stocks that are available to the fishing industry, and is not expected to have long-term effects since catch and climatic changes are the main factors that determine the annual recruitment of fish stocks (Baker et al. 1990)" (p. 9 section 3.1.2) This is a very strong statement to base solely on the Baker reference, and it ignores changes in species composition during ecological succession that may return the ecosystem to a new equilibrium state that has a different species composition from that seen prior to the disturbance. Data do not exist to make this sort of a statement, nor to refute it. Scientifically it is a non-issue.

The assertion of pages 9-10, section 3.1.2, based on Maki (1991), and a citation to Royce et al. 1991 9 (reference missing at page 45) that the record catch of pink salmon that occurred in 1990 proves that the EVOS, " ... did not have significant effects on the population of pink salmon." (p. 10) was rejected by the editors and peer reviewers of the American Fisheries Society when it was originally submitted by Royce in 1990. That the manuscript does not have the Royce et al. citation on page 45 is significant.

Note that the discussion and literature cited regarding the Amoco Cadiz (p. 10) appears to contradict the statement made on p. 9 regarding the apparent lack of mortality of adult finfishes resulting from oil spills.

The treatment of the key concept of ecological succession was not well balanced, despite repeated opportunities presented by the literature cites on pages 12-16. Instances where a disturbed community returned to its original equilibrium were emphasized (e.g. Hanson and Waters, 1974), whereas instances where communities could not recover (e.g. Fuchs and Statzner 1990 p. 16) were glossed over.

The significance of the work of Olmsted and Cloutman (1974) for recovery of communities impacted by EVOS was apparently not understood by the authors (p. 16, last paragraph). The fish communities in these small streams are composed two main species assemblages, sedentary residents, and highly transient opportunists (see Harima and Mundy 1974). The quick return of the transient species observed by Olmsted and Cloutman provided no evidence of ecosystem recovery within the time frame studied. Similarly in a study cited on p. 17, Turnpenny and Williams (1981) found that opportunists moved into a recovering tidewater stream, however the resident minnow did not return, despite the presence of populations in other parts of the stream. I believe other relevant examples could be found in The Ecology of Running Waters (Hines).

The assertion on p. 38, Management Recommendations, is not well founded; " ... a fishery is considered to have recovered from the impact of a disturbance when the catch per unit effort reaches the pre-disturbance level." Such a statement is essentially meaningless without reference to the stock structure on which the fishery operates. Case in point is Prince William Sound pink salmon where there are at least three principal pink salmon stocks, inter-tidal wild, supra-tidal wild, and hatchery. Such an unqualified statement also appears to contradict the manuscript's often repeated assertion regarding the effect of climate and physical factors on abundance of animal populations.

Literature cited

Harima, H. and P.R. Mundy. 1974. Diversity indices applied to the fish biofacies of a small stream. Transactions of the American Fisheries Society 103(3):457-461.

Holling, C.S. 1978. Adaptive Environmental Assessment and Management, Chapter 12: Pacific Salmon Management pp. 183-214. John-Wiley, New York, NY, USA, 377 pp.

MacCall, A. D. 1986. Changes in the biomass of the California Current ecosystem. in Sherman and Alexander.

Sherman, K. and L. M. Alexander (eds.). 1986. Variability and Management of Large Marine Ecosystems. Part One: Impact of Perturbations on the Productivity of REnewable Resources in Large Marine Ecosystems, pp. 1-86. American Association for the Advancement of Science Selected Symposium 99, 319 pp. Westview Press Boulder, CO.

Ref:f:\ ... \ams\text\nevissi.ams

# Review of "Comprehensive review and critical synthesis of the literature on recovery of ecosystems from disturbance (fish and shellfish)" by Nevissi, Sibley and Chang.

Reviewers preface: I have written this review primarily as a critique to aid the authors of the report in revisions of the draft I have seen. Thus the comments are generally critical, concerning what should be changed or added, rather than praising the strong parts and criticizing the weak parts.

The authors list a specific set of objectives (pages 1-2), and the format of this review is to list the objective, and then comment on how I think the report could be improved to better meet this objective.

## Objective: Review the literature on the recovery of finfish and commercially important shellfish following disturbance.

Not knowing the time or financial allocation for this paper, it is likely that my criticisms may reflect the limitations of the project budget rather than the work itself. The authors present a large set of examples of perturbed populations, and discuss the nature of their recovery. The majority of the examples are well known "text-book" fisheries examples that are helpfully summarized. Presumably the intended audience of this report would not be well versed in the history of different fisheries. The review is, naturally, far from comprehensive and the list of key words searched in information retrieval (page 2) is presumably the best explanation for what examples are contained and which are not.

Several obvious examples seem to have not been detected. These include 1) the recovery of the Fraser River sockeye from the Hells Gate slide of 1913, where the conventional explanation is that the IPSFC built fish passage ways at Hells Gate that permitted the recolonization of most of the Fraser River, but this interpretation has been challenged by Ricker, who argues that continued overfishing was the major reason that recovery was so slow; 2) the recovery of Skeena River sockeye salmon from the slide of 1953, in which artificial habitat was used as a principle component of rebuilding, and 3) the recovery of Frazer Lake (Kodiak) sockeye salmon from intense overescapement in the 1980's. These are only 3 of a long list of alternative examples that are probably more relevant to Exxon Valdez restoration than many of the examples given in the manuscript.

## Objective: Prepare a synthesis document of this literature that is pertinent to Prince William Sound, Lower Cook Inlet, and the Gulf of Alaska and:

I couldn't help but note that reasonably little attention was given to the recovery from oil spills. While the Amoco Cadiz, Arrow, Ixtox-1 were all mentioned, few detailed results were presented from these spills. Whereas there are 36 figures, almost all dealing with the impacts and recovery from overfishing, no figures show recovery from oil spills, which I would have thought, *a priori*, would be the most pertinent to the recovery from the Exxon Valdez. Either recovery from previous oil spills was very poorly studied, or the emphasis in this report was a bit misdirected.

## Objective: Describe the rates of recovery, duration and degree of recovery of fish and shellfish populations following disturbance

I noted a general lack of synthesis, the data reviewed are never really tied together with any coherent theory, in particular how anthropogenic effects will interact with natural variation.

For instance, at the population level, recovery will depend upon whether the perturbation is a single event or there is a continuing change in survival, recruitment or some other population parameter. Recovery will depend on the extent of reduction. If the population is wiped out, then there will be a need for immigration, otherwise the recovery will depends on the life history characteristics of the species. Recovery will also depend on whether competitors have increased when the species under consideration was reduced. Many standard ecological models can be used as a framework for consideration of recovery.

When we consider more than 1 species then there is potential for predator pits, competitive exclusion etc. The very slow recovery of the California sardine is felt to have been due to competition with anchovy. Again standard ecological models could be used to provide a framework for consideration of the impact of perturbation and time to recovery.

I think the report would benefit greatly from a figure or two (or tables) showing the relationship between type of perturbation, intensity of perturbation, dispersal characteristics, and other life history characteristics of the species.

## Objective: Estimates potential degree of recovery and expected rates of recovery

The authors make some recommendations on restoration approaches. However I found these recommendations very sweeping, and made without reference to the specifics of any particular perturbations of fish and shellfish. A catalog of alternative restoration actions include habitat restoration, reduced fishing mortality, re-introductions, and artificial propagation. The authors could provide guidelines on what actions would be most effective under what circumstances. For instance, when the species considered is completely eliminated and has low dispersive characteristics, then re-introductions might be appropriate. If the perturbation is ongoing, or reducing harvest rate is not easily accomplished, then perhaps short term artificial propagation might be used. I think the entire section on possible restoration methods should be expanded.

**Objective: Identifies indicator species, as well as population, community or species specific parameters that can be used to monitor the recovery cost effectively.**

Finally, I note that this report is not really about ecosystems, but rather deals primarily with populations. Populations have certainly been the focus of most of the studies funded since the Exxon Valdez spill, but it would be interesting to see if there is any evidence for ecosystem level impacts from other spills.

Finally, I note that in Table 3, PWS pink salmon are listed as unaffected by the Exxon Valdez spill on the grounds that records catch have been obtained after the spill. Field studies have shown impact on pink salmon in at several points in their life history, and it seems (to me at least) that the total return would have been higher if the spill had not occurred. I would recommend that this example be deleted from Table 3.

REVIEW OF "COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FROM DISTURBANCE (FISH AND SHELLFISH" DRAFT

by Charles H. Peterson
Peer Reviewer
16 November 1992

General Comments

This report serves the purpose of providing summaries of a great deal of past literature on natural recoveries of fish and shellfish populations. These summaries are likely to serve to inform restoration planners.

The report does need some careful revision in several key areas before production of a final draft. The major problem is the inclusion of several conclusions by the authors that lack adequate rigorous support. Many of these problematic conclusions are almost certainly wrong, but in addition all represent an unacceptable lack of rigor. I specify all these major problems below. In addition, this draft report suffers from a general lack of proper critical evaluation of some of the literature that is summarized. Too many conclusions from scientifically poor or incomplete studies are accepted uncritically. This is a problem that is hard to solve (particularly given my dissatistifaction with the authors' own inferences as well). I suggest that this difficulty is best addressed at this stage in the project by including in the Methods section somewhere explicit comments about how the issue of quality control on reporting results of literature conclusions was handled.

Specific Comments

Title pg - The title of this report is a contradiction in terms. A study of recovery of fish and shellfish is a study of population-based processes not an ecosystem study. In fact, the body of the report focuses on recovery at the level of the population and says little or nothing about the ecosystem-level processes (for example, predator-prey and other direct trophic interactions, competition among species, indirect effects, establishment of alternative "stable states", etc.).

pg vii - Here occurs the first of 3 spellings of bonita ("benito", "bonito" -pg 8, "bonita" - pg 9).

Exec Sum - The inclusion of suggested management practices in this document goes beyond the scope of the charge (as it appears on pp 1-2). More importantly, the recommendations that are included are superficial, naive, and poor. The authors apparently do not possess a detailed knowledge of the known EVOS damages to fish and shellfish. They thus dismiss all restoration as impractical and unnecessary, when that is patently false (for example, stream improvements could be quite effective for enhancing recovery of damaged Dolly Varden char and cutthroat trout populations). Furthermore, even though this review later identifies fishing as a major influence on fish and shellfish populations, the superficial set of recommendations fails completely to recognize that fishery management can be altered so as to effect more rapid recovery of exploited and damaged stocks.

Exec Sum - This review does not do a convincing job of demonstrating that species with high fecundity tend to recover most rapidly. This makes some intuitive sense, but there are apparent major exceptions (the clupeids) and no quantitative formal test of the hypothesis is presented. Alternatively, solid theoretical papers could be cited as support for this contention.

Exec Sum - To write that "rates of recovery depend upon the availability of colonizing individuals to reoccupy the area after the disturbance" states the obvious but is misleading by omission of all the other main factors involved. Furthermore, no formal analysis of how "availability" affects recovery rate is ever conducted in the body of this report.

Exec Sum - To explicitly identify shellfish populations as displaying "significant natural fluctuations in population size" is misleading to the degree that it implies that finfishes do not.

Exec Sum - The evidence presented here does not convince me that shellfish recover more quickly "from other types of disturbance than from overfishing".

Exec Sum - No adequate evidence or analysis is provided to support the contention that that species with limited mobility as adults recover less quickly. The larval stages of shellfish are the dispersal stages, covering distance scales similar to those achieved by finfish, in general. The authors imply here and in the text that simple reinvasion of a disturbed area is recovery despite the certainty that abundances are stull depressed over the entire population until repoduction has acted to replace losses. With such a realization, this contention about the significance of adult mobility becomes untenable.

Exec Sum - Catch statistics represent a poor means of monitoring recovery because they depend on effort, are aggregated in ways not reflective of the actual boundaries of damaged and control areas, and do nothing to address mechanistic process and understanding that might allow prediction of future change.

Exec Sum - I would agree that most species do not require active interventionist restoration to achieve recovery. However, the authors' failure to acknowledge those occasional instances where intervention may be cost-effective to speed up recovery and their failure to consider changes in fishery management as a valuable and effective restoration option devalues this conclusion.

pg 1 - Noting here that the spill timing was coincident with pink salmon outmigration is unbalanced: why choose only this one of many damaged species to mention in what should be a general overall introduction?

pg 2 - Is the bibliography indeed annotated?

pg 5 - Is there evidence in North Sea plaice for a stock-recruitment relationship to support the contention that having more eggs will allow more rapid population increase? If so, add the citation(s).

pg 8, Fig 13 - The information on the California sardine population dynamics fails to include recent (> 1960!) data, which show an upturn, and the text fails to present the scope of debate over causation (eg, see Rothschild's 1986 book).

pg 9 - There is no objective, formal test of the hypothesis that species with short life cycles recover most quickly. This would seem to be generally true, and the literature in ecological theory could be cited as support. However, the clupeids would seem to represent a major counter-example.

pg 9 - Royce et al. (1991) is the first of at least two citations from the text not listed in the References.

pg 9 - Because fish tend to be mobile does not at all imply that they necessarily can and do avoid damage from large oil spills. This is not correct and is contradicted by the report on the Amoco Cadiz spill responses given on pg 10.

pg 9 - The Baker et al. (1990) symposium contribution is a grossly and transparently biased document unworthy of any citation except in critique. Although this present report is intended to be a comprehensive review of recovery literature for fish and shellfish, some degree of interpretation and quality control would seem necessary on the part of the authors. Uncritical acceptance of rubbish just because it may be printed does not serve the RPWG effectively. I refer especially here to the contentions that adult fish are rarely killed by oil (contradicted by the Amoco Cadiz results reported on pg 10) and that long-term effects are not expected "since catch and climatic changes are the main factors that determine the annual recruitment of fish stocks". This is an illogical deduction.

pg 10 - Generation-to-generation fluctuations in pink salmon abundance are large enough to preclude the Maki (1991) method from detecting an effect of EVOS. Why aren't the more reliable NRDA results themselves used?

pg 10 - The inference (ascribed to the unlisted Royce et al. 1991 paper) that since herring and pink salmon are supposedly the most oil-spill-vulnerable finfishes that no other fish was impacted by EVOS is logically untenable and proved false by the NRDA studies, explicitly those of Dolly Varden char and cutthroat trout.

pg 10 - The claim that clams have generation times of 5-10 years is not necessarily so. Arctica islandica lives more than 100 years, as does Mercenaria campechiensis and presumably others.

pp 11-12 - The relevance of behavioral responses to Hurricane Allen and other tropical storms to population recovery from EVOS is tenuous.

pp 9-14 - No page numbers appear.

pg 16 et seq - Immigration may facilitate recovery but is not itself recovery where mortality has occurred. That is, mere redistribution of animals does not replace losses from mortality. This should be clarified in many of these examples of responses after small-scale disturbances.

pg 19 - The contention that rates of recovery depend on availability of colonizing individuals is not demonstrated by any formal test ot review data. To the degree that this implies that mere immigration represents recovery, it is also misleading.

pg 21 - There is no support provided for the contention that if a disaster occurs when a population is the near the low in its abundance cycle recovery will be slower than if near the peak. Density-dependent rebounds could be quite strong and may possibly render this claim false.

pg 23 on - The context that makes this presentation on oil fate relevant to population recovery is not made evident. Presumably, the relevance is derived from a focus here on depuration (quality of individuals) rather than recovery of abundance (quantity of individuals), but no adequate indication of this is given.

pp 29-30 - The literature in marine ecology contains many more examples of succession on rocky shores than the two studies (Hewatt 1935, Castenholz 1966) described here. The specific key words used in the literature search must have failed to uncover this vast and excellent literature (see Sousa review in Ann. Rev. Ecol. Syst. for the missing information and citations.).

pg 30 - There is no adequate empirical evidence or logic presented to support the contention that shellfish recover more slowly than finfish. Avoidance of the disturbance is irrelevant to rate of recovery, given a set magnitude of population reduction from which recovery is to be measured. And immigration by shellfish larvae is not inhibited at all by limited adult mobility because of the large dispersal scales of the typically planktotrophic larvae of shellfish.

pp 30-34 - Why is so much space devoted to a review of susceptibility to oil damage in seagrass and salt marsh systems? How is that responsive to the task of assessing recovery rates?

pg 33 - The seagrass restoration citation (Phillips 1981) is badly outdated.

pg 34 - The restoration reference for salt marshes (Dicks and Iball 1981) is outdated and a poor choice.

pg 34 - There is absolutely no support provided for the contention that "availability of reinvading individuals is the most important factor affecting recovery time". This is a subjective conclusion and is probably wrong.

pg 35 - For finfish that attach eggs to benthic substrata, the sensitivity to substrate and habitat cleanup may be as great as for shellfish.

pp 35-36 - The argument provided for why "recovery must be defined as the ecosystem reaching new equilibrium conditions rather than returning to pre-disturbance conditions" are utterly specious and unacceptable. It is surely true that no ecosystem is static so that recovery may need to defined as return to where the ecosystem would be expected to be (by reference to undisturbed controls) in the absence of the disturbance or disaster. However, that does not mean that recovery has occurred when essentially any altered ecosystem has become established. That is simply not recovery: it is replacement or substitution. Furthermore, the vast majority of ecologists now recognizes the non-equilibrium nature of all natural ecosystems, implying that any definition of recovery that requires an equilibrium is also inconsistent with modern ecological perspectives.

pg 36 - There is no adequate support provided (and much counter-evidence given) for the contention that "recovery of marine fish populations appears to be associated with environmental conditions rather than management practices".

pg 37 - Fisheries catch statistics represent a dreadful tool with which to monitor recovery because they vary with effort and gear changes, are often aggregated over areas that include both oiled and unoiled localities, and do not speak at all to process (thereby precluding prediction).

pg 37 - Appeldorn (1981) is another mystery reference not included in the References section.

pp 37-38 - The comments redered here on experimental design and monitoring design are so superficial as to be naive and misleading.

pg 38 - The authors write in apparent ignorance of any of the EVOS effects and of many restoration options when they claim categorically that no restoration of any species should be done in PWS. This entire section is amateurish, goes beyond the mandate of this review, and should be excised.

RPWG
R

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
**National Marine Fisheries Service**
**Office of Oil Spill Damage**
**Assessment and Restoration**
**P.O. Box 210029**
**Auke Bay, Alaska 99821**

December 14, 1992

Dr. Thomas E. Sibley
School of Fisheries (WH-10)
University of Washington
Seattle, WA 98195

Dear Tom:

Enclosed please find copies of three reviews that I asked Bob Spies and fellow peer reviewers to conduct on your report, "Comprehensive Review and Critical Synthesis of the Literature of Ecosystems From Disturbance (Fish and Shellfish)."

I would suggest that you take a few days to interpret the comments, determine how you will revise your report, then give me a call so that we might discuss and adopt a mutually agreeable course of action. Perhaps you would also be prepared to discuss the status of your budget. I trust that you will provide a copy of the reviews to Ahmad. Thank you.

Yours very truly,

John A. Strand,
Restoration Manager

Enclosures (3)

cc: John Armstrong
    Byron Morris
    RPWG

General Comments:

A strength of this approach is the systematic treatment of economically significant bony fishes, crustaceans, and molluscs. It is very useful to have statements based on literature records about the likelihood of recovery for these species. A further potential strength is the tilt toward literature that supports the time-heals-all-ecosystems hypothesis. This would become an actual strength if balanced by literature supporting the alternative hypothesis, "Ecological succession is a chaotic process leading to many possible equilibrium states."

Principal weaknesses lie in ignorance of some primary literature, a narrowness of the literature cited, and in confusion of correlative measures with conclusive evidence. Symptomatic of the confusion is the statement, "Shellfish populations typically recover more rapidly from other types of disturbance than from overfishing." (Page 2, Executive Summary). The authors do not present any data or literature to substantiate this assertion, the citations to papers contained in Caddy (1989) notwithstanding, nor am I aware that any exist.

The treatment of the key concept of ecological succession was not well balanced. The authors presume, without so stating, that any ecosystem will tend to return to its original state after perturbation, if the source of the perturbation is removed. They proceed to cite literature supporting this point of view, emphasizing findings that coincide with the steady-state hypothesis, and missing the aspects of the cites that are contradictory. I suggest that if they are willing to be hoist on this petard, they should state the equilibrium assumption up front. Maybe they do not realize they are functioning under an outdated hypothesis that has been absorbed into more recent thinking about ecosystem structure and function, for example that of Robert May, or see Sherman and Alexander (1986).

I do not necessarily disagree with the central conclusion they are laboring so mightily to reach, " ... do not recommend any intervention to enhance the finfish populations ... ", but the next part of this sentence, " ... since the most important commercial species have had record catches since the spill.", is most definitely a <u>non sequitur</u> that displays substantial ignorance of the specifics of the stock structure of the species involved. Why sully the other reasonably sound conclusions (e.g. " ... fishery statistics ... should be used to monitor the recovery of finfish populations." p. 2) of this report with such potentially inflammatory, and unfounded, statements? I present more specifics on this point below.

I also point out that the types of fishery statistics presently collected will probably have to be evaluated within the context of the roles they have to play as part of a comprehensive monitoring and evaluation program for the Prince William Sound ecosystem before one can make a blanket statement on their utility for gauging finfish recovery. In the old days, fishery folk and other autecologists concentrated on describing the behavior of the single species in isolation from their ecosystems, however it is now generally recognized that it may be necessary to characterize species assemblages in order to properly understand the behavior of the single species.

It is not clear to me whether any one person or group now has the information necessary to specify the types of data necessary to monitor the status of any component of the PWS ecosystem, including shellfish and finfish. Such monitoring and evaluation designs will have to be developed through experience in an adaptive framework (see Holling 1978).

This paper needs to be substantially revised and strengthened before release. The tense of verbs needs to be carefully examined to see whether data and literature actually support the use of the definite, as opposed to the conditional. Primary literature needs to be found and cited. An explanation of the motivation for exploring "overfishing" within the context of perturbation needs to be given, particularly since the impacts of fishing on crustaceans are so obscure. And most of all, the basic hypotheses need to be stated at the beginning, so the reader does not have to guess about the philosophical origin of the arguments presented.

Specific comments

"However, recovery may be more dependent upon physical oceanographic and climatic conditions that are variable and unpredictable than upon biological processes." (first page of Executive Summary) Statement contradicted by data, analysis, and literature cited in (MacCall 1986). The reference to Francis and Sibley (1991) in this regard on page 9 of the manuscript is not primary literature. I believe they have completely missed the point regarding the impact of physical oceanographic factors on the processes surrounding ecological succession, made by so many of the authors and references in Sherman and Alexander (1986).

" ... disturbances that significantly alter habitat such as channelization of streams, or flood damage." (Second page of Executive Summary) Where is the discussion of the Toutle River, Washington State, and citations to literature on recovery from volcanic eruption of Mt. St. Helens volcano in 1980?

" In all cases the rate of recovery depend (sic) upon the availability of colonizing individuals to reoccupy the area after disturbance." (Third page of Executive Summary) This statement is contradicted by data, analysis, and literature cited in

(MacCall 1986). The statement is not supported by Olmstead and Clout (1974) as implied on p. 16 of the manuscript.

In section 3.1.1 what happened to the salmon? A number of very well documented salmon populations in Alaska experienced unlimited commercial fishing for at least fifty years prior to any attempt at regulation (e.g. Bristol Bay sockeye salmon, reference Fried, ADFG, Div. Comm. Fish., Anchorage). These populations have recovered to unprecedented levels of abundance. Since one of the principal species of concern in EVOS is a salmon, why are they spending so much time on less well documented demersal finfish species such as cod and plaice, where the data refer directly primarily to catch at age? Compared to the quality and extent of data available for salmon, the cod and plaice data, although very old, are merely anecdotal.

" ... the loss of pelagic eggs and fish larvae has no immediate impact on the fish stocks that are available to the fishing industry, and is not expected to have long-term effects since catch and climatic changes are the main factors that determine the annual recruitment of fish stocks (Baker et al. 1990)" (p. 9 section 3.1.2) This is a very strong statement to base solely on the Baker reference, and it ignores changes in species composition during ecological succession that may return the ecosystem to a new equilibrium state that has a different species composition from that seen prior to the disturbance. Data do not exist to make this sort of a statement, nor to refute it. Scientifically it is a non-issue.

The assertion of pages 9-10, section 3.1.2, based on Maki (1991), and a citation to Royce et al. 1991 9 (reference missing at page 45) that the record catch of pink salmon that occurred in 1990 proves that the EVOS, " ... did not have significant effects on the population of pink salmon." (p. 10) was rejected by the editors and peer reviewers of the American Fisheries Society when it was originally submitted by Royce in 1990. That the manuscript does not have the Royce et al. citation on page 45 is significant.

Note that the discussion and literature cited regarding the Amoco Cadiz (p. 10) appears to contradict the statement made on p. 9 regarding the apparent lack of mortality of adult finfishes resulting from oil spills.

The treatment of the key concept of ecological succession was not well balanced, despite repeated opportunities presented by the literature cites on pages 12-16. Instances where a disturbed community returned to its original equilibrium were emphasized (e.g. Hanson and Waters, 1974), whereas instances where communities could not recover (e.g. Fuchs and Statzner 1990 p. 16) were glossed over.

The significance of the work of Olmsted and Cloutman (1974) for recovery of communities impacted by EVOS was apparently not understood by the authors (p. 16, last paragraph). The fish communities in these small streams are composed two main species assemblages, sedentary residents, and highly transient opportunists (see Harima and Mundy 1974). The quick return of the transient species observed by Olmsted and Cloutman provided no evidence of ecosystem recovery within the time frame studied. Similarly in a study cited on p. 17, Turnpenny and Williams (1981) found that opportunists moved into a recovering tidewater stream, however the resident minnow did not return, despite the presence of populations in other parts of the stream. I believe other relevant examples could be found in The Ecology of Running Waters (Hines).

The assertion on p. 38, Management Recommendations, is not well founded; " ... a fishery is considered to have recovered from the impact of a disturbance when the catch per unit effort reaches the pre-disturbance level." Such a statement is essentially meaningless without reference to the stock structure on which the fishery operates. Case in point is Prince William Sound pink salmon where there are at least three principal pink salmon stocks, inter-tidal wild, supra-tidal wild, and hatchery. Such an unqualified statement also appears to contradict the manuscript's often repeated assertion regarding the effect of climate and physical factors on abundance of animal populations.

Literature cited

Harima, H. and P.R. Mundy. 1974. Diversity indices applied to the fish biofacies of a small stream. Transactions of the American Fisheries Society 103(3):457-461.

Holling, C.S. 1978. Adaptive Environmental Assessment and Management, Chapter 12: Pacific Salmon Management pp. 183-214. John-Wiley, New York, NY, USA, 377 pp.

MacCall, A. D. 1986. Changes in the biomass of the California Current ecosystem. in Sherman and Alexander.

Sherman, K. and L. M. Alexander (eds.). 1986. Variability and Management of Large Marine Ecosystems. Part One: Impact of Perturbations on the Productivity of REnewable Resources in Large Marine Ecosystems, pp. 1-86. American Association for the Advancement of Science Selected Symposium 99, 319 pp. Westview Press Boulder, CO.

Ref:f:\ ... \ams\text\nevissi.ams

# Review of "Comprehensive review and critical synthesis of the literature on recovery of ecosystems from disturbance (fish and shellfish)" by Nevissi, Sibley and Chang.

Reviewers preface: I have written this review primarily as a critique to aid the authors of the report in revisions of the draft I have seen. Thus the comments are generally critical, concerning what should be changed or added, rather than praising the strong parts and criticizing the weak parts.

The authors list a specific set of objectives (pages 1-2), and the format of this review is to list the objective, and then comment on how I think the report could be improved to better meet this objective.

## Objective: Review the literature on the recovery of finfish and commercially important shellfish following disturbance.

Not knowing the time or financial allocation for this paper, it is likely that my criticisms may reflect the limitations of the project budget rather than the work itself. The authors present a large set of examples of perturbed populations, and discuss the nature of their recovery. The majority of the examples are well known "text-book" fisheries examples that are helpfully summarized. Presumably the intended audience of this report would not be well versed in the history of different fisheries. The review is, naturally, far from comprehensive and the list of key words searched in information retrieval (page 2) is presumably the best explanation for what examples are contained and which are not.

Several obvious examples seem to have not been detected. These include 1) the recovery of the Fraser River sockeye from the Hells Gate slide of 1913, where the conventional explanation is that the IPSFC built fish passage ways at Hells Gate that permitted the recolonization of most of the Fraser River, but this interpretation has been challenged by Ricker, who argues that continued overfishing was the major reason that recovery was so slow; 2) the recovery of Skeena River sockeye salmon from the slide of 1953, in which artificial habitat was used as a principle component of rebuilding, and 3) the recovery of Frazer Lake (Kodiak) sockeye salmon from intense overescapement in the 1980's. These are only 3 of a long list of alternative examples that are probably more relevant to Exxon Valdez restoration than many of the examples given in the manuscript.

## Objective: Prepare a synthesis document of this literature that is pertinent to Prince William Sound, Lower Cook Inlet, and the Gulf of Alaska and:

I couldn't help but note that reasonably little attention was given to the recovery from oil spills. While the Amoco Cadiz, Arrow, Ixtox-1 were all mentioned, few detailed results were presented from these spills. Whereas there are 36 figures, almost all dealing with the impacts and recovery from overfishing, no figures show recovery from oil spills, which I would have thought, *a priori*, would be the most pertinent to the recovery from the Exxon Valdez. Either recovery from previous oil spills was very poorly studied, or the emphasis in this report was a bit misdirected.

## Objective: Describe the rates of recovery, duration and degree of recovery of fish and shellfish populations following disturbance

I noted a general lack of synthesis, the data reviewed are never really tied together with any coherent theory, in particular how anthropogenic effects will interact with natural variation.

For instance, at the population level, recovery will depend upon whether the perturbation is a single event or there is a continuing change in survival, recruitment or some other population parameter. Recovery will depend on the extent of reduction. If the population is wiped out, then there will be a need for immigration, otherwise the recovery will depends on the life history characteristics of the species. Recovery will also depend on whether competitors have increased when the species under consideration was reduced. Many standard ecological models can be used as a framework for consideration of recovery.

When we consider more than 1 species then there is potential for predator pits, competitive exclusion etc. The very slow recovery of the California sardine is felt to have been due to competition with anchovy. Again standard ecological models could be used to provide a framework for consideration of the impact of perturbation and time to recovery.

I think the report would benefit greatly from a figure or two (or tables) showing the relationship between type of perturbation, intensity of perturbation, dispersal characteristics, and other life history characteristics of the species.

## Objective: Estimates potential degree of recovery and expected rates of recovery

The authors make some recommendations on restoration approaches. However I found these recommendations very sweeping, and made without reference to the specifics of any particular perturbations of fish and shellfish. A catalog of alternative restoration actions include habitat restoration, reduced fishing mortality, re-introductions, and artificial propagation. The authors could provide guidelines on what actions would be most effective under what circumstances. For instance, when the species considered is completely eliminated and has low dispersive characteristics, then re-introductions might be appropriate. If the perturbation is ongoing, or reducing harvest rate is not easily accomplished, then perhaps short term artificial propagation might be used. I think the entire section on possible restoration methods should be expanded.

**Objective: Identifies indicator species, as well as population, community or species specific parameters that can be used to monitor the recovery cost effectively.**

Finally, I note that this report is not really about ecosystems, but rather deals primarily with populations. Populations have certainly been the focus of most of the studies funded since the Exxon Valdez spill, but it would be interesting to see if there is any evidence for ecosystem level impacts from other spills.

Finally, I note that in Table 3, PWS pink salmon are listed as unaffected by the Exxon Valdez spill on the grounds that records catch have been obtained after the spill. Field studies have shown impact on pink salmon in at several points in their life history, and it seems (to me at least) that the total return would have been higher if the spill had not occurred. I would recommend that this example be deleted from Table 3.

REVIEW OF "COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FROM DISTURBANCE (FISH AND SHELLFISH" DRAFT

by Charles H. Peterson
Peer Reviewer
16 November 1992

General Comments

This report serves the purpose of providing summaries of a great deal of past literature on natural recoveries of fish and shellfish populations. These summaries are likely to serve to inform restoration planners.

The report does need some careful revision in several key areas before production of a final draft. The major problem is the inclusion of several conclusions by the authors that lack adequate rigorous support. Many of these problematic conclusions are almost certainly wrong, but in addition all represent an unacceptable lack of rigor. I specify all these major problems below. In addition, this draft report suffers from a general lack of proper critical evaluation of some of the literature that is summarized. Too many conclusions from scientifically poor or incomplete studies are accepted uncritically. This is a problem that is hard to solve (particularly given my dissatistifaction with the authors' own inferences as well). I suggest that this difficulty is best addressed at this stage in the project by including in the Methods section somewhere explicit comments about how the issue of quality control on reporting results of literature conclusions was handled.

Specific Comments

Title pg - The title of this report is a contradiction in terms. A study of recovery of fish and shellfish is a study of population-based processes not an ecosystem study. In fact, the body of the report focuses on recovery at the level of the population and says little or nothing about the ecosystem-level processes (for example, predator-prey and other direct trophic interactions, competition among species, indirect effects, establishment of alternative "stable states", etc.).

pg vii - Here occurs the first of 3 spellings of bonita ("benito", "bonito" -pg 8, "bonita" - pg 9).

Exec Sum - The inclusion of suggested management practices in this document goes beyond the scope of the charge (as it appears on pp 1-2). More importantly, the recommendations that are included are superficial, naive, and poor. The authors apparently do not possess a detailed knowledge of the known EVOS damages to fish and shellfish. They thus dismiss all restoration as impractical and unnecessary, when that is patently false (for example, stream improvements could be quite effective for enhancing recovery of damaged Dolly Varden char and cutthroat trout populations). Furthermore, even though this review later identifies fishing as a major influence on fish and shellfish populations, the superficial set of recommendations fails completely to recognize that fishery management can be altered so as to effect more rapid recovery of exploited and damaged stocks.

Exec Sum - This review does not do a convincing job of demonstrating that species with high fecundity tend to recover most rapidly. This makes some intuitive sense, but there are apparent major exceptions (the clupeids) and no quantitative formal test of the hypothesis is presented. Alternatively, solid theoretical papers could be cited as support for this contention.

Exec Sum - To write that "rates of recovery depend upon the availability of colonizing individuals to reoccupy the area after the disturbance" states the obvious but is misleading by omission of all the other main factors involved. Furthermore, no formal analysis of how "availability" affects recovery rate is ever conducted in the body of this report.

Exec Sum - To explicitly identify shellfish populations as displaying "significant natural fluctuations in population size" is misleading to the degree that it implies that finfishes do not.

Exec Sum - The evidence presented here does not convince me that shellfish recover more quickly "from other types of disturbance than from overfishing".

Exec Sum - No adequate evidence or analysis is provided to support the contention that that species with limited mobility as adults recover less quickly. The larval stages of shellfish are the dispersal stages, covering distance scales similar to those achieved by finfish, in general. The authors imply here and in the text that simple reinvasion of a disturbed area is recovery despite the certainty that abundances are stull depressed over the entire population until repoduction has acted to replace losses. With such a realization, this contention about the significance of adult mobility becomes untenable.

Exec Sum - Catch statistics represent a poor means of monitoring recovery because they depend on effort, are aggregated in ways not reflective of the actual boundaries of damaged and control areas, and do nothing to address mechanistic process and understanding that might allow prediction of future change.

Exec Sum - I would agree that most species do not require active interventionist restoration to achieve recovery. However, the authors' failure to acknowledge those occasional instances where intervention may be cost-effective to speed up recovery and their failure to consider changes in fishery management as a valuable and effective restoration option devalues this conclusion.

pg 1 - Noting here that the spill timing was coincident with pink salmon outmigration is unbalanced: why choose only this one of many damaged species to mention in what should be a general overall introduction?

pg 2 - Is the bibliography indeed annotated?

pg 5 - Is there evidence in North Sea plaice for a stock-recruitment relationship to support the contention that having more eggs will allow more rapid population increase? If so, add the citation(s).

pg 8, Fig 13 - The information on the California sardine population dynamics fails to include recent (> 1960!) data, which show an upturn, and the text fails to present the scope of debate over causation (eg, see Rothschild's 1986 book).

pg 9 - There is no objective, formal test of the hypothesis that species with short life cycles recover most quickly. This would seem to be generally true, and the literature in ecological theory could be cited as support. However, the clupeids would seem to represent a major counter-example.

pg 9 - Royce et al. (1991) is the first of at least two citations from the text not listed in the References.

pg 9 - Because fish tend to be mobile does not at all imply that they necessarily can and do avoid damage from large oil spills. This is not correct and is contradicted by the report on the Amoco Cadiz spill responses given on pg 10.

pg 9 - The Baker et al. (1990) symposium contribution is a grossly and transparently biased document unworthy of any citation except in critique. Although this present report is intended to be a comprehensive review of recovery literature for fish and shellfish, some degree of interpretation and quality control would seem necessary on the part of the authors. Uncritical acceptance of rubbish just because it may be printed does not serve the RPWG effectively. I refer especially here to the contentions that adult fish are rarely killed by oil (contradicted by the Amoco Cadiz results reported on pg 10) and that long-term effects are not expected "since catch and climatic changes are the main factors that determine the annual recruitment of fish stocks". This is an illogical deduction.

pg 10 - Generation-to-generation fluctuations in pink salmon abundance are large enough to preclude the Maki (1991) method from detecting an effect of EVOS. Why aren't the more reliable NRDA results themselves used?

pg 10 - The inference (ascribed to the unlisted Royce et al. 1991 paper) that since herring and pink salmon are supposedly the most oil-spill-vulnerable finfishes that no other fish was impacted by EVOS is logically untenable and proved false by the NRDA studies, explicitly those of Dolly Varden char and cutthroat trout.

pg 10 - The claim that clams have generation times of 5-10 years is not necessarily so. Arctica islandica lives more than 100 years, as does Mercenaria campechiensis and presumably others.

pp 11-12 - The relevance of behavioral responses to Hurricane Allen and other tropical storms to population recovery from EVOS is tenuous.

pp 9-14 - No page numbers appear.

pg 16 et seq - Immigration may facilitate recovery but is not itself recovery where mortality has occurred. That is, mere redistribution of animals does not replace losses from mortality. This should be clarified in many of these examples of responses after small-scale disturbances.

pg 19 - The contention that rates of recovery depend on availability of colonizing individuals is not demonstrated by any formal test ot review data. To the degree that this implies that mere immigration represents recovery, it is also misleading.

pg 21 - There is no support provided for the contention that if a disaster occurs when a population is the near the low in its abundance cycle recovery will be slower than if near the peak. Density-dependent rebounds could be quite strong and may possibly render this claim false.

pg 23 on - The context that makes this presentation on oil fate relevant to population recovery is not made evident. Presumably, the relevance is derived from a focus here on depuration (quality of individuals) rather than recovery of abundance (quantity of individuals), but no adequate indication of this is given.

pp 29-30 - The literature in marine ecology contains many more examples of succession on rocky shores than the two studies (Hewatt 1935, Castenholz 1966) described here. The specific key words used in the literature search must have failed to uncover this vast and excellent literature (see Sousa review in Ann. Rev. Ecol. Syst. for the missing information and citations.).

pg 30 - There is no adequate empirical evidence or logic presented to support the contention that shellfish recover more slowly than finfish. Avoidance of the disturbance is irrelevant to rate of recovery, given a set magnitude of population reduction from which recovery is to be measured. And immigration by shellfish larvae is not inhibited at all by limited adult mobility because of the large dispersal scales of the typically planktotrophic larvae of shellfish.

pp 30-34 - Why is so much space devoted to a review of susceptibility to oil damage in seagrass and salt marsh systems? How is that responsive to the task of assessing recovery rates?

pg 33 - The seagrass restoration citation (Phillips 1981) is badly outdated.

pg 34 - The restoration reference for salt marshes (Dicks and Iball 1981) is outdated and a poor choice.

pg 34 - There is absolutely no support provided for the contention that "availability of reinvading individuals is the most important factor affecting recovery time". This is a subjective conclusion and is probably wrong.

pg 35 - For finfish that attach eggs to benthic substrata, the sensitivity to substrate and habitat cleanup may be as great as for shellfish.

pp 35-36 - The argument provided for why "recovery must be defined as the ecosystem reaching new equilibrium conditions rather than returning to pre-disturbance conditions" are utterly specious and unacceptable. It is surely true that no ecosystem is static so that recovery may need to defined as return to where the ecosystem would be expected to be (by reference to undisturbed controls) in the absence of the disturbance or disaster. However, that does not mean that recovery has occurred when essentially any altered ecosystem has become established. That is simply not recovery: it is replacement or substitution. Furthermore, the vast majority of ecologists now recognizes the non-equilibrium nature of all natural ecosystems, implying that any definition of recovery that requires an equilibrium is also inconsistent with modern ecological perspectives.

pg 36 - There is no adequate support provided (and much counter-evidence given) for the contention that "recovery of marine fish populations appears to be associated with environmental conditions rather than management practices".

pg 37 - Fisheries catch statistics represent a dreadful tool with which to monitor recovery because they vary with effort and gear changes, are often aggregated over areas that include both oiled and unoiled localities, and do not speak at all to process (thereby precluding prediction).

pg 37 - Appeldorn (1981) is another mystery reference not included in the References section.

pp 37-38 - The comments redered here on experimental design and monitoring design are so superficial as to be naive and misleading.

pg 38 - The authors write in apparent ignorance of any of the EVOS effects and of many restoration options when they claim categorically that no restoration of any species should be done in PWS. This entire section is amateurish, goes beyond the mandate of this review, and should be excised.

RPWG
R

1700 South Shores Rd, San Diego, CA 92109

Hubbs-Sea World Research Institute

Tel: 619-226-3870 · Fax: 619-226-3944

Mr. Stan Senner
Oil Spill Restoration Office
645 "G" Street
Anchorage, AK
99501

29 March 1992

Dear Stan,

Due to circumstances beyond our control we will be delayed sending you a revised draft of our report "Review and critical synthesis of the literature on recovery of ecosystems following man-induced and natural-phenomena-related disturbances: harbor seals and killer whales". The report will be sent to you via Federal Express on Friday, 3 April or on Monday, 6 April. Thank you for your patience and understanding.

Sincerely,

Brent S. Stewart, Ph.D.

cc: Yochem
Jehl

PA06

STATE OF ALASKA

**DEPARTMENT OF FISH AND GAME**

*DIVISION OF OIL SPILL IMPACT*
*ASSESSMENT AND RESTORATION (OSIAR)*

R *WALTER J. HICKEL, GOVERNOR*

*P.O. BOX 3-2000*
*JUNEAU, ALASKA 99802-2000*
*PHONE: (907) 465-4125*

3/19/92

645 "G" Street
Anchorage, Alaska 99501
19 March 1992

COPY

Drs. Nadav Nur and David Ainley
Point Reyes Bird Observatory
4990 Shoreline Highway
Stinson Beach, California 94970

RE: COOP-91-039

Dear Drs. Nur and Ainley:

Thank you for the draft final report on your review and synthesis of the literature on the recovery of marine bird populations from environmental perturbations. John Strand and I have both reviewed the draft for the Restoration Planning Work Group. Sam Patten reviewed the document for the Alaska Department of Fish and Game, and we have invited two of our peer reviewers, Michael Fry and Daniel Roby, to review it as well. I spoke with Mike last week and asked that he submit any comments directly to you. Dan is recently back from South Georgia, and I have not been able to connect with him yet.

I enclose a copy of John Strand's comments for your consideration. Sam Patten has given me his comments orally. Sam is the principal investigator on the harlequin duck damage assessment study. His main concern was to be assured that you have covered the relevant literature on sea ducks. There is relatively little mention of sea ducks in the text, and perhaps you could make a special effort to make reference to sea ducks when you draw your conclusions.

My own comments are minor. You have covered the literature that we asked you to cover, and you have followed up in good faith on the feedback that we gave you after your presentation last autumn. I note the inclusion of oystercatchers and the table comparing life history traits and population growth rates. Both of these were suggested in my letter of 14 November.

The overall tone of the document is academic. Although I am comfortable with that, it may reduce its accessibility for resource managers. I have few specific suggestions, however, other than to be sure to define your terms. You also tend to have really long paragraphs, which make it harder to scan the text. Breaking the text up a bit more would help (e.g., the section on rate, duration, and extent of recovery [p. 7+] would benefit from subsection headings). John Strand has a number of editorial suggestions.

Your discussion of "What to Monitor: Population Size," is helpful, but would benefit from a bit more application to individual species or species groups.

The discussion on monitoring Alaskan common murres is good and appropriate, given that this species took a major hit and PRBO has direct experience with this species. Your comments about the possibility that asynchrony among adult breeders may not explain the reproductive failure at the colonies is interesting, but should be developed in a bit more detail. For example, in the sentence beginning at the very bottom of page 19, it is not clear with what prey abundance and availability have become "de-synchronized." How do you differentiate between a low proportion of breeders among individuals at a colony and individuals that are potential breeders but who are hanging around a colony but are out of synch? I'm not sure I expressed that well, but it reflects my confusion. At any rate, this is a key point and bears amplification.

I suggest that the critique of Exxon's Baker et al., which is very helpful, be removed from the report itself and placed in a letter to me. It can then be distributed separately. As is, it muddies the water in terms of the formal synthesis report.

In regard to Table 1, you may want to insert lines between studies for the same species and perhaps double lines between groups. Breaking up the text and inserting some lines would enhance readability.

In conclusion, I am pleased with the result, and with relatively minor, mostly editorial, changes, I will welcome the final report. I commend to you John Strand's comments, as well as those that I hope Mike Fry and Dan Roby mail to you.

Thank you for your efforts. I look forward to seeing the final product.

Sincerely,

Stan Senner

Stanley E. Senner
Restoration Program Manager

enclosure (1)
cc: RPWG
ADF&G OSIAR Div. files
Debbie Boyd, ADF&G Admin. Div.

DATE: March 9, 1992

COPY

MEMORANDUM FOR: Stan Senner

FROM: John Strand

SUBJECT: Review of Nur and Ainley's Critical Synthesis of Literature on Recovery of Marine Birds (Including Sea Ducks) Following Disturbance

GENERAL COMMENTS

I feel that the authors have done a credible job at finding relevant literature to review and have for the most part reviewed that literature adequately. I feel that their effort helps me better understand recovery of marine bird populations following disturbance. They have provided much useful data on possible/plausible rates of recovery (growth) and the factors, e.g., immigration, density, forage availability, etc., on which recovery or growth seem to depend. Their discussion of what demographic parameters are important to monitor is particularly relevant to our task of designing a meaningful monitoring program for bird species injured by the EXXON Valdez oil spill, although I have to ask if these parameters are equally applicable to all injured bird species?. The authors also do not provide much insight into how these parameters would be measured to determine whether and when recovery had been achieved.

From an editorial perspective, the report needs much work and polish. The authors are best advised to seek the skills of a professional editor.

TECHNICAL COMMENTS

1) Abstract, line 9. The sentence that begins "The approach was a broad one ... ," is not easily understood and should be revised. Perhaps the problem is editorial.

2) Scope of the Review; Taxa included, page 4, line 6. While you indicate that the literature was searched for citations on sea ducks, and you have included a number of references on ducks in the annotated bibliography, little of this information seems to have been incorporated into your report. A similar comment can be made regarding oystercatchers and other species.

3) Rate, Duration, and Extent of Recovery, page 8. In describing the data contained in Table 2, you mention use of the "upper quartile growth rate." What is the "upper quartile" statistic?

4) Influences on recovery rates, biotic and abiotic, page 12. Other than a brief mention of the effects of El Nino, I find little discussion of the effects of "abiotic" factors on recovery. If there is so little information, I would expect a statement to this effect. Again, perhaps the problem is editorial. Is the section on The Importance of Food Availability intended to include some of this information? If it is, I would have expected more information on the effects of El Nino. You seem to indicate on page 19 that you have information on the impacts of El Nino on the Farallon common murre populations, yet little of this information seems to be presented.

5) Defining Recovery, page 16. Which of the three definitions should we apply? If each have serious deficiencies, can you think of a better one?

6) What to Monitor: Population Size, page 16; also The Importance of Monitoring Additional Demographic Parameters, pages 17-20. Are the monitoring parameters recommended in these sections equally applicable to murres, kittiwakes, oystercatchers, sea ducks and other species? Also, the authors list several parameters that are admittedly difficult to measure or have serious drawbacks, e.g., adult survival, survival to breeding age, and proportion of the adult population that breeds. With respect to the latter, the authors state that "this parameter does not seem responsible for long-term changes in population size, though it may be responsible for short-term changes in breeding number (and thus fledging production.)" The authors offer us little else! With no other information, I must ask why even list this as a potentially useful monitoring parameter? Again, perhaps this kind of problem can be remedied by judicious editing!

7) Remarks on Monitoring Alaskan Common Murres, page 19. The citation attributed to Nysewander and Dippel seems to be missing from the Annotated Bibliography. Also, why do the authors single-out murres for special comment. What about other species?

8) Recovery vs Non-recovery, page 20. I don't think that this section does much for the report. The argument seems to be circuitous and I am not sure what message the authors want to convey. Does the discussion bear on the approach used in this literature search, or future literature searches? If it pertains to this search, then I suggest that the issue be addressed in the Methods section, page 5.

9) Recovery vs Non-Recovery, page 21. While I don't necessarily disagree with your conclusion that one cannot predict (I would rather use the word "estimate") recovery with any precision based on short-term data, we are nonetheless faced with the decision of implementing or not implementing restoration for many of the injured species, and we often have to work with very little data. These decisions are for the most part dependent upon what we perceive the rate of recovery to be, and what rate of recovery may be possible. That's where you come in. If this is not a rational approach, how then should we make these decisions? While I am aware there are lots of problems, the authors do not appear to provide us with much direction! Again, perhaps a good edit of the text will help.

10) Critique of the Review of Baker et al., page 23. Why do we need to spend so much effort (three pages) in refuting this one reference?

EDITORIAL COMMENTS

1) Abstract. This kind of report lends itself to an Executive Summary and not an abstract.

2) Table of Contents. This should be added.

3) The format (organization) is difficult to follow. The authors have used the same "bold" type for all headings and/or subheadings.

4) The section on Rate, Duration and Extent of Recovery is more than 5 pages long and is difficult to follow. It might be improved by the addition of subheadings.

5) Overview and Discussion and Conclusions, page 16. The only conclusion that I find is on page 21; are there others? Why do the authors also review the Baker et al. report in this section? This section could be better organized.

6) Table 1. Each page of the table needs a footnote to define the abbreviated data.

7) Where are the References? I don't believe all citations found in the text are found in the Annotated Bibliography!

8) Annotated Bibliography. The annotations are sometimes too cryptic, or there is no annotation at all. The first sentence is often incomplete and there are numerous punctuation errors.

9) Glossary. Even a short glossary would help!

cc: Byron Morris

RPWG
R

WALTER J. HICKEL, GOVERNOR

**DEPARTMENT OF FISH AND GAME**

P.O. BOX 3-2000
JUNEAU, ALASKA 99802-2000
PHONE: (907) 465-4125

*DIVISION OF OIL SPILL IMPACT
ASSESSMENT AND RESTORATION (OSIAR)*

COPY

12 September 1991

Nadav Nur
Point Reyes Bird Observatory
4990 Shoreline Highway
Stinson Beach, California 94970

Dear Nadav:

Thank you for your progress report on the marine bird literature synthesis, COOP-91-039. Your progress seems satisfactory. I note that since your expenses to date total $6458, the Department does not currently owe you additional money.

In regard to the meeting to review your results, what about 13-14 November in Anchorage? Alternatively, 5-6 November? Are you available on those dates? Do you expect to have a draft synthesis report ready then?

Please advise me about these dates. We are contacting the PIs on the other components of this project as well.

Sincerely,

Stan

Stanley E. Senner
Restoration Program Manager

cc: Debbie Boyd
OSIAR file
RPWG file

4990 Shoreline Highway
Stinson Beach
California 94970
1 415 868 1221
1 415 868 1946 (Fax)

POINT REYES
BIRD OBSERVATORY

9 September 1991

Re: COOP-91-039

Stan Senner, Restoration Program Manager
Restoration Planning Work Group
437 "E" Street, Suite 301
Anchorage, AK 99501

Dear Stan,

Below is the progress report on our research project, "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Marine Bird Populations from Environmental Perturbations." In addition, I enclose invoice for expenses incurred through 31 August 1991.

**Progress Report:**

From late June through the end of August, the emphasis of the project has been to identify and obtain relevant references for the literature review and critical synthesis. We have collected approximately 250 citations at this time, 195 of which were entered in our citation database as of 6 September 1991. Our librarian, Karen Hamilton, has conducted electronic searches, on-line and on compact disk, including searching the BIOSIS, Zoological Record, and Wildlife Review databases, as well as searching Current Contents. We now have photocopies of most of these references, and are awaiting arrival of copies of other references via Inter-Library Loan. In general, we have not had difficulty obtaining copies of references.

With the collection of references mostly completed, we are now beginning to review and annotate these references. These last-mentioned tasks are being carried out by Dr. David Ainley and myself. We look forward to finishing the review and synthesis by the end of October and to presenting our initial results at a workshop/seminar to be held in Alaska.

Sincerely,

Nadav Nur

Nadav Nur, Ph.D.

4990 Shoreline Highway
Stinson Beach
California 94970
1 415 868 1221
1 415 868 1946 (Fax)

POINT REYES
BIRD OBSERVATORY

August 31, 1991

## INVOICE ALSP #1-8

| | | |
|---|---|---|
| Labor | $ | 3932.00 |
| Supplies: | | |
| Xerox | | 84.00 |
| Phone | | 6.00 |
| Travel | | 634.00 |
| | | 4656.00 |
| Indirect Costs @ NSF Overhead @38.7% | $ | 1802.00 |
| Total Spent to Date | $ | 6458.00 |

Stan Senner, Restoration Program Manager
Restoration Planning Work Group
437 "E" Street, Suite 301
Anchorage, AK 99501

RPWG
R

RECEIVED
DEC 1 3 1991
OIL SPILL OFFICE

P
E
R
L

Pacific Estuarine Research Laboratory
Biology Department
San Diego State University
San Diego, CA 92182-0057

Telephone (619) 594-7422
FAX (619) 594-5676

2 December 1991

Dr. John A. Strand
Office of Oil Spill Damage Assessment and Restoration
NOAA
PO Box 210029
Auke Bay, Alaska 99821.

Dear John,

Thank you for giving me the opportunity to suggest revision options. Also, thank you for sending me reprints of several grey literature papers and two lists of references -- some of the papers look very useful.

I believe our report meets the requirements of the RFP and the guidelines given at the 20 June 1991 meeting in Seattle, and that major additions to the report will require additional time and money. I suggest that we decide on one of the following options:

| OPTION | DETAILS | DEADLINE | +COST |
|---|---|---|---|
| **1. Leave as is** | no changes | **31 December 91** | **$0** |
| **2. Minor changes/additions** | 1. Incorporate into the text some of the suggestions made by Simenstad and Armstrong.<br>2. Separate subtidal and intertidal studies in Table 1.<br>3. Include more information from the Pentec study (Houghton et al. 1991). | **31 March 91** | **$0** |
| **3. Major additions** | 1. Incorporate into the text some of the suggestions made by Simenstad and Armstrong.<br>2. Separate subtidal and intertidal studies in Table 1.<br>3. Include more information from the Pentec study (Houghton et al. 1991).<br>4. Include more grey literature on oil pollution.<br>5. Include more grey literature on dredging, drilling muds.<br>6. Add literature on earthquakes, land level changes, nuclear testing. | **30 June 92** | **$8,564** |

**4. Major additions and further synthesis 30 Sept. 92 $17,126**

1. Incorporate into the text some of the suggestions made by Simenstad and Armstrong.
2. Separate subtidal and intertidal studies in Table 1.
3. Include more information from the Pentec study (Houghton et al. 1991).
4. Include more grey literature on oil pollution.
5. Include more grey literature on dredging, drilling muds.
6. Add literature on earthquakes, land level changes, nuclear testing.
7. Add more literature on small scale experimental studies.
8. Provide a more comprehensive review of Baker et al. (1990).
9. Provide a more comprehensive extrapolation to the injured Alaskan ecosystem.

If we decide on Option 3 or 4, I will be sure to send you a rough draft of the final report well before the deadline date so that your comments can be included in the final draft.

I would like to clear up something you raised in your letter and that is: why are some papers in the References and others in the Bibliography? Our searches found 54 papers that deal with the recovery of invertebrate communities after disturbances. These papers were read and summarized for Table 1; their full citations and abstracts make up the Bibliography. Some of these papers (approximately 40%) were referred to in the text and so they are also cited in the References. Many other papers concerning some aspect of invertebrate recovery, but not primary references on the subject, were read and referred to in the text; their citations appear in the Reference list only. These papers include reviews (e.g, National Research Council 1975, 1985), methods (e.g., Krebs 1989, Mead 1988), information about the life history of particular species (e.g., Abbot and Haderlie 1980, Dayton 1973), etc.

I am looking forward to hearing from you and am particularly interested to see which option you prefer. I hope all is going well in Alaska.

Yours sincerely,

John

John M. Boland.

cc: Joy Zedler
Joe Jehl, Jr.

RPWG
R

4990 Shoreline Highway
Stinson Beach
California 94970
1 415 868 1221
1 415 868 1946 (Fax)

POINT REYES
BIRD OBSERVATORY

19 December 1991

Re: COOP-91-039

Stan Senner, Restoration Program Manager
ADF&G, RPWG
CACI Inc. - Commercial
Anchorage, AK

Dear Stan,

I would like to request a no-cost extension for our project, "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Marine Birds from Environmental Perturbation." The new termination date that we would prefer is 31 March 1992, which represents an extension of three months. Our draft report is nearing completion, and will be ready to submit soon. We have spent the last month obtaining additional references, particularly on Oystercatchers, as requested by the RPWG at the November meeting, and these can now be incorporated into our draft report and bibliography. The additional time requested will allow us to provide the RPWG with a superior product, and allow for ample time for review (by the RPWG and peer-reviewers) and revision.

Our project is requiring more time than we anticipated last February, with the result that labor costs are expected to be in excess of what we listed in our budget. I would like to request, therefore, that we be allowed to shift some money in the budget from the "outside services" category to the "labor costs" category. Such a shift would not be large, $3000 or less, and would not affect the total cost of the project.

Thanks for your assistance.

Sincerely,

Nadav Nur

Nadav Nur

RPWG
(R)

4990 Shoreline Highway
Stinson Beach
California 94970
(415) 868-1221
(415) 868-1046 (Fax)

POINT REYES
BIRD OBSERVATORY

1 November 1991

Re: Coop-91-039

Stan Senner
RPWG
CACI Inc. - Commercial
Anchorage, AK

Dear Stan,

I am sending you, with this letter, an outline of our draft report, for you to pass on to other members of the RPWG. I also include a Table which will constitute an important part of our report. The Table is very definitely incomplete--about 1/4 of the entries to it have not yet been entered by our secreterial staff, who this week have been working on the annotated bibliography (copies of which David Ainley and I will bring with us). But I thought an incomplete Table would still be of interest to you, and there's enough material there to think about. The Table shows population growth rates of seabirds, whether due to true recovery or due to growth (e.g. as a result of colonization). We thought it would be a useful exercise to assemble these results to answer the question, what rate of recovery can be expected, for different species, under different conditions, etc.?

Perhaps the outline and the table will give you a good sense of what the report will be like, but if you would like more information, I would be happy to send my provisional draft to you, such as it is, on Monday and could fax it to you sometime that morning.

I was thinking that we would submit the draft report by 13 November (sending it out by Federal Express that day), so that you would receive it by 14 November. I hope this is satisfactory.

Thanks for your help and interest in the project. It's been an educational experience for me.
I look forward to seeing you on Tuesday. We'll be staying at the Westmark Hotel, in case you wanted to leave a message.

With best wishes,

Nadav

Nadav Nur

# Comprehensive Review and Critical Synthesis of the Literature on Recovery of Marine Birds from Environmental Perturbation

Outline

## Introduction

Objectives of the Project.

Points to be addressed
1) Rate, duration and degree of recovery following disturbance.
2) Biotic influences on recovery.
3) Influence of management practices (habitat protection, restoration, etc.)
4) How best to monitor recovery and how to determine when recovery has occurred; choice of indicators

Rationale. Why we have proceeded the way we have.

Scope of the Review.

By Taxa: The search included all conventional seabirds (Penguins, the Procellariformes [Albatrosses, 3 families of Petrels], Pelecaniformers [Gannets and boobies, Pelicans, Cormorants and shags, Frigate birds, Tropic birds], Skuas and Jaegers, Gulls, Terns, Skimmers, Phalaropes, Alcids [Auks] Loons [Divers], and Grebes), as well as Sea Ducks (Eider, Scaup, Scoter, Merganser and other Mergus species, Oldsquaw, Harlequin, etc.) and select raptors (Eagles, Osprey).

By geographic region: No regions were excluded.

Time Period searched: The period since 1960 was emphasized, but we did search the literature from 1940 to 1960 as well.

## Methods

How the literature was searched: databases searched.

We tried to be thorough with regard to articles published since 1960, and have been somewhat selective with regard to articles published between 1940 and 1960. The papers are primarily from the 1970's and 1980's, but some are as recent as 1991. Some older papers are not included in the bibliography if more recent papers superceded them (e.g. included more recent censuses as well as older censuses).

Other points

## Results

1. Demographic capabilities, as exemplified by recovering or growing populations.
   i. Table of population growth rate (Table 1).
   ii. Role of immigration, with respect to observed population growth rates
   iii. What we conclude from Table 1.

2. Case histories; well-studied examples of recovery

3. Generalizations about recovery and growth
   i. Taxon by taxon
   ii. By geographic region.
   iii. By ecological niche.
   iv. By cause of perturbation

4. Factors influencing recovery, time to recovery, rate of recovery.
   i. Biotic
      1. Demographic capabilities as discussed above; this influences rate of recovery.
      2. Density dependence. "Positive feedback": at low density, reproductive success is impaired (Common Murre). This leads to instability of populations, enhancing the probability of extinction But at high density, "negative feedback". This would lead to population regulation.
      3. Dispersal ability and behavior.
      4. Food availability.

   ii. Management practices
      Above all, protection (establishment of refuges, sanctuaries).
        Prohibition of hunting.
        Examples of success.
      Food availability.
      Restoration through artificial breeding and recolonization, e.g. Atlantic Puffin
      Provision of nest sites.
      Control of gulls and skuas: implications for other species.

**Overview, Discussion, Conclusions**

1. How is recovery defined?
   Return to what it was?
   Return to what it would have been?
   Stable age distribution?

2. How to monitor species recovery, which can be broken down into two questions,
   a. How to monitor species, for whatever purpose
   b. How specifically to monitor their recovery (the answer to this depends partly on the answer to Question 1, How is recovery defined).

3. How to monitor population size.
   i. Nests vs. Individuals
      (see Harris papers)
      Alternatively monitor Nests and Individuals.
   ii. Fixed (permanent) sites vs. broad (general) measures of population size
   iii. Time scale.

4. The importance of monitoring demographic measures other than population size
   We make the case that it is important to measure more than pop. size.

Which additional measures should be monitored:
1) Fledging success.
By this we include clutch size and hatching success as well.
Why? 1) Does seem to be important determinant of population change.
2) Relatively easy to obtain.
3) May give good index of food availability (experience on Farallones), a good monitoring tool therefore for health/status of a population.
1b) Fledging Weight. A case to be made here, too. But we recognize that it is fairly disturbing to do so. May actually be a predictor of future survival, but that's not unanimous.
2) Adult survival. Requirement here for banding and either resighting or recapture. More disturbing than #1. Recent evidence indicates that this may be implicated in population changes.
3) Survival to breeding age/adulthood. Probably least known.
4) Proportion of the adult population that breed.

5. Which species to monitor?
Hard for us to answer. We don't find the concept of indicator species compelling or scientifically defensible.
Might want to focus on which were most impacted. But impact might best be measured by time to recovery.

6. Can a species recover? If it can't recover to what it was, what to use instead?

7. Time to recovery depends on impact to population--the greater the loss (mortality, productivity)--the greater the time.
The impact on a species vary., etc. Compare, e.g. gulls and murres.

Structure of the population (whether divided into subpopulations) is important. Division into subpopulations buffers the population and provides nucleus for regrowth.

8. The problem of local extinction: if a colony (or group of colonies) go extinct, it can be hard to reestablish.

9. Interspecific considerations: if one species declines (e.g. murres), another may take its place (e.g gulls) making it more difficult for the first to recover.

10. Review of study by Baker, Clark and Kingston. First, we counter their view (based on studies of seabirds in the North Sea) that oil industry activities have little deleterious impact on seabirds. Secondly, we discuss their specific point that a reservoir of non-breeders readily replaces mortality of birds and thus buffers a population.

Stan- this Table is incomplete, there's still 1- 1½ pages more of entries not yet entered.

TABLE 1. A summary of exponential growth rates expressed by percent increase per annum in various seabird populations.

| Species | Area (No.Sites) | Rate | Period | Chronology | Cause | Source |
|---|---|---|---|---|---|---|
| ALBATROSS | | | | | | |
| Diomedea albatrus | Torishima I | 6.6 | 1956-82 | Rec,In | E, | Hasegawa & DeGange 1982 |
| D. immutabilis | Laysan | 5.3 | 1911-57 | Rec | E,H | Rice & Kenyon 1962 |
| | Lisianski I | 10.4 | 1923-57 | Rec | E,H | |
| | Midway I | 27 | 1900-45 | Rec,In | E,H | |
| | | 4.0 | 1945-58 | Late | | |
| D. melanophrys | Heard I | 4.3 | 1954-87 | Rec,Late | E,D | Woehler 1991 |
| D. nigripes | Laysan | 8.7 | 1911-57 | Rec | E,H | Rice & Kenyon 1962 |
| | Lisianski I | 3.0 | 1923-57 | Rec | E,H | |
| | Midway I | 27 | 1900-45 | Rec,In | E,H | |
| | Torishima I | 13.2 | 1964-82 | Rec,In | E,Im | Hasegawa 1984 |
| PENGUINS | | | | | | |
| Aptenodytes forsteri | Amanda Bay | 7.1 | 1961-87 | G | | Woehler ms |
| | C.Washington | 9.5 | 1968-86 | G | | |
| | Franklin I | 5.8 | 1964-83 | G | | |
| | Haswell I | 2.3 | 1962-70 | G | | |
| | Kloa Pt. | 5.0 | 1977-85 | G | | |
| | Taylor Glacier | 6.7 | 1980-88 | G | | |
| A. patagonicus | Crozet I (2) | 10.2 | 1962-86 | Rec,Late | E | Jouventin & Weimirskirch 1990 |
| | Heard I | 24.0 | 1963-71 | Rec,In | E | Budd 1974 |
| | | 18.1 | 1969-88 | Rec | E | Woehler 1991 |
| | Kerguelan I (2) | 6.7 | 1963-86 | | E | Jouventin & Weimirskirch 1990 |
| | MacQuarie I | 9.1 | 1930-80 | Rec,All | E | Rousevell & Copson 1982 |
| | South Georgia I | 5.6 | 1925-80 | G,All | E | Croxall et al. 1984 |
| | | 17.3 | 1978-85 | Rec,Late | E | Woehler ms |
| Eudyptes chrysolophus | Kerguelan I | 0.7 | 1963-80 | G | F | Jouventin & Weimirskirch 1990 |
| Megadyptes antipodes | Otago Peninsula | 12.2 | 1942-52 | G | E,Im | Richdale 1957 |
| Pygoscelis adeliae | Ardley I | 8.5 | 1980-84 | G | | Woehler ms |
| | Aviation I | 7.4 | 1961-85 | G | | |
| | Buckle I (3) | 3.8 | 1973-84 | G | | |
| | C.Denison | 11.8 | 1974-82 | G | | |
| | Joubin Is (4) | 4.6 | 1984-90 | G | | |
| | Haswell I | 2.3 | 1912-62 | G,All | | Pryor 1968 |
| | Hope Bay | 2.2 | 1945-63 | G,Late | F | Conroy 1974 |
| | Peterman I | 18.0 | 1982-88 | Col,In | | Woehler ms |
| | Pt.Geologie | 1.7 | 1958-84 | G | C | Thomas 1986 |
| | Pr.Olav Coast (3) | 3.4 | 1972-81 | G | | Woehler ms |
| | Ross Sea (20) | 8.5 | | G | C | Taylor et al. 1990 |
| | C.Bird | 4.6 | 1967-87 | G | C | K.Wilson 1990 |
| | | 8.7 | 1981-87 | G | | Woehler ms |
| | C.Hallett | 1.3 | 1967-88 | Rec,All | D | |
| | | 9.8 | 1981-87 | G | C | Taylor et al. 1990 |
| | Beaufort I | 9.2 | 1963-87 | G | | Woehler ms |
| | | 5.7 | 1981-87 | G | C | Taylor et al. 1990 |
| | C.Royds | 5.2 | 1966-87 | G | C | Taylor & Wilson 1990 |
| | | 10.0 | 1980-87 | G | | Woehler ms |
| | C.Crozier | 7.7 | 1970-87 | G | | |
| | Unger I | 27.1 | 1980-85 | Col,In | | |
| | Sentry Rk | 42.8 | 1980-85 | Col,In | | |
| | Duke of York I | 16.8 | 1982-88 | G | | |
| | Downshire Cliffs | 3.5 | 1982-88 | G | | |
| | C.Wheatstone | 2.7 | 1964-1987 | G | | |
| | Coulman I (4) | 2.4 | 1964-88 | G | | |
| | Wood Bay | 4.1 | 1981-89 | G | | |
| | Inexpressible I | 3.0 | 1963-87 | G | | |
| | Franklin I (2) | 2.1 | 1981-86 | G | | |
| | Sabrina I | 5.6 | 1978-84 | G | | |
| | Signy I | 2.8 | 1957-82 | G | F | Croxall et al. 1984 |
| | Syowa Coast (10) | 9.9 | 1975-82 | G | | Woehler ms |
| | Windmill Is. (14) | 4.6 | 1961-89 | G | C | Woehler et al. 1991 |
| P. antarctica | Cuverville I | 24.9 | 1971-88 | Col,In | | Woehler ms |
| | Deception I (5) | 20.0 | 1953-66 | G,In | F | Conroy 1974 |
| | (7) | 3.5 | 1967-87 | G,Late | | Woehler ms |
| | Georges Pt | 18.9 | 1984-88 | Col,In | | |
| | Heywood I | 6.7 | 1966-87 | G | | |
| | Harmony Pt | 4.5 | 1972-87 | G | | |
| | Joubin I | 6.2 | 1984-90 | Col,In | | |
| | Livingston I (3) | 14.0 | 1957-65 | G,In | F | Conroy 1974 |
| | (4) | 1.0 | 1965-87 | G,Late | | Woehler ms |
| | Nameless I | 11.4 | 1984-90 | Col,In | | |
| | Seal I | 11.3 | 1970-88 | G | | |
| | Signy I | 6.6 | 1957-82 | G | F | Croxall et al. 1984 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Tupinier I | 5.4 | 1969-90 | G | | Woehler ms |
| P. papua | Livingston I (3) | 17.9 | 1957-65 | G | F | Conroy 1974 |
| | Harmony Pt | 6.4 | 1957-65 | G | F | |
| | Heard I | 1.9 | 1954-87 | Rec | E | Woehler 1991 |
| | Peterman I | 11.2 | 1982-88 | G | | Woehler ms |
| | Port Lockroy (2) | 12.5 | 1984-88 | G | | |
| | Pr.Edward I (14) | 12.6 | 1974-84 | G | | |
| | Thule I | 20.2 | 1966-79 | G | | |
| | Yankee Harbour | 19.9 | 1957-65 | G | F | Conroy 1974 |
| Spheniscus | | | | | | |
| magellanicus | Pen. Valdes | 3.0 | 1978-87 | G,Late | | Boersma et al. 1990 |
| PETRELS | | | | | | |
| Fulmarus antarcticus | Pt.Geologie | 6.0 | 1955-84 | G | | Thomas 1986 |
| F. glacialis | Funk I | 11.0 | 1959-80 | G,All | F | Kirkham & Montevecchi 1982 |
| | NE Atlantic | 7.0 | 1952-80 | G,Late | F | Ollason & Dunnet 1983 |
| | Great Britain | 16.0 | 1879-1901 | G/Col,In | | Evans 1984b |
| | | 10.0 | 1909-39 | G,Mid | | |
| | | 6.5 | 1939-69 | G,Late | | |
| | Orkney I | 4.6 | | | | |
| | Runde | 5.3 | 1947-81 | G,Late | | Barrett & Vader 1984 |
| | SW Norway | 10.2 | 1950-79 | Col,All | F | Toft 1983 |
| | Ydre Kitsigsut | 12.1 | 1971-83 | G,Late | | Evans 1984a |
| Puffinus diomedea | Selvagen Grande I | 1.2 | 1980s | Rec,In | E | Mougin et al. 1987 |
| P. tenuirostris | Fisher I | 6.0 | 1972-80 | Rec,In | E | Serventy & Curry 1984 |
| PELECANIFORMS | | | | | | |
| Pelecanus | | | | | | |
| occidentalis | Anacapa I | 37.0 | 1973-80 | Rec | P,F,Im | Anderson & Gress 1983 |
| | Coronado I | 8.6 | 1920-35 | Rec,All | E | Jehl 1973 |
| | | 24.0 | 1971-80 | Rec | P,F,Im | Anderson & Gress 1983 |
| | No. Carolina | 46.8 | 1977-83 | Rec,In | | Clapp & Buckley 1984 |
| | So. Carolina | 18.7 | 1978-82 | Rec,In | | |
| Phalacrocorax | | | | | | |
| aristotelis | Farne Is | 9.0 | 1910-65 | Rec,All | E | Potts 1969 |
| | | 11.0 | 1930-65 | G,In | E | Armstrong et al. 1978 |
| | | 40.0 | 1960-74 | Rec,In | Im | |
| | Isle of May | 7.7 | 1900-53 | Rec,All | E | Potts 1969 |
| | | 15.6 | 1962-83 | G | E | Aebischer 1986 |
| | SW Norway | 6.8 | 1950-79 | G | | Toft 1983 |
| Ph. atriceps | Arthur Harbor | 17.6 | 1973-87 | G | | Ainley & Sanders 1988 |
| | Heard I | 3.5 | 1951-85 | Rec | D | Woehler 1991 |
| | South Orkney Is | 2.0 | 1960-87 | G | | Cobley 1989 |
| Ph. auritus | Anacapa I | 25.0 | 1973-80 | Rec | P,F,Im | Anderson & Gress 1983 |
| | Br. Columbia | 8.6 | 1959-83 | G | E | Vermeer & Sealy 1984 |
| | Mandarte I | 10.8 | 1927-83 | G | E | |
| | Farallon I | 20.7 | 1972-82 | Rec,All | E | Ainley & Boekelheide 1990 |
| | | 70.0 | 1983-86 | Rec,All | E | |
| | Great Lakes | 21.5 | 1970-80 | Rec,In | P | Blokpol & Scharf 1990 |
| | | 38.4 | 1980-87 | Rec,Late | | |
| | Maine | 24.2 | 1934-45 | G,In | E | Buckley & Buckley 1984 |
| | | 1.6 | 1972-77 | G,Late | | Milton & Austin-Smith 1983 |
| | Nova Scotia | 9.4 | 1927-71 | G,In | E | |
| | | 10.2 | 1971-82 | G,Late | E,Im | |
| | St.Lawrence R | 3.0 | 1963-80 | G,Late | E | |
| | Texas | 24.4 | 1949-75 | G,All | E,Im | Morrison et al. 1983 |
| Ph. bougainvillii | Peru | 50.0 | 1953-57 | Rec | F | Tovar et al. 1987 |
| | | 10.0 | 1959-64 | Rec | F | |
| | | 1.2 | 1966-72 | Rec | F | |
| | | 8.2 | 1974-82 | Rec | F | |
| Ph. carbo | France | 4.0 | 1960-83 | G | E | Evans 1984b |
| | NW Overijessel | 17.0 | 1930-40 | Rec,In | E | Veldkamp 1986 |
| | | 12.0 | 1970-86 | | F | |
| | Nova Scotia | 3.8 | 1971-82 | G,Late | E | Milton & Austin-Smith 1983 |
| | Scotland | 4.0 | 1905-83 | G | E | Evans 1984b |
| Ph. olivaceous | Texas | 32.0 | 1967-75 | Rec,In | E,Im | Morrison et al. 1983 |
| Ph. pelagicus | Bare Pt | 8.8 | 1959-83 | G | E | Vermeer & Sealy 1984 |
| | Farallon I | 16.3 | 1976-81 | Rec,All | | Ainley & Boekelheide 1990 |
| | Mandarte I | 4.7 | 1915-83 | G | E | Vermeer & Sealy 1984 |
| Sula bassanna | Bird Rks | 1.0 | 1967-73 | G,Late | E,F | Nettleship 1976 |
| | Bonaventure I | 3.6 | 1919-76 | G | E | Brown & Nettleship 1984 |
| | | 2.2 | 1961-73 | G | E,F | Nettleship 1976 |
| | | 9.9 | 1961-66 | G | | |
| | Funk I | 19.3 | 1936-72 | G,All | E,F,Im | Kirkham & Montevecchi 1982 |
| | | 3.0 | 1959-72 | G,Late | E,F | Nettleship 1976 |
| | Great Britain | 3.0 | 1900-83 | G | | Evans 1984b |
| | Runde | 8.4 | 1969-74 | G,Late | | Brun 1979 |
| | | 7.5 | 1969-82 | G,Late | | Barrett & Vader 1984 |
| | Skarvklakken | 38.4 | 1969-82 | Col,In | Im | Barrett & Vader 1984 |
| | Syltefjord | 14.5 | 1969-74 | Col,In | | Brun 1979 |
| | | 18.3 | 1969-82 | Col,In | | Barrett & Vader 1984 |
| S. capensis | Algoa Bay | 3.6 | 1956-74 | G,Late | E,D | Randall & Ross 1979 |
| S. serrator | Colville | 4.9 | 1928-47 | G | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Hawkes Bay | 2.5 | 1931-46 | G | | |
| S. variegata | Peru | 10.0 | 1953-57 | Rec | F | Tovar et al. 1987 |
| | | 8.0 | 1959-64 | Rec | F | |
| | | 7.8 | 1966-72 | Rec | F | |
| | | 1.0 | 1974-82 | Rec | F | |
| DUCKS | | | | | | |
| Somateria mollissima | Baltic | 10.3 | 1969-81 | G | B,F | Stjernberg 1982 |
| | E. Canada | 5.7 | 1925-35 | G | E,H | Lewis 1937 |
| | Great Britain | 3.9 | 1958-82 | Rec | B | Coulson 1984 |
| | Scania | 5.1 | 1947-76 | Rec | E,H | Mathiasson 1980 |
| Histrionicus histrionicus | E U.S. | 23.7 | | G,All | H,Im | Vickery 1988 |
| SKUAS | | | | | | |
| Catharacta skua | Foula | 3.3 | 1880-1963 | Rec | E | Parslow 1967 |
| | Orkney | 9.3 | 1915-63 | Rec | E | |
| | Shetland | 7.0 | 1900-70 | G | E | Evans 1984b |
| C.maccormicki | Arthur Harbor | 7.6 | 1974-87 | G | | Ainley & Sanders 1988 |
| | McMurdo Snd (9) | 1-15 | 1957-83 | G,All | F,Im | Ainley et al. 1986 |
| | Pt.Geologie | 2.7 | 1966-81 | G,All | F | Jouventin et al. 1984 |
| Stercorarius parasiticus | Fair Isle | 11.6 | | Rec | E | Parslow 1967 |
| | | 3.7 | 1962-73 | G | E | O'Donald & Davis 1975 |
| GULLS | | | | | | |
| Larus argentatus | Berlengas I | 3.2 | 1939-81 | G,Late | F | Barcena et al. 1984 |
| | E Canada | 13.1 | 1925-35 | G,All | F,H | Lewis 1927 |
| | Funk I | 5.9 | 1956-80 | G,All | F | Kirkham & Montevecchi 1982 |
| | E U.S. | 4.5 | 1900-70 | G | F | Nisbet 1978 |
| | Lk Huron/Mich. | 12.3 | 1960-65 | G,All | F,H | Ludwig 1966 |
| | Muskeget I | 9.2 | 1925-40 | G,In | F | Kadlec & Drury 1968 |
| | Thatcher I | 92.0 | 1959-66 | G,All | F,Im | |
| | Great Britain | 12.8 | 1930-70 | G,All | F | Chabrzyk & Coulson 1976 |
| | Isle of May | 12.0 | 1907-70 | G,All | F | |
| | Walney I | 17.0 | 1904-64 | Col,All | E,F,Im | Parslow 1967 |
| | Holland | 12.1 | 1930-38 | G | F | Morser Bryuns 1958 |
| | | 5.3 | 1947-54 | G | C | |
| | Scania | 4.7 | 1947-76 | G | E | Mathiasson 1980 |
| | Sisargas I | 5.1 | 1948-81 | G,Late | F | Barcena et al. 1984 |
| | SW Norway | 3.6 | 1950-79 | G | F | Toft 1983 |
| L. a. heuglini | Meda I | 4.4 | 1961-82 | G | F,E | De Juana 1984 |
| L. atricilla | Jamaica Bay | 84.6 | 1979-84 | Col,In | Im | Buckley & Buckley 1984 |
| L. auduonii | Cabrera Is | 14.1 | 1974-82 | G,In | F,E | De Juana 1984 |
| | Chafarinas I | 8.5 | 1966-83 | G/Col,In | F,E,Im | De Juana et al. 1984 |
| | Columbrates I | 20.2 | 1974-82 | Col,In | F,E | De Juana 1984 |
| L. californicus | Western U.S. | 2.0 | 1920-80 | G,All | F,H | Conover 1983 |
| | Lahontan Lk | 7.0 | 1941-83 | G,All | F | Jehl et al. 1991 |
| | Mono Lk | 4.6 | 1916-76 | Rec,All | E | Winkler & Shuford 1988 |
| | | 15.1 | 1950-76 | G,Late | H | Jehl et al. 1984 |
| | Pyramid Lk | 19.5 | 1927-60 | Rec,All | E,F | Jehl et al. 1991 |
| | San Fran. Bay | 80.0 | 1980-89 | Col,In | F,Im | Ainley & Hunt 1990 |
| | Stillwater | 17.6 | 1950-77 | Col,All | F,H | Jehl et al. 1991 |
| L. delawarensis | E Canada | 2.4 | 1925-35 | G,All | H | Lewis 1937 |
| | Maritime Prov | 20.9 | 1972-86 | G,Late | F,Im | Lock 1988 |
| | New Foundland | 11.2 | 1940-80 | G,All | F,Im | |
| | St.Lawrence R | 7.6 | 1945-67 | G,All | F,H | Ludwig 1974 |
| | Lk Erie | 23.6 | 1945-67 | G,All | F,H | |
| | | 19.1 | 1976-84 | G,Late | F,H | Blokpol & Scharf 1990 |
| | Lk Huron | 22.1 | 1930-45 | G,In | F,H | Ludwig 1974 |
| | | 8.4 | 1945-67 | G,Mid | F,H | |
| | | 10.1 | 1976-84 | G,Late | F,H | Blokpol & Scharf 1990 |
| | Lk Michigan | 17.3 | 1945-67 | G,All | F,H | Ludwig 1974 |
| | | 11.3 | 1976-84 | G,Late | F,H | Blokpol & Scharf 1990 |
| | Lk Ontario | 14.4 | 1930-45 | G,In | F,H | Ludwig 1974 |
| | | 22.2 | 1945-67 | G,Mid | F,H | |
| | | 9.5 | 1976-84 | G,Late | F,H | Blokpol & Scharf 1990 |
| | Lk Superior | 11.3 | 1976-84 | G,Late | F,H | |
| | Western U.S. | 6.0 | 1920-80 | G,All | F,H | Conover 1983 |
| L. dominicanus | Lk Wainono | 33.0 | 1969-77 | G,All | F,H,Im | Pierce 1980 |
| L. fuscus | Spain (2) | 77.8 | 1973-81 | Col,In | F,Im | Barcena et al. 1984 |
| | SW Norway | 3.7 | 1950-79 | G | F | Toft 1983 |
| | Walney I | 29.0 | 1930-66 | Rec,All | E,F,Im | Parslow 1967 |
| L. glaucescens | NW Washington(7) | 2.0 | 1963-70 | G,Late | F | Reid 1988 |
| | Colville I | 3.0 | 1963-75 | G | F | Amlaner et al. 1977 |
| | Protection I | 5.9 | 1976-84 | G,Late | F | Reid 1988 |
| | SW Br.Columbia(4) | 4.0 | 1900-60 | G | F | Reid 1988 |
| | Mandarte I | 4.7 | 1915-60 | G | F | Vermeer & Realy 1984 |
| | Mitlenatch I | 3.6 | 1922-75 | G | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| L. marina | E Canada | 6.2 | 1925-35 | G,All | F,H | Lewis 1937 |
| | E U.S. | 17.0 | 1926-65 | Col,All | F,Im | Nisbet 1978 |
| | New England | 18.7 | 1930-65 | G,In | F | Buckley & Buckley 1984 |
| | | 2.0 | 1965-77 | G,Late | F | |
| | England/Wales | 15.0 | 1880-1930 | G,In | E,F | Parslow 1967 |
| | | 1.4 | 1930-56 | G,Late | E,F | |
| | Funk I | 17.1 | 1956-80 | G,All | E,F | Kirkham & Montevecchi 1982 |
| | Isles of Scilly | 1.5 | 1930-66 | G,Late | E,F | |
| | SW Norway | 1.7 | 1950-79 | G | F | Toft 1983 |
| L. occidentalis | Alcatraz I | 7.7 | 1982-88 | G,Late | F | Boarman 1989 |
| | Santa Barbara I | 19.0 | 1980-84 | G | F,Im | Ainley & Hunt 1990 |
| L. ridibundus | Lk Tasersuaq | 52.0 | 1971-80 | Col,In | | Evans 1984a |
| | England/Wales | 11.2 | 1938-58 | G | E,F | Parslow 1967 |
| Rissa tridactyla | Berlengas I | 20.1 | 1975-81 | Col,In | | Barcena et al. 1984 |
| | E Canada | 15.7 | 1970-83 | Col,All | F | Lock 1987 |
| | Germany | 30.0 | 1952-62 | G,In | F | Evans 1984b |
| | | 19.5 | 1972-82 | G,Late | | |
| | Great Britain | 3.5 | 1900-69 | G,All | E,F | Coulson 1983 |
| | | 1.0 | 1969-79 | G,Late | E,F | |
| | SW Norway | 7.4 | 1950-79 | G | | Toft 1983 |
| | | 8.6 | 1956-79 | G,All | | Munkejord & Folkedal 1981 |
| | Kjor | 38.9 | 1956-63 | G,In | | |
| | Urter | 28.7 | 1973-80 | Col,In | | |
| | W Greenland | 9.0 | 1965-74 | G | F | Evans 1984a |
| TERNS | | | | | | |
| Sterna albifrons | Long I | 14 | 1924-72 | Rec,All | E,Im | Nisbet 1973 |
| | Loir/Allier Val | 1.5 | 1905-80 | G | | Evans 1984b |
| | Massachusetts | 10.2 | 1923-50 | Rec,All | E,Im | Nisbet 1973 |
| St. arctica | | 5.5 | 1890-1946 | Rec,All | E | |
| St. caspia | E Canada | 3.4 | 1925-35 | G,All | H | Lewis 1937 |
| | Lk Huron/Mich | 4.0 | 1960-65 | G,All | F | Ludwig 1966 |
| | Lk Huron | 2.6 | 1980-87 | G,Late | F | Blokpol & Scharf 1990 |
| | Lk Michigan | 3.8 | 1976-87 | G,Late | | |
| | Lk Ontario | 28.7 | 1976-87 | G,Mid | | |
| St. dougalli | Massachusetts | 1.4 | 1872-1938 | Rec,All | E | Nisbet 1973 |
| St. hirundo | | 4.0 | 1885-1920 | Rec,All | E | |
| | Great Lakes | 2.3 | 1900-60 | Rec,All | E | Blokpol & Scharf 1990 |
| | Maine | 4.3 | 1900-40 | Rec,All | E | Nisbet 1973 |
| St. sandvicensis | Angholmarna | 14.0 | 1945-76 | | | Mathiasson 1980 |
| | Potaviken | 30.7 | 1939-52 | | | |
| | Maklappen | 20.4 | 1912-38 | Rec,All | E,Im | |
| | SE Britain | 3.2 | 1920-64 | G | E | Parslow 1967 |
| ALCIDS | | | | | | |
| Alca torda | Hornoy | 9.0 | 1967-80 | G | | Barrett & Vader 1984 |
| Cepphus grylle | E Canada | 10.1 | 1925-35 | Rec,All | H | Lewis 1937 |
| | SW Norway | 0.9 | 1950-79 | G | | Toft 1983 |
| Cerorhinca monocerata | Cleland I | 19.2 | 1967-88 | Col,All | | Rodway 1990 |
| | Farallon I | 56.4 | 1972-82 | Rec,All | P,E,Im | Ainley & Boekelheide 1990 |
| Fratercula arctica | E Canada | 2.6 | 1925-35 | Rec,All | H | Lewis 1937 |
| | Mantinicus Rk | 4.7 | 1937-77 | Rec,All | | Buckley & Buckley 1984 |
| | Hornoy | 30.3 | 1967-80 | G | | Barrett & Vader 1984 |
| | SW Norway | 1.8 | 1950-79 | G | | Toft 1983 |
| F. cirrhata | Farallon I | 6.4 | 1971-82 | Rec,All | P | Ainley & Boekelheide 1990 |
| Ptychoramphus aleuticus | Farallon I | 5.0 | 1870-1920 | Rec,All | F | Ainley & Lewis 1972 |
| Uria aalge | E Canada | 5.4 | 1925-35 | Rec,All | H | Lewis 1937 |
| | Funk I | 10.8 | 1936-1972 | Rec,All | E | Kirkham & Montevecchi 1982 |
| | Farallon I | 7.9 | 1972-82 | Rec,All | E | Ainley & Boekelheide 1990 |
| | Hornoy | 36.4 | 1974-82 | G | | Barrett & Vader 1984 |
| | Humberside | 7.0 | 1972-76 | G | | Stowe 1982 |
| | Isle of Cana | c.13 | 1973-82 | G | | Swann & Ramsey 1983 |
| EAGLES | | | | | | |
| Pandion haliaetus | New England | c. 9 | 1976-81 | Rec | P | Spitzer et al. 1985 |

Rec=recovery from population decline; duration: In=initial period, Mid=middle period, Late=late period; G=growth of established population, All=entire period

Factors involved: E=relaxation from exploitation, F=enhanced food supply, D=relaxation from disturbance, H=habitat improvement, Im=immigration, P=lessening of pollution

RPWG
R

**Restoration Planning Work Group**
**645 "G" Street**
**Anchorage, Alaska 99501**
**907-278-8012**

14 November 1991

Drs. Nadav Nur and David Ainley
Point Reyes Bird Observatory
4990 Shoreline Highway
Stinson Beach, California 94970

Dear Nadav and David:

Thank you for participating in the restoration group's review of the literature synthesis projects on ecosystem recovery from environmental disturbances. We appreciated your presentation and look forward to receiving your draft report. The purpose of this letter is to following up our meeting on the morning of the 6th.

As we indicated then, we are pleased with your initial efforts, based on your presentation on the 5th. There were, however, a few specific suggestions from members of the restoration group and our peer reviewers.

In your analysis of potential recovery rates, it was suggested that you do more to explore relationships to such factors as clutch size, longevity, breeding frequency, and age of first breeding. If possible, you also should add oystercatchers to the species for which you obtain data. (To get you going, I have already sent one reference regarding the European oystercatcher.) There also was a suggestion that you further describe factors operating where populations have not recovered from environmental disturbances (why didn't recovery occur?). It would be appropriate to do this on a representative rather than comprehensive basis.

Lastly, just a reminder to be sure to include any recommendations you may have in regard to monitoring--best indicators, methods, etc. Check for the RFP for how we worded the items.

Thank you again for your efforts. We look forward to having your draft final report to review.

Sincerely,

Stanley E. Senner
Restoration Program
Manager (ADF&G)

cc: OSIAR file
Debbie Boyd
John Strand
RPWG file

**Restoration Planning Work Group**

Privileged and Confidential
Attorney Work Product

COPY

MEMORANDUM

6 NOVEMBER 1991

TO: Don Siniff and Dan Costa

FR: Stan Senner, for Restoration Planning Work Group (RPWG)

RE: Review of Draft Report Synthesis of Marine Mammal Recovery Literature

Here is a copy of a draft literature synthesis report on marine mammal recovery literature prepared by Brent Stewart at Hubbs-Sea World Research Institute. Members of RPWG are reviewing this document and we invite your comments as well.

I also have enclosed a copy of the Request for Proposals, to which Hubbs-Sea World responded. This will inform you about our objectives in relation to the report that Brent prepared. We would appreciate your insights about the document overall (Does it meet RPWG objectives? Are there gaps? Alternative approaches or considerations?), as well any specific comments you may want to write in the margins.

Please note that we asked Brent to summarize literature on harbor seals and killer whales and other marine mammals relevent to those species. We asked that he not attempt to cover the sea otter literature, because we believed that others in the NRDA program (including Don) had that literature well in hand.

In terms of timing, everything in the oil spill program is at your earliest convenience. We would appreciate having your comments by 22 November, at the latest. If this is not possible, please let me know.

Please return your marked up copy and any other comments to me:

Stan Senner
Oil Spill Restoration Office
645 "G" Street
Anchorage, AK 99501
(907) 278-8012
(fax) 276-7178

Thank you in advance for your assistance with this request.

enclosures (2)

cc: RPWG
Brent Stewart/Joe Jehl

RPWG
R

7 AUG 92

John - As we discussed, the Boland report is much better in this 2nd draft. I'm returning my draft copy and have made some suggestions for minor changes in the text (these comments are in the report margins). A couple additional comments are listed below.

The definition of recovery Boland uses is good but it shouldn't come so late in the report (p 32).

The studies on recovery depend a lot on how far the stations sampled were from the "edges" of the disturbed area and how large the disturbed area was. I'd emphasize this somewhere. ~~It~~ This also weakens the usefulness of the fact that 76% of the studies didn't show recovery - there are so many variables between the studies - all the 76% tells me is that most of the investigators should have undertaken longer studies.

Thanks for the opportunity to review this draft John. Again, other than the Exec. Summary (which I believe should be rewritten), the report is much improved.

John Armstrong
(206) 553-1368

John Armstrong

# COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING DISTURBANCES:

# MARINE INVERTEBRATE COMMUNITIES

by

**John M. Boland**, Postdoctoral Research Associate.

Project supervision:

**Joy B. Zedler**, Professor of Biology

Pacific Estuarine Research Laboratory (PERL)

Biology Department

San Diego State University

San Diego, CA 92182-0057

FINAL DRAFT - CONFIDENTIAL

18 JUNE 1992

Project sponsored by:

The Oil Spill Restoration Planning Office

Environmental Protection Agency

U.S. Departments of Agriculture, Commerce and Interior

437 E Street, Suite 301

Anchorage, Alaska 99501

## TABLE OF CONTENTS

## EXECUTIVE SUMMARY

This paper is a comprehensive review and critical synthesis of the readily available literature on recovery of benthic invertebrate communities following disturbances. It was commissioned by the staff of the Oil Spill Restoration Planning Office to assist them in their management of Alaska's Prince William Sound area following the oil spill of the *Exxon Valdez.*

Benthic invertebrate communities are very productive, rich in species and support food webs that include commercially and ecologically important species. These communities are vulnerable to disturbances, including storm damage, sewage pollution and oil pollution. Many scientific studies have described the recovery of these communities after a disturbance and I review 79 of these studies here.

First, I focused on the time the communities took to recover. Based on the studies evaluated, their time frames and types of disturbances studied, I had six general conclusions:

1. Most of the studies (76%) reported that recovery did not occur in the time allowed by the investigators.
2. Recovery was more likely after a small disturbance than after a large disturbance.
3. Recovery was equally as likely in intertidal and subtidal habitats.
4. Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.
5. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates.
6. I estimate the recovery time of an invertebrate community on a hard substrate after an oiling event to be 10 - 20 years and that in a soft substrate after an oiling event to be 10 - 25 years.

Second, I discuss four abiotic factors that appear to effect recovery. Recovery is generally slower (a) after a large oil spill than after a small oil spill, (b) in soft sediments than on hard sediments, (c) in the high intertidal zone than in the low intertidal zone, and (d) at high latitudes than at temperate latitudes.

Third, I discuss the management practices that may influence recovery. In particular, I point out the problems associated with clean-up methods and bioremediation, and suggest that transplantation of some species should be considered.

Finally, I recommend an approach to determine when recovery has occurred. I think that the following six points are crucial to a successful study.

1. A definition of recovery is necessary. I suggest: "Complete recovery after an oil spill occurs when (a) all the species that were present before the oil spill are again present; (b) each of these species has reached their original abundances and biomasses, (c) each of these species has reached their original age distributions, and (d) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.
2. The hypotheses being tested should be clearly stated. The following hypotheses are appropriate: that there are no significant differences in (a) the species that are present in oiled and unoiled areas; (b) the abundances and biomasses of the species in oiled and unoiled areas; (c) the age distributions of the species in oiled and unoiled areas; and (d) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

defined as testing all the hypotheses cited in #2 above

3. None of the studies cited in Table 1 provides a good example of how to conduct a recovery study. It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem.

4. Natural communities are spatially and temporally heterogenous. This means (a) that it is necessary to study many unoiled and many oiled sites so that the range of natural variability can be determined, (b) that a large area should be sampled at each site, and (c) that many samples are required for reliable estimates of population densities.

5. All the results that are necessary and sufficient to test the hypotheses should be presented in the research report. omit

6. Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the community.

# 1.0 INTRODUCTION

## 1.1 Background

On 24 March 1989 the tanker *Exxon Valdez* ran aground in Alaska's Prince William Sound causing the largest oil spill in U.S. history. Approximately 11 million gallons of North Slope crude was lost at sea. The oil spread over an area of >900 square miles and oiled 1, 244 miles of the shorelines in the Prince William Sound, and on the Kenai Peninsula, Alaska Peninsula and Kodiak Island (Alaska Department of Environmental Conservation, 1989).

A tremendous clean-up and restoration effort has followed the spill and the managers of this effort would like to know what to expect in the recovery of these habitats. In particular, they would like answers to questions such as: How long will recovery take? What factors are likely to affect recovery? What indicators of recovery should the biologists be measuring? In an attempt to answer these questions for invertebrate communities I have reviewed the literature on recovery of invertebrate communities after various disturbances, including oil spills.

Benthic invertebrate communities in the intertidal and shallow subtidal zones are particularly vulnerable to oil spills because much of the oil is deposited and concentrated in these habitats (National Research Council 1985) and, because most invertebrates are relatively immobile, they are unable to escape the toxic and smothering effects of oiling. The recovery of these communities is relatively slow, i.e., several years, and the damage caused by an oil spill can often still be detected several years after a major spill (e.g., Southward and Southward 1978).

Benthic invertebrate communities are very productive, rich in species and support complex food webs that frequently include commercially and ecologically important species. For instance, the benthic invertebrates in Alaska support many species of bottom feeding fish (e.g., black rockfish), birds (e.g., oystercatchers), and mammals (e.g., gray whale, sea otter, brown bear, black bear, even man -- subsistence harvesting of mussels and clams). Also many benthic invertebrates have planktonic larvae and these become important components of planktonic food webs which include pelagic fishes (e.g., salmon, herring), birds (e.g., puffins, kittiwakes, murres, bald eagles), and mammals (e.g., harbor seals). Damages to the benthic invertebrate communities can therefore have wide-spread effects.

The **effects** of disturbances on benthic invertebrate communities have been quite well studied, particularly during the past 20 years (e.g., Kvitek et al. in press, see Connell and Keough 1985, and Sousa 1985, for reviews). However, long-term studies of **recovery** in these communities are quite rare -- I have found only 79 studies that deal with recovery and most of these (62%) followed recovery for a rather short time -- three years or less. My review of these recovery studies expands upon earlier reviews by Mann and Clark (1978), Thistle (1981), and Ganning et al. (1984), and provides a different perspective to the review by Baker et al. (1990).

### 1.2 Objectives

There are two objectives to this paper:

1. To review the readily available literature on recovery of invertebrate communities after a disturbance. I will focus on the rate of recovery and factors that may affect recovery.
2. To extrapolate the information obtained in the review to the injured Alaskan ecosystem. In particular, to identify the most practical indicators of recovery to measure, and to recommend an approach to determine when recovery has occurred.

## 2.0 TECHNICAL APPROACH

### 2.1 Information Retrieval and Sources of Data

I searched in many places for recovery papers. These included:

GENERAL REFERENCES

1. Aquatic Sciences and Fisheries Abstracts -- 1982 to 1990. Using the key words: oil-spills-benthic; intertidal-recruitment; intertidal-succession; subtidal-succession; disturbance-recovery-invertebrates; disturbance-recovery-marine; and oil-invertebrates.

2. The reference lists in: Vesco and Gillard 1980; Sousa 1984; Foster et al. 1988.

OIL POLLUTION REFERENCES

3. Oil Spill Public Information Center's Collection List (1366 entries) -- June 1991.

4. Proceedings of the American Petroleum Institute Oil Spill Conferences from 1975 through 1991 (e.g., American Petroleum Institute 1991).

5. The reference lists in: National Research Council 1975, 1985; Wolfe 1976; Stevenson 1978; Cox 1980; Cairns and Buikema 1984; Boesch and Rabalais 1987; Mielke 1990; Houghton et al. 1991a.

6. Marine Pollution Bulletin for the years 1985 through 1990.

DREDGING and DRILLING MUD REFERENCES

7. The reference lists in: Kester et al. 1982; National Research Council 1983; Ketchum et al. 1985; Cullinane et al. 1990.

EARTHQUAKES, LANDLEVEL CHANGES and NUCLEAR TESTING REFERENCES

8. The reference lists in: Kirkwood 1971; National Research Council 1971, 1973; Merritt and Fuller 1977.

9. Citation Index for recent citations of: Hubbard 1971; Baxter 1971; Haven 1971; O'Clair 1977; Lebednik and Palmisano 1977.

### 2.2 Analysis and Synthesis

Papers were excluded from the review if: (1) they dealt with the effect of a disturbance and not recovery after the disturbance (e.g., Maki 1991, see Teal and Howarth 1984, and National Research Council 1985 for reviews); (2) they dealt with only the effect of oil on the physiology, biochemistry or behavior of species (e.g., Percy 1977, see National Research Council 1985 for review); and (3) they were not in English (e.g., NOAA-CNEXO 1982). Thus the papers that are included in this review deal with the population and community level recovery after many kinds of disturbances (from whale feeding excavations to oil and sewage spills), in several different habitats (from subtidal soft sediments to rocky shores), and from many parts of the world (from the Straits of Magellan to Norway).

I grouped the papers according to the nature of the habitat (soft substrates and hard substrates, intertidal and subtidal), the size of the disturbance (small, if less than square meters; medium if square meters; and large if square kilometers), and the type of disturbance (non-organic, organic, and oil pollution).

## 3.0 REVIEW OF READILY AVAILABLE INFORMATION ON RECOVERY

### 3.1 Benthic Invertebrates

#### 3.1.1 Rate, Duration, and Degree of Recovery Following Disturbance

It is important to define what is meant by the terms disturbance and recovery. Disturbance is "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established" (Sousa 1984). Typical disturbances in benthic invertebrate communities are oil pollution, sewage pollution, the shearing force of large waves, and the foraging activities of animals, such as whales.

The majority of the papers discussed below do not define recovery, however their implied definition was usually "the return of all population densities to pre-disturbance levels or to undisturbed levels". For the purposes of this section I have chosen to keep to this definition. However, in Section 4.2.1 I discuss further the definition of recovery.

Here I review many different types of disturbances and deal with soft and hard sediments separately because there are some differences in the recovery of their benthic invertebrate communities.

SOFT SUBSTRATES

**A) Succession model**

The effects of organic pollution on infaunal invertebrate communities have been studied for many years and a general model has emerged of the succession that occurs in these communities during recovery (Pearson and Rosenberg 1978, Rhoads and Germano 1982). Figure 1A describes part of this model. In general, a heavy input of organic material (e.g., sewage, pulp-mill effluent) onto the sediment reduces the oxygen content of the sediment and a black anaerobic layer rises to the sediment surface. The combination of

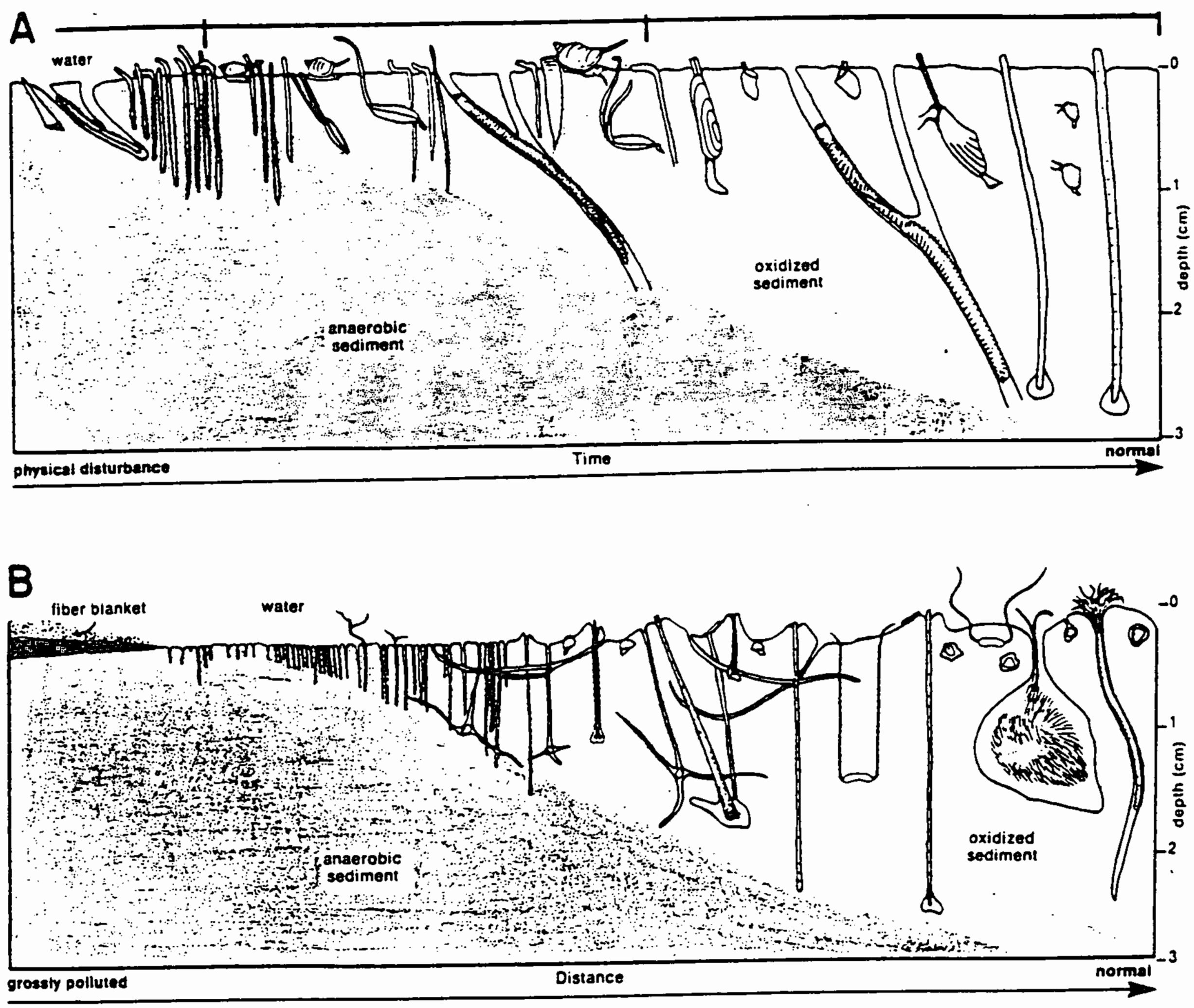


Figure 1. A diagram showing the variations in a typical benthic infauna community. The changes that occur in time during recovery from a disturbance (A) and the changes that occur in space around a source of pollution (B). From Rhoads and Germano (1982); used without permission.

high sulphide, low pH, and low oxygen concentrations in anaerobic sediment may cause complete defaunation. With no further input of organic material, currents carry away some of the organic material, conditions improve and a few macroinvertebrate species invade. These opportunistic, or "pioneer", species are usually epibenthic or surface-dwelling species (e.g., small tubiculous polychaetes) that are able to tolerate the conditions and take advantage of the rich organic material available. As conditions improve further and oxygen penetrates farther into the sediment, other species invade. These species, called "equilibrium" species or late succession species, include sub-surface deposit feeders whose burrowing activities result in further aeration of the sediment. Finally, these late succession species grow large, other late succession species invade, some (or all) of the opportunists drop out, and the community is indistinguishable from an undisturbed community.

Notice that the succession began when the area was invaded by relatively small, abundant, surface dwelling polychaete opportunists and ended when the area was inhabited by a suite of relatively large, rare, deep dwelling late succession species that include polychaetes, mollucs, crustaceans and echinoderms. Not only does the diversity of phyla increase but the number of foraging modes also increases, from non-selective sub-surface deposit feeders (e.g., *Capitella*) and carnivores, to suspension-feeders, omnivores, carnivores, and selective surface deposit feeders (Pearson and Rosenberg 1978).

The second part of the model describes how three important community characteristics (total number of species, total number of individuals, and total biomass) change during recovery of the community following an organic pollution event (Pearson and Rosenberg 1978; Figure 2). The total number of species increases steadily but then declines slightly because the opportunistic species tend to drop out. The total number of individuals rises very rapidly because the opportunists can be very dense but as the opportunists are replaced by late succession species the number of individuals drops quickly and eventually levels off at a relatively low number. The total biomass tends to increase steadily to a plateau usually with two peaks -- one early in the succession when opportunists are abundant and the other in the middle of succession when the greatest number of species are present in the community.

The end point of the succession is termed the "climax." This climax may only exist as an average condition on a relatively large spatial scale because frequent disturbances will prevent all parts of the habitat from reaching the climax state at the same time (Sousa 1984). The habitat will appear spatially heterogenous, i.e., many small patches at different stages of succession will be scattered in the large climax community.

The successional patterns described here also occur in space (Figure 1B). As one proceeds from a point source of organic pollution one will find in turn: an afaunal area, an area dominated by surface dwelling polychaetes, an area where there is a mixture of opportunistic and late succession species (transitional), and finally an area dominated by late succession species. This spatial pattern has been studied more than the temporal pattern (e.g., Pearson 1975, Swartz et al. 1986).

An important aspect of this model is that the composition of the early and late communities are quite predictable. The opportunistic species that invade during the initial stages of recovery from enrichment are distributed world-wide and the composition of the community they form is usually very similar from place to place (Pearson and Rosenberg 1978). It is therefore predictable. The late succession species that form the community during the final stage of recovery are more locally distributed and the "normal" communities they form differ from site to site depending on the habitat and the faunal region. However, the composition of these "normal" communities is predictable from undisturbed areas nearby. Only the transitional community is unpredictable. This is

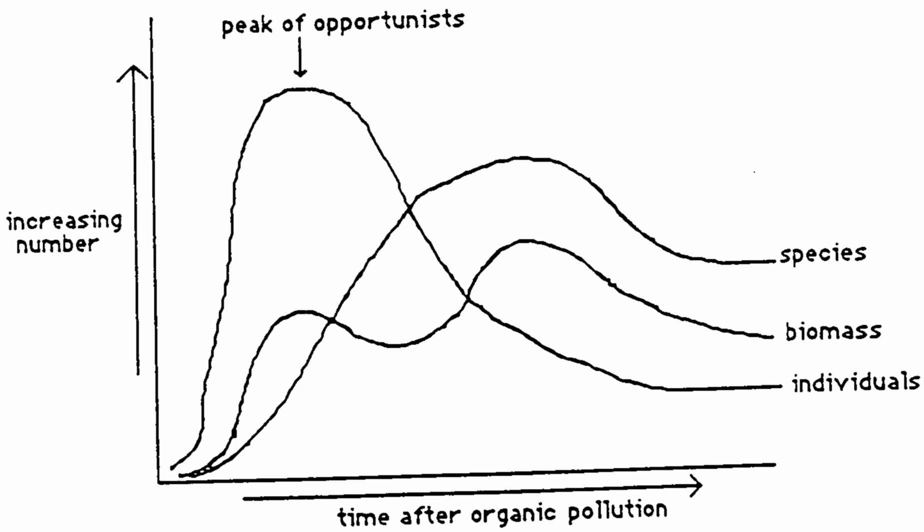


Figure 2. The fluctuations that occur in the number of species, number of individuals, and total biomass during the recovery of a typical benthic infauna community. From Pearson and Rosenberg (1978).

because both the recruitment of the late succession species and the elimination of the opportunistic species is unpredictable.

Another important aspect of this succession is that a large number of species at a site does not necessarily indicate a fully recovered community. Actually a fully recovered site has fewer species, fewer individuals and less biomass than a partially recovered site! It will probably have the following characteristics: the anaerobic layer will be deep, several phyla will be present and several feeding modes will be present. However, a site can be considered to have fully recovered only when it is structurally and functionally indistinguishable from undisturbed reference sites.

can you generalize like this about "recovered sites"

### B) Recovery times

Fifty-three studies dealt with the recovery of invertebrate communities in soft bottom habitats (Table 1). In deciding whether an area had recovered or not, I adopt the decision of each author, i.e., if the author determined that the area had recovered then I entered it as a "Yes", and if the author determined that it had not recovered then I entered it as a "No". The words "yes" and "no" could be replaced with "recovered" and "recovering".

a. Non-organic disturbances

A few studies dealt with the recovery of invertebrate communities after they were disturbed by animals. These disturbances tended to be on a relatively small scale -- even the excavations made by the gray whales are usually less than $50m^2$ in size (Oliver and Slattery 1985). Recovery of these communities was relatively rapid -- some recovery had occurred in just a few days and in most cases full recovery was expected to occur within one year. Recovery occurred relatively quickly in other small scale disturbances as well, e.g., experimentally defaunated areas (e.g., Zajac and Whitlatch 1982a, b). Most authors attributed this to the rapid invasion of small areas by animals from the water column and the surrounding areas.

Recovery from more extensive disturbances, such as following dredging, a red tide, an earthquake or a hurricane, were slower -- recovery had not been completed in any of these cases and most of the studies had lasted for more than one year. One study found that recovery had not occurred in an area of mine tailings after 12 years (Ellis and Hoover 1990a, b).

really depends on location/site (protected, exposed, currents...) type of pollutant

b. Anthropogenic pollution

Organic pollution and oil pollution have been described as similar -- both forms of pollution are frequently extensive and affect the sediment and its inhabitants in similar ways (Glémarec 1986). Several studies dealt with the recovery of invertebrate communities following an organic pollution event (Table 1). Most commonly the authors reported that recovery was not complete, but recovery did occur in one case (Rosenberg 1976).

Rosenberg (1976) monitored the subtidal benthic community in the Saltkallefjord before and after a paper mill stopped dumping organic material. He found that recovery of the community was slowest in the most polluted sites; after approximately six years these sites had partially recovered -- they had the same number of species as the less polluted sites but the species compositions were not similar. After eight years, however, the compositions of the most polluted and least polluted sites were similar, and they were similar to that recorded prior to the establishment of the paper mill, forty years earlier.

most disturbed? is there a better or more needs a bit more explanation — ie, pits?, crabs, rays...?

Table 1. A summary of the papers dealing with the recovery of marine invertebrate communities after a disturbance. For each paper the type of disturbance (dist.) and its size (Sm. = small, M = medium, L = large) are given. The time is either the recovery time (if recovery occurred) or the time between the disturbance and the last visit to the site (if recovery did not occur). The community is determined to have recovered if the authors said it had recovered or if the disturbed site was indistinguishable from a reference site. Quotes from the papers are included to amplify the answers. "REF" refers to the type of reference site(s) used (S = space, i.e., undisturbed site(s), T = time, i.e., the same site(s) prior to disturbance); "exp." = experimental; and "defaun." = defaunation. In addition, an * indicates that pollution was the source of the disturbance and, although it was substantially reduced, it was not completely eliminated. The Bibliography contains the full citation and abstract of each of these papers.

| DIST. and SIZE | HABITAT | SITE | TIME | RECOVERY OF COMMUNITY ? | REF. | SOURCE |
|---|---|---|---|---|---|---|
| **Soft Substrates** | | | | | | |
| Non-organic disturbance | | | | | | |
| exp. pits, Sm. | intertidal | Oregon | 24 days | **Yes**, "harpacticoids, juvenile spionids, cumaceans, and tanaids returned rapidly to ambient densities" | S | Savidge & Taghon 1988 |
| crabs, Sm. | subtidal | Scotland | 1 mo. | **Yes**, "the community returned to its original state within 25 to 30 days" | S | Hall et al. 1991 |
| rays, Sm. | subtidal | S. California | 1-1.5 mo | **Yes**, "the third phase of colonization is the gradual return of several numerically dominant species to predisturbance densities on a scale of 4-6 weeks" | S | Van Blaricom 1982 |
| walruses, Sm. | subtidal | Bering Sea | 2.5 mo. | **No**, "the infauna had not recovered by this time" | S | Oliver et al. 1985 |
| exp. mounds, Sm. | intertidal | Scotland | 4.5 mo. | **No**, "numbers remained low throughout the recovery period, being only 50% of the control population" | S | McLusky et al. 1983 |
| exp. pits, Sm. | intertidal | Scotland | 4.5 mo. | **Yes**, "the basins had populations equal to the controls" | S | McLusky et al. 1983 |
| whales, Sm. | subtidal | Bering Sea & Brit. Columbia | 7 mo. | **Yes**, "community patterns probably were re-established within the experimental excavations" | S | Oliver & Slattery 1985 |

Table 1 (cont.)
**Soft Substrates** Non-organic disturbance (cont.)

| DIST. and SIZE | HABITAT | SITE | TIME | RECOVERY OF COMMUNITY ? | REF. | SOURCE |
|---|---|---|---|---|---|---|
| exp. defaun., Sm. | subtidal | Connecticut | 1.08 yr. | **Yes**, "recovery to ambient conditions occurred rapidly in the lower reach, while successional changes in the middle and upper basins continued at least until the end of the winter" | S | Zajac & Whitlatch 1982a, b |
| exp. defaun., Sm. | subtidal | Lake Erie | 2.17 yrs. | **No**, "late colonizers ... reached natural abundances only after several months if at all" | S | Soster & McCall 1990 |
| dredging, M. | subtidal | Italy | 6 mo. | **No**, "the 6-month post-dredging communities still showed a noticeable qualitative dissimilarity with respect to the predredging period and neighbouring non-dredged areas" | T & S | Pagliai et al. 1985 |
| dredging, M. | subtidal | New York | 11 mo. | **No**, "the bay sediments exhibited an overall reduction in epi- and infaunal populations, which did not approach recovery levels 11 mo. after dredging" | T | Kaplan et al. 1974 |
| drill cuttings, M. | subtidal | New Jersey | 6 mo. | **No**, "although polychaete species composition was unaffected by the drilling, polychaete densities were significantly lowered" | T & S | Maurer et al. 1981 |
| drill cuttings, M. | subtidal | North Sea | 1.33 yrs. | **No**, "results ... indicate partial recovery of macrofaunal communities" | T & S | Mair et al. 1987 |
| red tide, M. | intertidal | Florida | 2 yrs. | **No**, "although species composition was fairly constant, the distribution of individuals among species changed greatly" | T | Dauer & Simon 1976 |
| mine tailings, M. | subtidal | West Canada | 12 yrs. | **No**, "biological differences between tailing and non-tailing areas remain after 12 years" | S | Ellis & Hoover 1990a, b |
| earthquake, L. | intertidal | Alaska | 1 yr. | **No?**, "some species have apparently experienced little reproduction since the earthquake" | T | Hubbard 1971 |

Table 1 (cont.)
**Soft Substrates** Non-organic disturbance (cont.)

| | | | | | | |
|---|---|---|---|---|---|---|
| earthquake, L. | intertidal | Alaska | 1 yr. | **No**, post-earthquake clam abundances were 64% the (estimated) pre-earthquake abundances | T | Baxter 1971 |
| hurricane, L. | subtidal | Chesapeake Bay | 2.5 yrs. | **No**, "the deep mud bottom community ... had not recovered 2.5 years after the storm" | T | Boesch et al. 1976 |
| Anthropogenic pollution | | | | | | |
| organic, L. | subtidal | L.A. Harbor | 1 yr. | **No**, but there was an "upgrading of species composition from a polluted to a semi-healthy species composition in the immediate area"* | None | Reish et al. 1980 |
| organic, L. | subtidal | Sweden | 4 yrs. | **No**, but "the echinoderms, which were the dominating animal group ... began to be re-established"* | T | Rosenberg 1972 |
| organic, L. | subtidal | England | 7 yrs. | **No**, "in the middle reaches a fauna tolerant of organic pollution is very abundant"* | S | Shillabeer & Tapp 1989 |
| organic, L. | subtidal | Sweden | 8 yrs. | **Yes**, "the basic recovery ... took five years, and ... after eight years it was not possible to distinguish between a normal and a recovery -influenced succession"* | T & S | Rosenberg 1976 |
| organic, L. | subtidal | Texas | 12 yrs. | **No**, but "it was evident that the Neches river estuary had been greatly improved"* | None | Harrel & Hall 1991 |
| Oil pollution | | | | | | |
| exp. oiling, Sm. | salt marsh | Georgia | 5 mo. | **Yes**, "increased periwinkle density in the oiled area was due to recolonization of the area by juvenile forms" | T & S | Lee et al. 1981 |

Table 1 (cont.)
**Soft Substrates** Oil pollution (cont.)

| | | | | | | |
|---|---|---|---|---|---|---|
| exp oiled mud, Sm. | intertidal | Wales | 10 mo. | **No,** "total faunal density and abundance of certain species remain depressed for the duration of the experiment" | S | Dixon 1987 |
| exp oiling, Sm. | intertidal | Virginia | 10 mo. | **No,** oligochaetes, polychaetes and amphipods more abundant in control even after 39 wks. | S | Bender et al. 1977 |
| exp oiling, Sm. | intertidal | Washington | 1.25 yrs. | **No,** "for individual species densities as well as overall abundance ... oiled substrates had recovered only about one-half" | S | Vanderhorst et al. 1980 |
| oil spill, M. | subtidal | L.A. Harbor | 11 mo. | **No,** "population levels appeared normal ... although total numbers have not equalled the (pre-oiling) levels"* | T & S | Reish et al. 1980 |
| oil spill, L. | subtidal | Sweden | 10 mo. | **No,** "the soft bottom community did not show even the beginning of a recovery" | T | Linden et al. 1979 |
| oil spill, L. | eelgrass | France | 1 yr. | **No,** but "recovery took place relatively rapidly... all numbers were at the same level as the year before, the filter feeding amphipoda being the only exception" | T | Jacobs 1980 |
| oil spill, L. | subtidal | France | 1 yr. | **No,** "one year later, several species eliminated from the polluted area, had still not yet begun to recover" | T | Cabioch 1980 |
| oil spill, L. | intertidal | Alaska | 1.25 yrs. | **No,** "shoreline treatment and oil contamination each caused major negetive impacts ... but the effects of the treatment predominated" | S | Houghton et al. 1991a, b |
| oil spill, L. | coral & mangroves | Panama Canal | 1.5 yrs. | **No,** "after 1.5 years only some organisms in areas exposed to the open sea have recovered" | T & S | Jackson et al. 1989 |

Table 1 (cont.)
**Soft Substrates** Oil pollution (cont.)

| | | | | | | |
|---|---|---|---|---|---|---|
| oil spill, L. | intertidal | Washington | 2.5 yrs. | **No**, bivalve biomass and infaunal species number still higher in unoiled site * | S | Blaylock & Houghton 1989 |
| oil spill, L. | intertidal | Arctic | 2 yrs. | **No**, "neither in 1979 or 1980 were living macrobenthic organisms recorded" | S | Gulliksen & Taasen 1982 |
| oil spill, L. | intertidal | France | 2 yrs. | **No**, "the original community has been replaced by a new community containing a very small number of tolerant species" | T & S | Laubier 1980 |
| oil spill, L. | subtidal | France | 2 yrs. | **No**, "there is no question that on a quantitative basis the stricken communties have not yet recovered to their previous richness and diversity" | T & S | Laubier 1980 |
| oil spill, L. | subtidal | Nova Scotia | 2.25 yrs. | **No**, "longer term effects involved extensive mortalities of *Mya arenaria* and *Spartina alterniflora*." | None | Thomas 1973 |
| oil spill, L. | saltmarsh | S. Chile | 2.33 yrs. | **No**, "observations ... at the east inlet of Puerto Espora demonstrated that the benthic macrobiota is still very scarce" | S | Guzman & Campodonico 1981 |
| oil pollution, L. | subtidal | Finland | 3 yrs. | **No**, "3 or 4 years is not long enough for monitoring the final stages of a postabatement succession" | S | Leppäkoski & Lindström 1978 |
| oil spill, L. | intertidal | France | 3 yrs. | **No**, "the biological environment has not returned to its pristine condition " | T & S | Conan 1982 |
| oil spill, L. | salt marsh | Massachusetts | 3 yrs. | **No**, "the interstitial fauna ... showed an extremely reduced number of individuals and species" | S | Hampson & Moul 1978 |
| oil spill, L. | subtidal | Baltic | 3.4 yrs. | **No**, "full recovery is likely to require more than 5 years and may take a decade or more" | T & S | Elmgren et al. 1983 |

Table 1 (cont.)

**Soft Substrates** Oil pollution (cont.)

| | | | | | | |
|---|---|---|---|---|---|---|
| oil spill, L. | intertidal | California | 5 yrs. | **No**, "the present densities (of *Emerita analoga* and *Nepthys californiensis*) have not approached the pre-oil status for this area" | T | Chan 1977 |
| oil spill, L. | intertidal | Massachusetts | 5 yrs. | **No**, "after more than five years the fauna had only slightly recovered" | S | Michael et al. 1975, Sanders 1978, Sanders et al. 1980 |
| oil spill, L. | subtidal | Massachusetts | 5 yrs. | **No**, "recovery had begun but it was not very far advanced" | S | Michael et al. 1975 Sanders 1978, Sanders et al. 1980, |
| oil spill, L. | salt marsh | Nova Scotia | 5 yrs. | **No**, "soft-shell clams ... have shown persistent mortalities proportional to oil content of the sediment" | None | Thomas 1977 |
| oil spill, L. | subtidal | France | 5.5 yrs. | **Yes**, recovery of the fauna took between 66 mo. (# individuals and species) and 84 mo. (biomass) | None? | Glémarec 1986 |
| oil spill, L. | intertidal | Massachusetts | 7 yrs. | **No**, "the persistent reduction in fiddler crab populations observed at Wild Harbor at least 7 years after the original oil spill" | S | Krebs & Burns 1977 |
| oil spill, L. | intertidal | Nova Scotia | 7 yrs. | **No**, "species diversity was uniformly higher at control than oiled stations. Analysis of abundance and biomass data ... showed a significant overall difference between oiled and control stations" | S | Thomas 1978 |
| oil spill, L. | subtidal | France | 8 yrs. | **No**, "the amphipod populations ... have not yet fully recovered 8 years after the pollution" | T | Dauvin 1987 |
| oil spill, L. | intertidal | France | 10 yrs. | **No**, "the amphipod populations ...were in the least advanced state of recovery" | T | Dauvin & Gentil 1990 |
| oil spill, L. | subtidal | France | 10 yrs. | **Yes**, "the population structure tended towards a return to the inital situation" | T | Ibanez & Dauvin 1988 |

Table 1 (cont.)

**Hard Substrates**

Non-organic disturbances

| | | | | | | |
|---|---|---|---|---|---|---|
| exp. removal, Sm. | intertidal | Oregon | 1.75-. 3.17 yrs. | **Yes**, "the timing and magnitude of successful barnacle recruitment appeared to cause much of the variation in the rate of succession" | S | Farrell 1991 |
| exp. removal, Sm. | intertidal | Washington | 3 yrs. | **No**, "when members of a sparse, isolated group of mussels were lost, no recovery was seen within periods ranging up to 3 yr." | T & S | Dethier 1984 |
| exp. removal, Sm. | intertidal | California | 3 yrs. | **No**, "*Mytilus californianus* did not recruit to the patches from the plankton during the 3 years" | T & S | Sousa 1984 |
| exp. removal, Sm. | intertidal | California | 4 yrs | **Yes**, "leads to development of ... the equivalent late successional stage in a minimum of 4 years" | T & S | Sousa 1979(a & b), 1980 |
| exp. removal, Sm. | intertidal | Washington | 5.5 yrs. | **Yes**, "recovery should occur in roughly 40 mo." | T & S | Paine & Levin 1981 |
| nuclear test, M. | intertidal | Alaska | 3.5 yrs. | **No**, "significant changes were still observed in some plots 3.5 years after the test" | T & S? | Lebednik & Palmisano 1977 |
| nuclear test, M. | intertidal | Alaska | 3.75 yrs. | **No**, "plot 1 is the only plot ... to show signs of recolonization by intertidal organisms after 33 months post-event" | T & S | O'Clair 1977 |
| earthquake, L. | intertidal | Alaska | 1.25 yrs. | **No**, "the inferred climax community had not yet become established in the post-earthquake intertidal zone" | S | Haven 1971 |
| earthquake, L. | intertidal | Chile | 4 yrs. | **No**, "rapid invasion by barnacles" but "no settlement of the competitively dominant inter-tidal mussel" | S | Castilla 1988, Castilla & Oliva 1990 |
| earthquake, L. | intertidal | Alaska | 5 yrs. | **Yes**, "with some exceptions these communities have returned to essentially their pre-earthquake condition" | S | Haven 1971 |

Table 1 (cont.)

**Hard Substrates**

Oil pollution

| | | | | | | |
|---|---|---|---|---|---|---|
| exp. oiling, Sm. | mesocosms | Norway | 1 yr. | **No,** "most responses were back to normal, and population regeneration of mussels and amphipods had started, but some physiological dysfunctions were still detected" | T & S | Bakke 1986 |
| exp. oiling, Sm. + dispersants | subtidal | Panama | 1.7 yrs. | **No,** "recovery of sea urchins was complete after 1 year but the recovery of corals and other encrusting organisms will probably take several years" | T & S | Ballou et al. 1989 |
| oil spill, M. + dispersants | intertidal | Ireland | 2 yrs | **Yes,** "the rocky-shore littoral community ... had largely recovered from the effects of the oil spill" | S | Flower 1983 |
| oil spill, M. | intertidal | Washington | 2.5 yrs. | **Yes,** "the area affected has returned to an apparently normal state as determined by our level of investigation"* | S | Clark et al. 1975 |
| oil spill, M. | intertidal | Wahington | 5 yrs. | **Yes,** "the community balance in this rocky intertidal ecosystem does not appear to be markedly altered"* | S | Clark et al. 1978 |
| oil spill, L. | intertidal | Sweden | 1 yr. | **No,** "the recovery of the littoral fauna was well under way one year after the spill but was not yet complete" | T | Linden et al. 1979 |
| oil spill, L. | intertidal | sub-Antarctic | 1 yr. | **No,** "densities of marine invertebrates appeared to have been markedly reduced in the lower littoral and sublittoral zones" | S | Pople et al. 1990 |
| oil spill, L. | intertidal | Alaska | 1.25 yr. | **No,** "lower densities of limpets and littorines" and *Nucella lamellosa* in oiled sites | S | Houghton et al. 1991a, b |
| oil spill, L. | intertidal | France | 2 yrs. | **Yes,** "the recovery of areas exposed to waves, currents and winds is almost complete" | T & S | Laubier 1980 |

Table 1 (cont.)

| **Hard Substrates** | Oil pollution (cont.) | | | | | |
|---|---|---|---|---|---|---|
| oil spill, L. | intertidal | Nova Scotia | 2.25 yrs. | **No**, "longer term effects involved extensive mortalities of *Fucus spiralis*" | None | Thomas 1973 |
| oil spill, L. | intertidal | Baltic | 4 yrs. | **Yes**, "no significant evidence of lasting detrimental effects can be found when natural annual variations ... are taken into account" | S | Notini 1978 |
| oil spill, L. | intertidal | Nova Scotia | 5 yrs. | **No**, "sporelings of fucoid algae have repeatedly settled in this zone but have never survived to a size where they could be identified" | None | Thomas 1977 |
| oil spill, L. | intertidal | California | 5 yrs. | **No**, "crab numbers are only half the pre-spill numbers" | T | Chan 1977 |
| oil spill, L. | intertidal | Nova Scotia | 7 yrs. | **No**, "species diversity was uniformly higher at control than oiled stations. Analysis of abundance and biomass data ... showed a significant overall difference between oiled and control stations" | S | Thomas 1978 |
| oil spill, L. | intertidal | Shetland Is. | 9 yrs. | **No**, "the biological communities at the sites that were cleaned mechanically were obliterated and still have not recovered" | T & S | Rolan & Gallagher 1991 |
| oil spill, L. + dispersants | intertidal | England | 10 yrs. | **No**, "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 yr; heavily oiled places that received repeated application of dispersants have taken 9-10 yr and may not be completely normal yet" | T | Southward & Southward 1978 |

c. Oil pollution

Many studies dealt with the recovery of benthic infaunal communities after being oiled (Table 1). The scale of the oil pollution ranged from small experimental oilings to major oil spills.

The recovery of invertebrates after a small scale oiling was quite slow. Above I pointed out that recovery in small areas is usually fast, but when oil is applied to the sediment the recovery is slower. For example, in the study by Vanderhorst et al. (1980), recovery was not complete after 16 months. Although the species lists were similar in the control and oiled sites, the abundances of the species were significantly lower in the oiled sites.

Only two of the 25 studies describing the recovery of soft bottom invertebrate communities after a large-scale oiling found full recovery (Glémarec 1986, Ibanez and Dauvin 1988; Table 1). The recovery times for these studies were 5.5 years, and 10 years, respectively. More typically the researchers return to a site three to ten years after an oil spill, and determine that recovery still has not occurred (e.g., Thomas 1977).

by why definition

out of place -- should come after you define recovery, at end of paper

I suspect that insufficient time has been allowed for full recovery to occur at most of these study sites. I conclude that the recovery of soft sediment invertebrate communities after an oil spill can take longer than ten years, but how much longer one cannot say.

HARD SUBSTRATES

**A) Succession**

Succession on rocky shores has been well studied in temperate zones (e.g., Dayton 1971, Lubchenco 1983, Sousa 1984, Farrell 1991) and a general view of the process has emerged (Paine and Levin 1981). In the absence of disturbance, the competitive dominant species spreads out and occupies nearly 100% of the primary space. For example, mussels are the competitive dominant on exposed Washington shores and they can form beds that cover 100% of the rock surface (Dayton 1971). Disturbance by waves, logs or starfish predation opens gaps in the beds of the competitive dominant. These gaps are relatively small, usually less than 1m² (Paine and Levin 1981). Small gaps are filled by the growth or movement of animals from the surrounding area. Large gaps are invaded by these means and by the settlement of species out of the plankton. The first settlers are usually small algal species, followed by barnacles and worms, and finally by the dominant large algae and/or mussels. Thus a succession generally occurs, but this succession is not particularly predictable -- the rates at which species invade depend upon the presence of their larvae in the water column and inhibition of one species by another can occur . Frequently a shoreline looks like a mozaic where gaps at different stages of succession are scattered about the matrix of the competitive dominant.

reword

An important principle has come out of these studies -- the intermediate disturbance principle: the highest number of species is found in a system with an intermediate degree of disturbance (Paine 1966, Connell 1978). If the combined disturbance from all sources (e.g., predation, wave action) is low, then the system becomes dominated by the competitive dominant and its attendant species (i.e., a relatively low number of species). If the combined disturbance is high, then few opportunities arise for most species to recruit successfully -- therefore the total number of species is again low. Only when the combined disturbance is intermediate do conditions favour a large number of species. This pattern is usually studied in space, i.e., at several places at the same time, but it is also observed at one place over time, i.e., during the recovery of invertebrate communities after a disturbance (Connell 1978). In this respect recovery on hard sediments is similar to that in soft sediments -- the greatest number of species occur before full recovery. Therefore, again, the presence of a large number of species does not necessarily indicate that a site has recovered.

An important feature of the studies that have led to these generalizations about succession on rocky shores is that the disturbances examined are unlike oil pollution -- the bare spaces, or gaps, are relatively small and organic enrichment is rarely involved. However, Southward and Southward (1978) stated that the general sequence of recolonization after the Torrey Canyon oil spill was similar to that described above for small-scale experiments where the rocks were scraped clean.

### B) Recovery times

I reviewed 26 studies that dealt with the recovery of invertebrate communities on hard substrates (Table 1). In this section, as above, in deciding whether an area had recovered or not, I adopt the decision of each author, i.e., if the author determined that the area had recovered then I entered it as a "Yes", and if the author determined that it had not recovered then I entered it as a "No". The words "yes" and "no" could be replaced with "recovered" and "recovering".

a. Non-organic disturbances

Several studies in Table 1 deal with the recovery of rocky shore invertebrate communities after non-organic disturbances. Recovery was relatively common and rapid -- between 1.75 years (Farrell 1991) and 5.5 years (Paine and Levin 1981); however, some sites had not recovered after more than three years (e.g., O'Clair 1977, Castilla 1988).

Boulder beaches are common in Alaska and the recovery of the communities on boulder beaches is therefore of special interest. Sousa (1979a, 1979b, 1980) showed that the recovery of early successional assemblages on boulder beaches takes approximately 5 months, middle successional assemblages 2.5 years, and late successional assemblages a minimum of 4 years.

Landslides and elevation changes resulting from earthquakes and nuclear testing are examples of extreme physical disturbances. Uplifting from the 1964 Alaska earthquake and the 1971 "Cannikin" nuclear test caused a die-off of most species whose elevation was raised. These species were being replaced by others that generally occur higher up the shore (e.g., O'Clair 1977, Haven 1971).

It must be remembered that these disturbances are not necessarily similar to oil spills because several were relatively small and none involved the addition of toxic organic material.

b. Oil pollution

Many studies have dealt with the recovery of rocky shore invertebrate communities after oiling (Table 1). In general, recovery was common and occurred relatively quickly (five years or less) after small and medium sized oil spills, but recovery was less common and occurred relatively slowly after large spills (even after ten years a site may not be fully recovered).

Southward and Southward (1978) noted that "heavily oiled places that received repeated application of dispersants have taken nine to ten years and may not be completely normal yet." Thomas (1978) found that, seven years after an oil spill, the oiled communities still did not resemble the unoiled communities. The fucoid algae (e.g., *Fucus*), in particular, were slow to recover.

CONCLUSIONS

Whereas Table 1 contains the details of recovery of invertebrate communities Table 2 shows an overview of Table 1. The general trends are:

**1. Most of the studies report that recovery did not occur in the time allowed by the investigators.** Recovery occurred in only 24% of the studies (Table 2). This means that either: recovery was going to occur in all cases but the assessment of recovery was conducted too early, i.e. prior to recovery (Teal 1990, Harding 1990); or recovery was not going to occur in all cases because the systems were irreparably damaged and will never recover to their pre-disturbance conditions.

**2. Recovery was more likely after a small disturbance than after a large disturbance.** Recovery was reported in 50% of the studies following a small disturbance, 25% of the studies following a medium disturbance, and in only 13% of the studies following a large disturbance (Table 2). This suggests that recovery times are relatively fast after a small disturbance but slow after a large disturbance.

**3. Recovery was equally as likely in intertidal and subtidal habitats.** Recovery was reported in 25% of the intertidal studies and 19% of the subtidal studies (Table 2).

**4. Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.** Recovery was reported in 33% of the stuidies following a non-oiling disturbance and in only 17% of the studies following an oiling disturbance (Table 2). This suggests that recovery times are relatively fast after a non-oiling disturbance but slow after an oiling disturbance. A reason for these trends is that oil persists longer than other disturbances (e.g., sewage); Ganning et al. (1984) estimated that the minimum residence time of oil on mud flats was 10 years..

**5. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates.** Recovery was reported in 31% of the studies of oiling of hard substrates and in only 10% of the studies of oiling of soft substrates (Table 2). Again, this suggests that recovery times are relatively fast on hard substrates but slow in soft substrates. One reason for these trends is that oil persists longer in soft sediments than on hard substrates (Vandermeulen 1977; see Section 3.1.2 for further discussion).

you haven't defined recovery yet

**6. I estimate the recovery time of an invertebrate community on a hard substrate after an oiling event to be 10 - 20 years and that in a soft substrate after an oiling event to be 10 - 25 years.** Recovery occurred in only 17% of the oiling studies thus making calculations of mean recovery times impossible (Table 2). However, with what data we have at present, it appears that these estimates of 10 - 20 years and 10 - 25 years are reasonable.

These recovery time estimates are similar to those estimated by most others (e.g., Vandermeulen 1978 -- 5 to 15 years). Only the Exxon Corporation biologists who

Table 2. The number of studies that recorded full recovery (yes) and incomplete recovery (no) of invertebrate communities. They are grouped according to the size of the disturbance, nature of the habitat, nature of the disturbance, and oiling in different habitats. The studies are from Table 1.

| INVERTEBRATE COMMUNITY RECOVERY | | | | |
|---|---|---|---|---|
| | | | | |
| | YES | NO | TOTAL | % YES |
| | | | | |
| **total** | 19 | 60 | 79 | 24 % |
| | | | | |
| **size of disturbance** | | | | |
| small | 10 | 10 | 20 | 50 % |
| medium | 3 | 9 | 12 | 25 % |
| large | 6 | 41 | 47 | 13 % |
| | | | | |
| **nature of habitat** | | | | |
| intertidal | 12 | 36 | 48 | 25 % |
| subtidal | 6 | 25 | 31 | 19 % |
| | | | | |
| **nature of disturbance** | | | | |
| not oiled | 11 | 22 | 33 | 33 % |
| oiled | 8 | 38 | 46 | 17 % |
| | | | | |
| **oiling in different habitats** | | | | |
| oiling of soft substrates | 3 | 27 | 30 | 10 % |
| oiling of hard substrates | 5 | 11 | 16 | 31 % |

reviewed the literature on recovery of cold water marine environments after oil spills have much faster recovery time estimates (Baker et al. 1990). They concluded that "rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." Their lower estimated recovery times can be partly attributed to their definition of recovery (see Section 4.2.1). Good

However, they also used references selectively. Their paper covers the same topics as mine -- it includes a section on the benthic environment and a table (their Table 7) which is much like my Table 1. When a comparison is made of the two tables it is obvious that theirs is short of some important references -- the relatively long-term studies of soft sediments that found that recovery was not complete (e.g., Elmgren et al. 1983, Sanders 1978, Sanders et al. 1980, Thomas 1977, Dauvin 1987). In addition, in some cases, they chose to present the rosiest picture. For example, Southward and Southward (1978) state that "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 years; heavily oiled places that received repeated application of dispersants have taken 9-10 years and may not be completely normal yet." Baker et al. (1990) describe these results in their table as "good recovery after 2 years." It is clear that the ~~research of~~ paper by Baker, ~~Clark, Kingston and Jenkins~~ et al. must be read with some skeptism.

### 3.1.2 Effects of Abiotic Factors on Recovery

Because recovery occurred in so few of the studies cited in Table 1, it is extremely difficult to make correlations between abiotic factors and recovery times. However, drawing on the data and observations presented in the papers, I conclude that four abiotic factors influence recovery.

NATURE OF THE OIL SPILL

It has been noted that each spill is unique because numerous variables affect spill impact. These include type of spill, duration of exposure, volume and type of oil, oil state and age (degree of weathering), weather, season, use of dispersants, etc. (Straughan 1972). However, the severity of the oil spill and its areal extent appear to affect the recovery time most (Southward and Southward 1978, Sanders et al. 1980); high concentrations of oil will kill more of the resident species, making recovery slower, and large areas killed by oiling ~~are difficult for~~ take longer for invertebrates to ~~be~~ recolonize, partly because large areas are recolonized primarily by larvae and partly because sources of new individuals are far away (Sousa 1984). Good

HABITAT

Recovery is slower in soft sediments than on rocky shores (Vandermeulen 1977, Table 2). The main reason for this appears to be the lingering effects of oil in soft sediments. The time taken for oil to weather and disperse after an oil spill depends on the water flow in the habitat (National Research Council 1985). Ganning et al. (1984) reported that the estimated minimum residence time of oil spilled in the following habitats was: 6 months on rocky shores, 4 years on sandy shores, and 10 years on mud flats. Factors that promote oil retention are weak tidal action, weak currents and fine sediments (Vandermeulen 1977, Gundlach 1987). Although recovery starts as soon as organisms can tolerate the conditions, which is well before all the oil has dissappeared, it appears that the residual hydrocarbons retard recovery of the invertebrate communities by taking up space, by killing individuals, and by reducing their reproductive output (Southward and Southward 1978).

Also lingering oil may cause "delayed effects". The effects of an oil spill may be delayed up to three years after the spill; however the cause-and-effect relationship is often difficult to demonstrate. Conan (1982) gives two examples: was the death of all the intertidal individuals of the species *Tellina fabula* (a clam) several months after an oil spill due to oil? Also was the poor recruitment of *Tellina fabula* and *Donax vittatus* for the two years following a spill due to oil?

The disturbance level in the habitat will also influence the recovery time because a frequently disturbed habitat will have younger adults than an infrequently disturbed habitat. For instance, intertidal boulders are frequently disturbed by large waves that cause the boulders to roll over and thereby crush or smother the organisms growing on them (Sousa 1979a, b); stable rocky shores are also affected by the large waves but less so (Dayton 1971). Thus stands of old organisms are rare on boulder beaches but common on stable rocky shores. One would therefore predict that recovery would be faster on boulders than on stable rocky shores.

## TIDAL HEIGHT

Position in the intertidal zone is important to the recovery of the community after a disturbance -- low- and mid-tidal communities recover more quickly than high-tidal communities (e.g., Farrell 1991). This appears to be related to the amount of time underwater and its influence on growth rates and larval survivorship.

Position in the intertidal zone is also important to the natural self-cleaning of stranded oil -- oil stranded half-way up the shore is removed more quickly than oil stranded at the top of the shore (Vandermeulen 1977, Thomas 1977, 1978). This appears to be due to the amount of time underwater and the differing forces of waves in the low and high intertidal.

The recovery of the high intertidal species is likely to take a long time partly because recovery is naturally slower than that of the mid-tidal species and partly because oil stranded in the high intertidal zone slows the process still further. Describing the recovery of the intertidal communities five years after the Arrow oil spill, Thomas (1977) stated that "recolonization has proceeded from lower to higher levels but has not yet occurred in the high tide zone."

## TEMPERATURE

Cool temperatures slow biological processes. Cold water organisms are longer lived, have longer generation times, lower fecundity and slower growth rates than their warm water counterparts (Southward and Southward 1978, Roberts 1989). Recovery of invertebrate communities is therefore expected to proceed more slowly at high latitudes (Dunbar 1968, Southward and Southward 1978, Clarke 1979). The only study that I found that tested this idea was by Oliver and Slattery (1981) -- unfortunately it is an abstract from the proceedings of a meeting and it is therefore sadly incomplete (no time scales are given). However, they report on the recovery of benthic infauna to defaunated soft-bottom habitats in and around Monterey Bay and in Antarctica. They state that the rate of succession "was dramatically extended at the cold polar latitude".

### 3.1.3 Dependency of Recovery on Habitat Protection, Changes in Management Practices, and Other Restoration Approaches

THE CLEAN-UP OF AN OIL SPILL

Stranded oil disperses slowly and so cleaning up as much of the stranded oil as possible is an important first step on the road to recovery of the system. However, many of the methods used to clean-up oil spills appear to be more harmful than the oil itself. For instance, in 1967 after the Torrey Canyon spill off England, 10,000 tons of toxic dispersants (also called detergents) were used in the cleaning operations, and most of the invertebrate mortalities could be attributed to the dispersants rather than the oil (Southward and Southward 1978). More recently mechanical removal (Rolan and Gallagher 1991) and high pressure→hot water (Broman et al. 1983, Houghton et al. 1991a) have been used to clean oiled shores, but both treatments also kill many organisms.

These studies show that the effects of the cleaning are detrimental to the invertebrate communities both in the short-term (Broman et al. 1983, Houghton et al. 1991a) and in the long-term (Rolan and Gallagher 1991). Recovery is likely to be slower in cleaned areas because, in general, very large clearings take longer to recover than patches that have some of the original inhabitants intact (Sousa 1984, Smith and Brumsickle 1989).

Thomas (1978) believes that some clean-up methods on rocky shores do more harm than good, but suggested that clean-up of oil from soft sediments would promote recovery. He stated that "if clean-up methods for lagoons could be improved so that oil could be removed without sediment penetration or disturbance, clean-up should help to minimize oil pollution effects" (Thomas 1978). However, this is easier said than done.

BIOREMEDIATION TO SPEED-UP RECOVERY

In most bioremediation a nitrogen-phosphorus fertilizer is sprayed onto the stranded oil. This fertilizer provides extra nutrients for naturally occurring micro-organisms (i.e., bacteria and fungi) that break down oil. This technique, long employed against toxic wastes, can more than double the speed of oil removal (EPA 1990). The micro-organisms feed on the oil, reduce its toxicity, and increase its removal by waves and currents (Lee and Levy 1991). Two problems with this approach are that bacteria may not be active below the top few inches of soft sediments and that micro-organisms are relatively slow to break-down oil in cold marine habitats (Cretney et al. 1978, Atlas et al. 1978). The first large-scale use of bioremediation took place in Prince William Sound during 1989 as a series of experiments. The preliminary results of the experiments look promising (EPA 1990, Chianelli et al. 1991), but the effects on long-term recovery of the communities are not known.

## HABITAT PROTECTION DURING RECOVERY

None of the studies described in Table 1 compared the recovery of communities in habitats that were protected from humans to recovery in unprotected habitats. However, there are a few studies on rocky shores that indicate that human interference -- trampling, souvenir collection, handling, and bait collection -- does have a negative effect on the community (Zedler 1978, Beauchamp and Gowling 1982, Ghazanshahi et al. 1983, Addessi 1992). Therefore limiting human access to a community would likely promote recovery.

## OTHER RESTORATION APPROACHES

*change this heading to a couple more specific headings — Do nothing ... — Transplanting spp. ..*

Given sufficient time, full recovery after an oil spill is likely to occur naturally. ~~It~~ will probably take a long time in areas (a) that were heavily oiled, (b) that were heavily oiled and destructively cleaned, (c) where the sediments are soft, and (d) where the oiling was extensive (see Section 3.1.2). In order to speed recovery, managers will want to consider restoration options.

One option is to do nothing. Teal (1990) advises against active restoration. He states ~~that it is best~~ to leave the area alone after picking up as much oil as possible. He believes that we know so little about the ecosystems we are trying to restore that we could do more harm than good.

Another option is to transplant species into the disturbed sites. Species' recovery rates will depend on life-history characteristics and tolerance of oil. The species that have larvae in the plankton all, or most, of the year will recruit quickly into large disturbed spaces. On the other hand, the species whose larvae are rarely found in the plankton or whose larvae have extremely short-range dispersal, will recruit slowly into the same patches. Species with poor larval recruitment include many asteroids and some echinoids (Simenstad, pers. com.). Examples of species with short-range dispersal are soft corals (Gerrodette 1981), amphipods (Cabioch 1980), some *Octopus* (Hochberg and Fields 1980), many of the snails in the order Neogastropoda (Abbott and Haderlie 1980), and several species of algae (Dayton 1973, Paine 1979, Sousa 1984). Most of these propagules disperse less than 2m from the adult. Recruitment of such species to disturbed patches will correlate with the abundance of propagule-releasing adults in the immediate vicinity of the clearing. Thus the complete recolonization of large bare areas by these types of species will take a very long time. These short-range dispersal species would be the most likely to benefit from transplantation. Short-range dispersal is also more common in the Arctic than in temperate waters (Thorson 1950). *add reference! / do drifting Fucus plants that are sexually mature release gametes; there are large mats of floating Fucus in Prince William Sound*

The alga, *Fucus*, ~~is a~~ short-range dispersal species that is an important species on hard substrates in Alaska -- ~~it is common and provides~~ cover and food for many invertebrate species. The recovery of *Fucus* may well determine the pattern of recovery for the community as a whole. To speed the recovery of *Fucus*, particularly in large disturbed areas, managers may consider transplanting plants into the area.

Unfortunately there is little information on how to conduct the restoration of marine communities. The restoration of kelp beds in southern California may provide an example for the restoration of the damaged ecosystems in Alaska. *Macrocystis pyrifera*, the giant kelp, forms the main component of southern California's kelp forests. Although an adult plant produces millions of spores, and although the spores and gametes are planktivorous, colonization of disturbed areas can be slow. Population declines of this species around sewer outfalls and power plants, and during warm water years, have stimulated many attempts at restoration (see Foster and Schiel 1985 for review). Transplants have been made of three stages in the life-cycle of the plant -- adult sporophytes, juvenile sporophytes and microscopic sporophytes. Most restoration attempts using these methods have not had suitable controls, so their success rates are difficult to determine (Foster and Schiel 1985). However, *Macrocystis* has returned to some of the transplanted areas.

If transplantation is attempted, I recommend that care be taken to not damage the areas from which the transplants are taken. In addition, I recommend that any major restoration project begin with an experimental phase so that the success rates of different methods can be evaluated. This will help rule out techniques that don't work and will help identify promising approaches that can be developed further (see PERL 1990). This research will provide valuable information on restoration techniques (a subject about which little is known) as well as further our knowledge of the Alaskan ecosystems. All major restoration projects should be continually evaluated with a long-term monitoring program that will allow managers to take advantage of unforeseen benefits and to address unexpected problems quickly.

## 4.0 EXTRAPOLATION TO THE INJURED ALASKAN ECOSYSTEM

### 4.1 Identification of Most Practical and Cost Effective Indicators of Recovery to Measure

What is needed to determine whether recovery has occurred is an extensive study of the abundances, biomasses, age distributions, growth rates and reproductive condition of all the species influenced by the spill (see Section 4.2). If any of these characteristics goes unmeasured then a conclusion that recovery has occurred may be criticized. However, should insufficient funds be available to conduct a thorough study it is appropriate to consider alternative approaches.

"Indicator species" have been used extensively in pollution studies. Indicator species are those species which, by their presence and abundance, provide some indication of the prevailing environmental conditions. The best indicator species are those that have narrow and specific environmental tolerances, because they will show a marked response to quite small changes in environmental quality (Abel 1989). However, indicator species provide only a general overview of the approximate position of the community in the successional process, i.e., whether the community is generally in the early or the late successional stage. ~~They are therefore not particularly useful in the Alaskan case.~~ let others decide this

A viable alternative to examining all the invertebrates is to sample only "target species." These are species that are abundant in certain zones, are key space occupiers, or are consumers known to play an important role in community structure (Dethier 1991). Sampling only target species would have the advantage of reducing costs and allowing increased replication. Dethier (1991) compiled a list of recommended target organisms for the Washington coast and I have repeated it here (Table 3A). I have added a short list of suggested target species for the Alaskan coast from Houghton et al. (1990a; Table 3B).

There are two problems with the target species approach. First, in considering oil effects "confining sampling to dominant species might miss a significant oil effect, or underestimate the degree of impact" (Dethier 1991). And second, "in considering recovery from oil spills it is important to take into account not only the dominant species, which might recolonize and recover quickly, but also the uncommon ones which may take longer to return to former abundances (e.g., because of limited dispersal or small 'source' populations)" (Dethier 1991).

However, I suggest that a sound determination of recovery after an oil spill could be based on the study of the abundances, biomasses, age distributions, growth rates and reproductive condition of several target species. The choice of target species will be critical. Houghton et al. (1990a) have begun a target species study of growth rates in Prince William Sound but their study is of four molluscs only. I suggest that target species should come from several different phyla, a few different feeding modes, and mostly from late successional stages.

---

Table 3. Target species recommended for intensive sampling effort on (A) the Washington coast (Dethier 1991); and (B) the Alaskan coast (Houghton et al 1990)

make these stand out more since the actual table is 3 not 3A or 3B

**A) WASHINGTON COAST**

ROCKY SHORES

| **Wave-exposed** | **Wave-protected** |
|---|---|
| *Eudistylia vancouveri* | *Fucus* spp. |
| *Mytilus californianus* | *Endocladia muricata* |
| *Mytilus edulis* | *Mastocarpus papillatus* |
| *Pollicipes polymerus* | *Neorhodomela larix* |
| *Anthopleura elegantissima* | *Phaeostrophion irregulare* |
| *Nucella* spp. | *Lacuna* spp. |
| *Pisaster ochraceus* | |
| *Katharina tunicata* | |
| *Endocladia muricata* | |
| *Mastocarpus papillatus* | |
| *Corallina vancouveriensis* | |
| *Dilsea californica* | |

| COBBLE SHORES | SANDY SHORES |
|---|---|
| *Fucus* spp. | *Eohaustorius* spp. |
| *Gelidium coulteri* | *Excirolana* spp. |
| *Phyllospadix* spp. | *Euzonus mucronatus* |
| *Odonthalia floccosa* | total number of polychaetes |
| *Tegula funebralis* | |
| *Hemigrapsus* spp. | |
| *Leptasterias hexactis* | |

**B) ALASKAN COAST**

| ROCKY SHORES | BOULDER/COBBLE SHORES |
|---|---|
| *Fucus* spp. | *Fucus* spp. |
| red algae | red algae |
| *Mytilus edulis* | green algae |
| *Nucella lamellosa* | Lottiidae |
| *Pagurus* spp. | |

SOFT SUBSTRATES
polychaeta
gastropoda
bivalvia
crustacea

---

## 4.2 Recommended Approach to Determine When Recovery has Occurred

### 4.2.1 Definition of Recovery

It is important that in a study of recovery that one state one's objectives clearly and define what one will or will not accept as a fully recovered ecosystem. The objectives will guide the entire project, including the sampling design, statistical tests and conclusions. Without clear objectives, the work will end up with a poorly directed sampling design and weak conclusions.

If one's objective is to determine whether an area has fully recovered from an oil spill then one must define what one will accept as recovered. Most of the researchers in Table 1 did not explicitly define recovery but their implicit definition was:

- "the return of all population densities to pre-disturbance levels or undisturbed levels."

However, there are many other possible definitions of recovery.

- American Heritage Dictionary (1973): "return to a normal condition; the getting back of something lost."

- Ganning et al. (1984): "the restoration to original functional and structural conditions with original species present in original numbers."

- Ganning et al. (1984): "returning the ecosystem to within the limits of natural variability."

- Lewis (1982): "complete recovery (has occurred when) there are no discernable after-effects."

- Boesch et al. (1987): "complete recovery is the time required for a disturbed community to exhibit variation that is within the bounds of variation seen in undisturbed, control areas."

- Conan (1982): "a new stable age distribution and equilibrium species assemblages attained".

- National Research Council (1975; page 91): "Complete recovery means that (1) the faunal and floral constituents that were present before the oil spill are again present and (2) they have their full complement of constituent age classes."

- Committee on Restoration of Aquatic Ecosystems, National Research Council (in press) " the return of an ecosytem to a close approximation of its condition prior to disturbance."

None of these definitions is completely satisfactory. They give a general description of the term but few specifics. I suggest the following definition of recovery -- it is a combination of the definitions:

- Boland (this report): "Complete recovery after an oil spill occurs when (1) all the species that were present before the oil spill are again present; (2) each of these species has reached their original abundances and biomasses, (3) each of these species has reached their original age distributions, and (4) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.

Prespill data on species abundances, biomasses, age distributions, growth rates and reproductive conditions are necessary for determining when recovery has occurred, however these data are usually unavailable. In these cases, studies of many unoiled sites must be conducted instead. These unoiled sites should be chosen carefully and should include all the habitats that were oiled. All the appropriate data should be collected in the unoiled sites soon after the oil spill and used as the baseline data representing the prespill conditions in the oiled sites.

Therefore, when one is testing for recovery one is testing the hypotheses that there are no significant differences in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that the recovered community does not have to be identical to the undisturbed community, only not statistically different from the undisturbed community, i.e., it is varying within the bounds exhibited by undisturbed systems (see definition by Boesch et al. 1987).

Notice also that my definition, like those above, focuses on the structure of the community rather than its functioning. Too little is known about the functioning of marine communities to include it in the definition. One hopes that when the structure returns the functioning will return too.

My definition of recovery is based upon that used by many researchers and the dictionary definition. However, the biologists working for The Exxon Corporation have recently proposed a different definition of recovery and this is:

- Baker et al. (1990): "recovery is marked by the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and functioning normally. It may not have the same composition or age structure as that which was present before the damage, and will continue to show further change and development." This definition is very different to all the others outlined above in that it will consider a community recovered when it is only on the road to recovery. This is unacceptable. For instance, using this definition one may consider a mussel bed to have recovered if the rocks are completely covered with healthy opportunistic species such as green algae.

The defintion of recovery of Baker et al. (1990) leads them to estimate recovery times that are relatively fast. For instance, they say that "rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." In subtidal sand and mud systems "recovery times are 1 to 5 years, but they can be 10 years or longer in exceptional cases" (Baker et al. 1990). My literature survey suggests that recovery times are longer than these, and in general, these numbers should be doubled to obtain true estimates of recovery times (Section 3.1.1).

In conclusion, the definition of recovery is an extremely important part of the study

### 4.2.2. Methods to be used in a Recovery Study

The researchers need to test the hypotheses that there are no significant difference in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice first, that no mention has been made of summarizing statistics like species diversity, total number of species, total biomass or total number of individuals -- as we have seen in Section 3.1.1, these numbers cannot be used to show when recovery has occurred. Second, that identifications need to be made to the species level. Some research has shown that little information is lost when identifications are made to the family level (Warwick 1988) but this applies to only some analyses, and too little is known about the Alaskan invertebrates to support this view.

In my opinion, none of the papers cited in Table 1 provides a good example of how to conduct a recovery study. Sanders et al. (1980) critized past research on recovery by saying that the researchers have arrived at "conclusions that are, at best, equivocal interpretations of insufficient and ambiguous data. Such inadequacies are usual in many pollution-related studies of benthic ecology, including those in which important decisions are based." It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem. Many books and papers describe appropriate sampling programs and methods to be used for studying marine benthos (e.g., Green 1979, Gauch 1982, Holme and McIntyre 1984, Mead 1988, Underwood 1981, Hurlbert 1984, Stewart-Oaten et al. 1986, Carney 1987, Gray et al. 1988, Krebs 1989, PERL 1990, Dethier 1991), and these sources should be consulted.

Natural communities are spatially and temporally heterogenous. This means:
(1) that it is necessary to study many sites nearby that were not oiled and many sites within the oiled area so that the range of natural variability can be determined (Mann 1978, Ganning et al. 1984);
(2) that a large area should be randomly sampled at each site; because communities change with water depth, a useful design is stratified random sampling inwhich one blocks with water depth (Gray et al. 1988); and
(3) that a large number of samples are required for reliable estimates of population densities; even to estimate population densities to within 20-40% of their true value may require several hundred samples at each site (Abel 1989). Even well funded studies such as Houghton et al (1990a) fail in all three respects.

### 4.2.3. Results and Conclusions of a Recovery Study

All the results that are necessary and sufficient to test the hypotheses should be presented in the research report. Frequently researchers collect a lot of information but report only species diversity. Some also report total biomass and total abundance but rarely do papers go beyond these summarizing statistics and describe the abundances of individual species. This is a weakness because, as we have seen above (Figure 2), "climax" communities do not have the greatest number of species, biomasses, or individuals. Also, these summarizing statistics cannot be used to test the hypotheses.

Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the functioning of the community.

Finally, the conclusions of any recovery study should be clearly presented.

## 5.0 LIST OF INDIVIDUALS CONTACTED DURING STUDY

Mr. Dennis C. Lees,
ERC Environmental and Energy Services Co. (ERCE),
5510 Morehouse Drive,
San Diego, CA 92121.

Dr. John S. Oliver,
Moss Landing Marine Laboratories,
Moss Landing, CA 95039.

## 6.0 ACKNOWLEDGEMENTS

I thank Jeff Crooks and Stacey Baczkowski for searching for papers, reading papers and helping compile Table 1; John Oliver and Dennis Lees for suggesting several recovery sources; Bruce Nyden, Dawn Makis, Michelle Cordrey and Bric Standish for typing most of the Bibliography; and Joy Zedler for helpful comments on early drafts of this manuscript. Constructive criticism of the first draft by John Strand, John Armstrong, Charles Peterson, Charles Simenstad and Art Weiner substantially improved this report.

## 7.0 REFERENCES

Abbot, D.P., and E.C. Haderlie. 1980. Prosobranchia: marine snails. In R.H. Morris, D.P. Abbott and E.C. Haderlie (eds.) Intertidal invertebrates of California. Stanford University Prerss, Stanford, California.

Abel, P.D. 1989. Water pollution biology. Ellis Horwood Limited Publishers, Chichester, England.

Addessi, L. 1992. Impacts of human disturbances on a rocky intertidal community. Masters thesis, SDSU, San Diego, Ca.

RPWG
R

# MEMORANDUM

# State of Alaska
## DEPARTMENT OF FISH AND GAME

**To:** Deborah Boyd
Contracts Coordinator

**Date:** 17 April 1992

**File No:** REST 1.4

COPY

**Telephone No:** 907-278-8012

**From:** Stanley E. Senner SES
Restoration Program Mgr.

**Subject:** COOP-91-039

On 31 March the Point Reyes Bird Observatory (PRBO) submitted final versions of the "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Marine Bird Populations from Environmental Perturbations" and "Annotated Biobliography." I have enclosed their letter of transmittal for your file.

These documents fulfill PRBO's obligations under COOP-91-039, using Exxon Valdez oil spill funds provided through the Department. Copies of the two documents are in the files of the Restoration Planning Work Group and are being distributed to the OSIAR Division and others as appropriate.

I do not yet have a final invoice from PRBO, but I will forward it to you when I do. I trust that payment was made on their previous invoice (31 December 1991) as per my memorandum dated 5 March 1992 (copies enclosed). Would you confirm that?

Thank you for your assistance.

enclosures (3)

cc: Mike Dean

4990 Shoreline Highway
Stinson Beach
California 94970
1 415 868 1221
1 415 868 1946 (Fax)

POINT REYES
BIRD OBSERVATORY

31 March 1992

Stan Senner, Restoration Manager
ADF&G, RPWG
c/o CACI
645 G Street
Anchorage 99501

Tel. (907) 276-7178

Dear Stan,

I enclose our revised annotated bibliography and our revised final report. I enclose four copies of each. I hope you find the revisions satisfactory. I never did receive comments from Mike Fry or Dan Roby, and so have responded to your and John Strand's comments.

Would you like a floppy disk with a Wordperfect version of the bibliography and report? If so, I would be happy to supply one, but in the meantime I'll wait to hear from you (I did 'phone you earlier today to ask).

Alan Bruce (who is stepping in for Bob Maynard as Controller) will send you invoice separately.

Sincerely yours,

Nadav

Nadav Nur

4990 Shoreline Highway
Stinson Beach
California 94970
1 415 868 1221
1 415 868 1946 (Fax)

POINT REYES
BIRD OBSERVATORY

To: Stan Senner, Restoration Program Manager

December 31, 1991

Re: COOP-91-039
Year-to-date expenses incurred

| | |
|---|---|
| Direct Labor | $19 983 |
| Direct Operating Expenses | 3 635 |
| Indirect Expenses | 9 140 |
| Total to Date | $32 758 |

Please remit progress payment (25%) of $8 933.

# MEMORANDUM

# State of Alaska

## DEPARTMENT OF FISH AND GAME

**To:** Deborah Boyd
Contracts Coordinator

**Date:** 5 March 1992

**File No:** REST 1.4

COPY

**Telephone No:** 907-278-8012

**From:** Stanley E. Senner SES
Restoration Program Mgr.

**Subject:** COOP-91-039

For your records, the Point Reyes Bird Observatory (PRBO) submitted a draft final report on 19 February. That report is now under review; we hope to have a final version by 31 March.

When PRBO submitted its progress report last September (09/09/91), we did not pay them anything because the expenses they had incurred to date did not exceed the 25 percent ($8,933) that we provided up front. By now, however, they have incurred $32,758 in expenses, which is most of the $35,733 available. In submitting the draft final report, PRBO has requested payment of a second 25 percent, $8,933 (see the enclosed letter and invoice). This would leave $17,867 unpaid until after the final report is in and we are fully satisfied with it.

I am pleased with PRBO's work to date, and I have no problem with paying them an additional 25 percent at this time. If you have no problem with this, I recommend that you initiate a warrant for $8,933.

Thank you for your assistance.

enclosure (1)

cc: Mike Dean

RPWG
R

437 E Street, Suite 301
Anchorage, Alaska 99501
(907) 271-2461
FAX: (907) 271-2467

# Oil Spill Restoration Planning Office

TO: William Warren-Hicks

OFFICE/PHONE: fax (919) 781-3150 9524

FROM: Kristen Ballard

DATE: 6/21/90

NUMBER OF PAGES: 2

**MESSAGES:**

Authors omitted from "OILCITES.50" Bibliography list. (listed by page number from March 19 Prelim. Draft of Annotated Bibliography of Relevant Lit.)

Pg #'s

| | | | |
|---|---|---|---|
| 17 | 141 | 221 | 386 |
| 30 | 160 | 242 | 406 |
| 60 | 162 | 331 | 418 |
| 73 | 179 | 342 | 419 |
| 78 | 183 | 350 | 424 |
| 94 | 191 | 357 | 425 |
| 98 | 220 | 371 | |

Bill:

Also, missing from the March 19 Draft of Relevant Lit. Annotated Bibliography, but lissted in the OILCITES.50 bibliography are below:

Thorhaug, A. (1979). *Mitigation of estuarine fisheries nurseries: seagrass restoration.* Presented at the Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats Fort Collins, CO (USA) 16 Jul 1979. Gen. Tech. Rep. U.S. Dept. Agriculture, Fort Collins, CO (USA). p 667-669.

Krebs, C.T.; Tanner C.E. (1981). *Restoration of oiled marshes through sediment stripping and Spartina propagation.* In: Parrotte, R.B. (ed). Proceedings of the 1981 Oil Spill Conference, Atlanta, March 2-5, pp.375-385.

This is a partial listing. I had just begun looking for omissions just before I called you on 6/21/90. I will continue to look for other titles that we wish to aquire and will send you an updated list when it is complete (hopefully by Monday, 6/25 at the latest).

Thank you for your attention to this matter-

Kirsten

KPWG
R

# REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: HARBOR SEALS AND KILLER WHALES

by


Brent S. Stewart, Ph.D.
Staff Scientist

Pamela K. Yochem, D.V.M.
Staff Scientist

Joseph R. Jehl, Jr., Ph.D.
Staff Scientist, Research Director

Hubbs-Sea World Research Institute (HSWRI)
1700 South Shores Road
San Diego, CA 92109

Principal Investigator: Joseph R. Jehl, Jr., Ph.D.


**FINAL REPORT**

to

Restoration Planning Work Group
EXXON Valdez Oil Spill Office
645 "G" Street
Anchorage, Alaska 99501

30 June 1992

## EXECUTIVE SUMMARY

Populations of marine mammals have suffered large reductions, sometimes to near extermination, by aboriginal and commercial harvests, incidental or indiscriminate killing, and epizootics during the past two centuries. After killing ended, many populations increased at annual rates varying from 7-21% in pinnipeds and 2-12% in cetaceans. The causes for recent steady declines, following population recoveries, of northern fur seals, northern sea lions, and harbor seals in the Bering Sea, Aleutian Islands, and western Gulf of Alaska, and of southern elephant seals in most of the southern ocean, remain unexplained.

Epizootics.--Recent epizootics killed over 18,000 seals (mostly harbor seals) in Europe, and an estimated several thousand at Lake Baikal; population responses following those reductions are undocumented. Historical occurrences of epizootics and the prevalence of antibodies to various viruses in current seal populations suggest that seals that survive these challenges provide nuclei for population recovery.

Climate.-- Seal and sea lion populations in the Pacific were reduced by the 1982-83 El Niño Southern Oscillation (ENSO) event. Recent studies have indicated only temporary demographic consequences. Historical, large-scale fluctuations in ocean conditions related to ENSOs may have influenced population changes in Antarctic pinnipeds, though not to the extent of affecting population persistence.

Overall long-term population data demonstrate the potential of pinnipeds and cetaceans to sustain high rates of growth following population reduction, even to very low abundance, so long as breeding and foraging habitats are not degraded.

Pollution.-- Fouling of pinnipeds and cetaceans by oil has evidently had insignificant effects on populations; substantial mortality has never been observed, even following catastrophic spills. The effects of oiling depended on whether oil coated the body surface, was ingested, or aromatic hydrocarbons were inhaled. Most reports have been based on casual observations; results of systematic experiments have often been ambiguous.

Vulnerability of cetaceans is highest for species with small ranges, coastal/ice-dwelling/riverine habitats, limited diets, poor behavioral flexibility, and small populations. Species with large ranges, oceanic distribution, diverse prey, adaptable behavior, and large populations are least vulnerable. For pinnipeds, stressed or nursing animals, and recently-weaned pups are potentially vulnerable. But marine mammals are long-lived and even the loss of an entire cohort would have insignificant long-term demographic effects.

Prolonged inhalation of hydrocarbon vapors appears to pose the greatest risk to the viability of individuals. Animals with parasitic lung disease, which is relatively common in pinnipeds, would be especially vulnerable to respiratory challenges. Yet, for most pinnipeds, particularly in northern habitats, it is unlikely that petroleum vapors could become sufficiently concentrated to represent a threat.

Contaminants in food.--Pinnipeds are unlikely to directly ingest hydrocarbons, and their prey seem unlikely to accumulate residues. Thus, toxicity is not expected to be a significant health risk, except possibly in bearded seals, walruses, or harbor seals foraging in heavily contaminated benthic environments. Of greater significance is the potential direct effects of fouling on benthic communities, which may be transmitted to other parts of the food chain; for example, a reduction in octopus abundance might depress the recovery of harbor seals.

Killer whales consume a wide variety of prey, including fish, birds and mammals. They are unlikely to ingest toxic hydrocarbons, unless they prey on species that have accumulated residues.

Future research.--Because there are few data on pre-EVOS abundance of harbor seals and killer whales in the EVOS area, it is impossible to use simple counts of animals to decide whether a population has recovered. For harbor seals, it may be possible to use early post-spill data on abundance, distribution, and pup production as a reference point for future assessments. However, other recovery criteria (e.g., habitat occupation; an arbitrarily-established, desired local population size; physical or physiological condition of individuals) need to be developed. Evaluation of the recovery process will require long-term monitoring of population abundance and seasonal distribution. Future research should document the movement patterns of harbor seals and killer whales in Prince William sound and their seasonal use of habitats in the EVOS area using satellite-linked or conventional VHF telemetry and intensive photo-identification studies (primarily killer whales). Surveys should cover a larger area and be conducted at all seasons of the year; this is especially needed for killer whales. Monitoring should be conducted at several year intervals--and at a level to provide statistically valid results-- to permit long-term, cost-effective evaluation.

Table of Contents

1.0. Introduction

1.1. Background

On 24 March 1989, around 11 million gallons of North Slope crude oil spilled into Prince William Sound from the grounded oil tanker EXXON Valdez. About 60% of the oil was not recovered and drifted or was blown southwest along the Kenai Peninsula toward Shelikof Strait, resulting in the fouling of over 1200 miles of mainland and island coastline and an unknown area of ocean bottom. Resident populations of harbor seals and killer whales may have been affected during the spill by inhalation of volatile, short-chain hydrocarbons, ingestion of oil, immediate destruction of prey resources and long-term food chain contamination. Evidently, substantial numbers of harbor seals became oiled in the EXXON Valdez oil spill (EVOS) area. Some were likely exposed to toxic aromatic hydrocarbons in areas very near the spill source. Killer whale numbers have declined in the EVOS area since 1989; known (photo-identified) whales have been reported missing from well-studied killer whale pods in nearby areas of Prince William Sound. Additional studies have been conducted on the distribution and abundance of killer whales in Prince William sound to determine the relationship of the EVOS to changes in whale abundance but results of those studies have not yet been published. When abstracts or summaries were included in source documents we quoted them directly in our annotated bibliography. When no abstracts or summaries were present in the documents reviewed we constructed new abstracts.

1.2. Objectives

Here we summarize, in the form of an annotated bibliography, published information on the population effects of oil spills on harbor seals and other relevant pinnipeds and killer whales and other relevant cetaceans throughout their ranges. We also summarize demographic information on the responses of pinniped and cetacean populations to other anthropogenic and natural disturbances and on rates and patterns of population recovery. We use this data base as a guide to understanding population growth rates of harbor seals and killer whales, particularly in the Gulf of Alaska. We include comparative data for cetaceans and pinnipeds and summarize their population responses to anthropogenic (especially oil spills) and natural disturbances.

## 2.0. Technical Approach

### 2.1. Information retrieval and sources of data

Computerized literature searches were made through DIALOG (accessing BIOSIS, AQUATIC SCIENCES AND FISHERIES ABSTRACTS and OCEANIC ABSTRACTS) and MELVYL (accessing all University of California book and periodical holdings). Direct searches were made of current scientific literature at libraries at Scripps Institute of Oceanography, San Diego State University, UCLA, and UC Davis. Finally, our personal and Institute libraries were the most productive sources of information on pinniped and cetacean biology. The literature recoveries from these initial searches were used in a hierarchical way to provide additional key words for additional searches and additional reference lists of previously published literature.

## 3.0. Review of available information of recovery of marine mammal populations from anthropogenic and natural disturbances

### 3.1. Rate, duration, and degree of recovery following disturbance.

#### 3.1.1. Pinnipeds

##### A. Harbor seals

Harbor seals are relatively abundant residents of Prince William Sound and the Gulf of Alaska. Little is known of their daily and seasonal hauling patterns, absolute abundance, movements, life history parameters and diet within the EVOS area, but detailed information does exist for local populations elsewhere. Daily terrestrial abundance of harbor seals is greatest at mid-day or during daytime low tides and seasonal terrestrial abundance is greatest during the molt in spring or summer and least in winter; breeding occurs from late winter through early spring or summer depending on latitude (e.g., Schneider and Payne 1983, Stewart 1984, Terhune and Almon 1983, Thompson et al. 1989, Yochem 1987). Terrestrial abundance at a large haulout area on Tugidak Island near the EVOS area declined substantially (about 85%) from 1976 through 1988 for unknown reasons, although large numbers of pups were harvested annually from 1964 through 1972 (Pitcher 1990). The trend in Prince William Sound was not documented. The decline in abundance at Tugidak Island is sharp contrast to the steady increases in harbor seal populations in most other parts of the species' range during the past several decades (e.g., Harvey et al. 1990, Heide-Jorgensen and Harkonen 1988, Olesiuk et al. 1990a, Stewart et al. 1988, Stewart et al. 1992).

Seasonal site-fidelity and short- and long-distance movements of harbor seals have been documented in some areas (e.g, Brown and Mate 1983, Pitcher and MacAllister 1981, Yochem et al. 1987) as have seasonal, sexual, and age-class segregation (e.g., Allen et al. 1988, Godsell 1988, Kovacs et al. 1990, Thompson et al. 1990). No comparable data are available for the EVOS-Prince William Sound area. The diet of harbor seals is relatively broad with benthic and epibenthic species of cephalopods and fish generally predominating (e.g., Brown and Mate 1983, Harkonen 1987, Olesiuk et al. 1990b, Pierce et al. 1991, Pitcher 1980a, 1980b, Thompson et al. 1991).

Harbor seal populations have been increasing in most areas where they have been studied in recent years where commercial or subsistence harvesting is low or absent (e.g., Harvey et al. 1990, Heide-Jorgensen and Harkonen 1988, Olesiuk et al. 1990a, Stewart et al. 1988, Stewart et al. 1992). Documented rates of population increase are relatively high, around 5-22% per year (Table 1). Most of the increases have occurred after bountied and indiscriminate killing and harvesting were outlawed. Degree of recovery is generally impossible to judge as pre-exploitation abundances are unknown. In a few other areas, however, populations have declined or fluctuated at low levels. In some cases chronic pollution is believed to be responsible for reproductive failures and depressed populations of harbor and other seals (Helle et al. 1976, Reijnders 1978, Zakharov and Yablokov 1990). There has also been a persistent decline in the western Gulf of Alaska around Tugidak Island (Pitcher 1990), and perhaps in Prince William Sound. Causal factors may include 1) degradation of habitat (reduction of prey resources, natural environmental changes, virulent pathogens, etc.) or 2) substantial undocumented mortality associated with commercial fishing operations or native subsistence harvest.

In 1988 an epizootic killed over 18,000 seals, mostly harbor seals in European waters. In Swedish and Danish waters of the Kattegat and Skagerak more than 5300 harbor seals died; the population had previously numbered about 9100 and had increased from 1978-1988 at more than 12% per year (Dietz et al. 1989, Heide-Jorgensen and Harkonen 1988). An epizootic in the Soviet Union's Lake Baikal in 1987 killed several thousand Baikal seals (Grachev et al. 1989). Disease outbreaks in other species in the western Atlantic, Pacific, and Antarctic were less severe (Borst et al. 1986, Geraci et al. 1982, Hinshaw et al. 1984, Laws and Taylor 1957, Smith et al. 1974, Vedros et al. 1971), but there is no evidence of long-term demographic consequences in those areas. There are no published data on population responses following the 1987 and 1988 disease outbreaks. No long-term population effects of oil pollution on harbor seals or any other pinnipeds have been documented; documentation of chronic effects of oil pollution on individuals has been equivocal (Geraci and St. Aubin 1987, St. Aubin 1990).

B. Other pinnipeds

Throughout the world, populations of many pinniped species have been increasing at relatively high rates. Northern elephant seals (Mirounga angustirostris), for example, have been increasing at about 14% per year for nearly one hundred years (Stewart 1992). The duration of increases for other species varies according to the time at which commercial harvesting ended; pre-exploitation abundance of any of those species is unknown. Following sustained population growth in the early 1900s, northern fur seals (Callorhinus ursinus) in the Bering Sea declined substantially, for unknown reasons, from the 1960s through the late 1980s. Northern sea lions have decreased steadily during the past two decades throughout the Aleutian Islands and western Gulf of Alaska, whereas their populations in the eastern Gulf of Alaska, Canada and Oregon and Washington have remained relatively stable or increased slightly. Southern elephant seals have also been declining in most areas of the Southern Ocean in recent years, following a period of recovery from commercial harvesting (Laws 1992).

Low reproductive success and high pup mortality among several species of pinnipeds in the Pacific in 1982 or 1983 coincided with the 1982/83 El Niño Southern Oscillation (ENSO; De Long and Antonelis, 1991; DeLong et al., 1991; Guerra C. and Portflitt K., 1991; Majluf, 1992; Stewart and Yochem, 1991; Trillmich and Dellinger, 1992). These results were evidently related to reduction, redistribution or disappearance of prey populations near rookeries. There is little evidence of substantial adult mortality nor in long-term demographic effects from that intense oceanographic disturbance, except perhaps at the Galapagos Islands.

3.1.2. Cetaceans

A. Killer Whales

Killer whales are widely distributed in the world's oceans (Dahlheim 1981). They occur in deep pelagic waters and in coastal areas, along ice edges, and in pack ice as well as in the tropics (Mitchell and Reeves 1988). Local movements and distribution appear to be largely dictated by distribution and availability of prey (Dahlheim 1981, Braham and Dahlheim 1982, Heimlich-Boran 1988). A partial list of prey items by geographic area was presented by Anon. (1982). Killer whales consume a variety of marine vertebrates and invertebrates, including fish, cephalopods and mammals. There are differences in food habits between sympatric populations in some areas: resident pods in

British Columbia and Washington consume mainly fish (especially salmon) whereas transients feed mostly on marine mammals, especially harbor seals (Heimlich-Boran 1988).

Using photo-identification, Olesiuk et al. (1990c) calculated a number of population parameters for killer whales off British Columbia and Washington. They reported an annual rate of increase of 2.92%; the percentage of mature females pregnant varied from 2.7-4.1%. Neonate mortality was 43%. The mean life expectancy was 50.2 years for females and 29.2 years for males, with predicted maximum life spans of 80-90 and 50-60 years, respectively. From computer simulations the authors predicted that the killer whales in this region could sustain a maximum non-selective harvest of 2.84%. They further predicted that a stationary population at carrying capacity would comprise 37% juveniles, 20% mature males, 14% reproductive females, and 29% post-reproductive females. Leatherwood et al. (1990) reported the following age structure among Prince William Sound killer whales: 22.41% adult males, 9.48% adult females (defined as females in close association with a calf), 3.9% calves, and 64.22% immatures and others (this group includes immature animals, adult females not associated with calves, and recently matured males that lack a prominent dorsal fin).

From 1962-1977, a total of 66 killer whales was removed from a few pods in British Columbia and Washington by a live-capture fishery to supply captive whales for oceanaria. Since then, the cropped pods have had higher birth rates (4.56%), lower mortality rates (bulls, 2.5%; cows 0.46%; juveniles, 1.99%) and have increased in number faster (pod growth rate = 3.01%) than uncropped pods (birth rate = 3.15%, pod growth rate = 1.67%) in the same areas (Bigg 1982, Balcomb et al. 1982).

Leatherwood et al. (1990) documented a minimum of 221 killer whales in Prince William sound in 1987 from photographs of their dorsal fins and color patterns. Those whales belonged to nine "resident" and eight "transient" pods, as defined by Bigg (1982). Recent DNA research has supported the hypothesis that these pods are genetically distinct (Hoelzel and Dover 1991). The combined mortality rate for all ages and both sexes from 1984-86 was 1.9% in three pods, but 7.4% in another (AB pod). The latter pod has been interfering with the blackcod (Anoplopoma fimbrica) longline fishery since 1985 and bullet wounds have been observed on some of its members. Leatherwood et al. (1990) did not report an annual rate of population increase for killer whales but noted that 9 calves were born in 1986 and 1987. In British Columbia and Washington, where killer whales have been studied using the same techniques, annual rates of increase ranged from 1.67 to 3.01% (Balcomb et al. 1982, Bigg 1982, Olesiuk et al. 1990c) and annual mortality rates from 0.7% (adult females) to 2.81% (adult males).

Geraci and St. Aubin (1987) and Geraci (1990) reviewed the effects of oil on cetaceans and included a table of reports of cetaceans associated with oil. Only one incident involving killer whales was found, in which two whales (one sick, one dead) were observed in association with diesel fuel (quantity unknown) off the Alaskan peninsula.

Aside from occasional reports of mass die-offs or strandings (e.g., Oritsland and Christensen 1982, Christensen 1990), the most significant cause of killer whale morality has been commercial whaling. For example, Christensen (1982) reported that 2399 killer whales were killed in Norwegian coastal waters between 1938 and 1980. This represented a mean annual catch of 57 whales. Christensen (1982) noted, however, that the length (and therefore presumably the age structure) of the catch did not change during that period. Although no population growth rates are available, the percentage of pregnant females ranged from 12-32.8%, as determined by catch data (Anon. 1982). Similar percentages of pregnant females have been calculated from Antarctic catch data (12.72-18.97%). Off Marion Island in the southern Indian Ocean, 36.3% of adult females observed had calves (Condy et al. 1978), although some may not have been young-of-the-year.

### B. Other cetaceans

Population growth rates and related parameters have been measured in other species that have experienced significant human disturbance, usually in the form of harvesting (either as target species, right whales for example; or incidental catch, dolphins in the Eastern Tropical Pacific (ETP) for example).

The relatively low birth and death rates of killer whales are mirrored by another large odontocete, the sperm whale. Females produce a calf only every 3-6 years, and the natural mortality rate is less than 1% per year (Gosho et al. 1984). A decrease in calving interval (from 6 to 5.2 years) has been documented in an exploited population off Durban, South Africa (Best et al. 1984).

Reilly and Barlow (1986) estimated that dolphins could approach a population growth rate of 9%, but they thought that rate was unlikely to be attained under most conditions. Barlow (1985) reported the following differences among a more intensively fished dolphin population in the ETP: smaller percent pregnant, larger percent lactating, and larger percent immature than less-exploited dolphin populations in the ETP. The highest rates of annual population increase in baleen whales are reported for southern right whales and range from 7.6% (Payne et al. 1990) to 11.7% (population as a whole) or 13% (cow-calf pairs) (Bannister 1990) (Table 2). Gray whales have increased at annual rates of about 4% or greater since the early 1900s, despite a harvest rate of about 1.2% per year (Reilly et al. 1983) and Bowhead whales, which also are harvested for subsistence purposes, increased at an annual rate of around 3% from 1978 through 1988 (Zeh et al. 1991). Moderate rates of increase for other whales were summarized by Best (1990). Reproductive rates have been reported for humpback whales; the mean calving rate (calves per mature female per year) is about 0.4 (Perry et al. 1990, Clapham and Mayo 1990). The mean calving interval for gray whales is 2.11 years and the birth rate (ratio of calves to adults) is about 0.14 (Reilly 1984).

3.2. Dependency of recovery on habitat protection, changes in management practices, and other restoration approaches.

In virtually all cases, recent population recoveries of pinnipeds and cetaceans has been due to the termination of commercial harvesting or indiscriminate or incidental killing. Many species were reduced to very low levels during the harvesting periods and several were believed to have been exterminated. Presumably, foraging and breeding habitats were not degraded by the harvesting. The presence of abundant prey resources and good quality breeding habitat are probably the most important factors that allow sustained population growth, as soon as commercial exploitation ceases.

Quick resumption of population growth of eastern North Pacific pinnipeds (i.e., California sea lions, northern elephant seals, harbor seals) following the 1982/83 ENSO was evidently due to rapid recovery of prey resources; i.e., the degradation of habitat and reduction of carrying capacity was short-lived (Stewart, 1992; Stewart et al. 1992; Stewart and Yochem, unpubl; R. L. DeLong, pers. comm.). A consensus of recent literature on population modelling is the recognition that rapid and large population changes can occur with only moderate increases in adult mortality; population growth is less sensitive to changes in juvenile survival. Thus, if adult mortality is high during, after, or both, a population reduction (e.g., because of subsistence harvests or undocumented killing), the recovery may delayed or a continued decline may also occur. Changes in harbor seal management practices (i.e., documenting all subsistence takes with respect to age and sex composition of harvest in and near the EVOS area, reducing and strictly regulating subsistence harvests) would probably be the most effective means of stimulating rapid population recovery.

3.3. Indicators of recovery that are the most practical and cost effective to measure

There are few data available on the pre-EVOS status of killer whales and harbor seals in the affected EVOS area. For harbor seals, relative abundance and distribution and relative annual production of young would be indicators that could be directly compared with early post-spill data and with similar data from comprehensive data bases from other regions. However, collection of data on haulout patterns, movements, and diet would be useful for determining whether changes in local abundance of seals might be due to lowered reproduction among resident seals or simply to movements of surviving seals to more favorable breeding or foraging habitats or to changes in haulout patterns related to dietary shifts.

Photo-identification studies (perhaps in combination with VHF or satellite telemetry) of killer whales should be continued to document relative pod sizes and composition, home range (of residents) and large-scale movements (of residents and transients), and reproductive rates. Those studies should be made over a broader area in Prince William Sound and during more seasons than previous studies. Monitoring in alternate years or every three years would probably be most efficient as the studies should be continued for 15 years or more to provide any useful information on population trends.

Bigg (1982) and Balcomb et al. (1982) measured birth rates, mortality rates and net population change in cropped versus uncropped pods with relatively good success.

3.4. Approaches and strategies for determining how indicators of recovery are best monitored and tested to determine when recovery has occurred

First, "recovery" must be defined for killer whales and harbor seals because there are few or no pre-EVOS data to compare with post-EVOS data. One guideline for evaluating "recovery" might be whether or not animals have regained the ability to maintain self-replicating or growing populations. To determine whether or not and when these abilities have been regained would require long-term studies of abundance coupled with an assessment of seasonal movements of animals in and out of the area and of the magnitude of immigration and emigration. The case of harbor seals in Prince William Sound is further complicated by a probable declining trend prior to the EVOS (cf. Pitcher 1990). To evaluate the health or demographic trends of local Prince William Sound populations of these species, a combination of approaches would be most productive and should be conducted every two or three years. Combinations of satellite and VHF telemetry, aerial and boat surveys, ground observations, dietary studies (for harbor seals) and photo-identification studies (for killer whales) should be used but should be planned carefully to give statistically valid results and to avoid the possibility of the studies themselves (i.e., disturbance) complicating interpretations of movements, reproduction and trends in abundance.

These studies need to be integrated with research by other groups on benthic, epibenthic, and mid-water column fish and invertebrate communities to determine the effects of their recoveries on local killer whale and harbor seal distribution.

## 4.0. Acknowledgements

We thank J. Francine, R. Pytesky, S. Bond, F. T. Awbrey, and K. Miller-McLune for assisting with literature collection, summary and preparation of the annotated bibliographic data base and S. Senner, J. Strand, D. Costa, and D. Sinniff for their reviews of the draft report.

## 5.0. References

Allen, S. G., C. A. Ribic, and J. E. Kjelmyr. 1988. Herd segregation in harbor seals at Point Reyes, California. Calif. Fish Game 74:55-59.

Allen, S. G., H. R. Huber, C. A. Ribic, and D. G. Ainley (1989). Population dynamics of harbor seals in the Gulf of the Farallones, California. Calif. Fish Game 75:224-232.

Anon. 1982. Report of the workshop on identity, structure and vital rates of killer whale populations, Cambridge, England, June 23-25, 1981. Rep. int. Whal. Commn 32:617-631.

Balcomb, K. C. III, J. R. Boran, S. L. Heimlich. 1982. Killer whales in Greater Puget Sound. Rep. int. Whal. Commn 32:681-685.

Bannister, J. L. 1990. Southern right whales off Western Australia. Rep. int Whal. Commn Spec. Iss. 12:279-288.

Barlow, J. 1985. Variability, trends, and biases in reproductive rates of spotted dolphins, Stenella attenuata. U. S. Fish. Bull. 83:657-669.

Best, P. B. 1990. Recovery rates in whale stocks that have been protected from commercial whaling for at least 20 years. Appendix 6 of Annex F, Report of the International Whaling Commission 40:129-130.

Best, P. B., P. A. S. Canham, N. Macleod. 1984. Patterns of reproduction in sperm whales, Physeter macrocephalus. Rep. int. Whal. Commn Spec. Iss. 6:551-79.

Bester, M. N. 1980. Population increase in the Amsterdam Island fur seal, Arctocephalus tropicalis, at Gough Island. S. Afr. J. Zool. 15:229-234.

Bigg, M. 1982. An assessment of killer whale (Orcinus orca) stocks off Vancouver Island, British Columbia. Rep. int. Whal. Commn 323:655-666.

Borst, G. H. A., H. C. Walvoort, P. J. H. Reijnders, J. S. van der Kamp, and A. D. M. E. Osterhaus. 1986. An outbreak of a herpesvirus infection in harbor seals (Phoca vitulina). Journal of Wildlife Diseases 15:593-596.

Braham, H. W. 1984. Review of reproduction in the white whale Delphinapterus leucas, narwhal, Monodon monoceros, and Irrawaddy dolphin, Oracella brevirostris, with comments on stock assessment. Rep. int. Whal. Commn. Spec. Iss. 6:81-89.

Braham, H. W. and M. E. Dahlheim. 1982. Killer whales in Alaska documented in the Platforms of Opportunity Program. Rep. int. Whal. Commn. 32:643-646.

Brown, R. F. and B. R. Mate. 1983. Abundance, movements, and feeding habits of harbor seals, Phoca vitulina, at Netarts and Tillamook Bay, Oregon. U. S. Fish. Bull. 81:291-302.

Butterworth, D. S., J. H. M. David, L. H. McQuaid, and S. S. Xulu. 1987. Modeling the population dynamics of the South African fur seal Arctocephalus pusillus pusillus. NOAA Tech. Rep. NMFS 51:141-164.

Calambokidis, J., B. L. Taylor, S. D. Carter, G. H. Steiger, P. K. Dawson and L. D. Antrim. 1987. Distribuition and haul-out behavior of harbor seals in Glacier Bay, Alaska. Can. J. Zool. 65:1391-1396.

Chapman, D. G. 1981. Evaluation of marine mammal population models. In: C. W. Fowler and T. D. Smith (eds.). Dynamics of large mammal populations. John Wiley and Sons, New York.

Christensen, I. 1982. Killer whales in Norwegian coastal waters. Rep. int. Whal. Commn 32:633-641.

Christensen, I. 1990. A note on recent strandings of sperm whales (Physeter macrocephalus) and other cetaceans in Norwegian waters. Rep. int. Whal. Commn 40:513-515.

Clapham, P. J., and C. A. Mayo. 1990. Reproduction of humpback whales (Megaptera novaeangliae) observed in the Gulf of Maine. Rep. int. Whal. Commn Spec. Iss. 12:171-175.

Condy, P. R. 1978. Distribution, abundance, and annual cycle of fur seals (Arctocephalus spp.) on the Prince Edward Islands. S. Afr. J. Wildl. Res. 8:159-168.

Condy, P. R., R. J. van Aarde, and M. N. Bester. 1978. The seasonal occurrence and behaviour of killer whales Orcinus orca, at Marion Island. J. Zool., Lond. 184:449-464.

Cooper, C. F. and B. S. Stewart. 1983. Demography of northern elephant seals, 1911-1982. Science 219:969-971.

Croxall, J. P. and R. L. Gentry (eds). 1987. Status, Biology, and Ecology of fur seals. NOAA Tech. Rept NMFS 51:212 pp.

Dahlheim, M. E. 1981. A review of the biology and exploitation of the killer whale, Orcinus orca, with comments on recent sightings from Antarctica. Rep. int. Whal. Commn

31:541-546.

DeLong, R. L. and G. A. Antonelis. 1991. Impact of the 1982-1983 El Niño on the northern fur seal population at San Miguel island, California. pp. 75-83. In: F. Trillmich and K. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin.

DeLong, R. L., G. A. Antonelis, C. W. Oliver, B. S. Stewart, M. C. Lowry, and P. K. Yochem. 1991. Effects of the 1982-83 El Niño on several population parameters and diet of California sea lions on the California Channel Islands. pp. 166-184. In: F. Trillmich and K. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin.

DeMaster, D. P., D. J. Miller, D. Goodman, R. L. DeLong, and B. S. Stewart. 1982. Assessment of California sea lion fishery interactions. Trans. N. Amer. Wildl. Nat. Res. Conf. 47:

Dietz, R., M. P. Heide-Jorgensen, and T. Harkonen. 1989. Mass deaths of harbour seals (Phoca vitulina) in Europe. Ambio 18:258-264.

Felleman, F. L., J. R. Heimlich-Boran, and R. W. Osborne. 1991. The feeding ecology of killer whales (Orcinus orca) in the Pacific Northwest. pp. 113-141. In: Dolphin Societies (K. Pryor and K. S. Norris, eds.). Dolphin Societies. U.C. Press, Berkeley, CA. 397 pp.

Geraci, J. R. 1990. Physiologic and toxic effects on cetaceans. In: J. R. Geraci and D. J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks. Academic Press, New York.

Geraci, J. R. and D. J. St. Aubin. 1987. Effects of offshore oil and gas development on marine mammals and turtles. pp. 587-617. In: D. F. Boesch and N. N. Rabalais (eds).

Long-term environmental effects of offshore oil and gas development. Elsevier Applied Science, London and New York.

Geraci, J. R., D. J. St. Aubin, I. K. Barker, R. G. Webster, V. S. Hinshaw, W. J. Bean, H. L. Ruhnke, J. H. Prescott, G. Early, A. S. Baker, S. Madoff and R. T. Schooley. 1982. Mass mortality of harbor seals: pneumonia associated with influenza A virus. Science 215:1129-1131.

Godsell, J. 1988. Herd formation and haul-out behavior in harbour seals (Phoca vitulina). J. Zool., Lond. 215:83-98.

Gosho, M. E., D. W. Rice, and J. F. Breiwick. 1984. The sperm whale, Physeter macrocephalus. Mar. Fish. Rev. 46:54-64.

Grachev, M. A., V. P. Kumarev, L. V. Mamaev, V. L. Zorin, L. V. Baranova, N. N. Denikina, S. I. Belikov, E. A. Petrov, V. S. Kolesnik, R. S. Kolesnik, V. M. Dorofeev, A. M. Beim, V. N. Kudelin, F. G. Nagieva and V. N. Sidorov. 1989. Distemper virus in Baikal seals. Nature 338:209.

Guerra, C., C. G., and G. Portflitt K. 1991. El Niño effects on pinnipeds in northern Chile. pp 47-54. In: F. Trillmich and K. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin.

Harkonen, T. 1987. Seasonal and regional variations in the feeding habits of the harbour seal, Phoca vitulina, in the Skagerrak and the Kattegat. J. Zool., Lond. 213:535-543.

Harkonen, T. and M. P. Heide-Jorgensen. 1990. short-term effects of the mass dying of harbour seals in the Kattegat-Skagerrak area during 1988. Z. Saugetierk. 55:233-238.

Harkonen, T. and M. P. Heide-Jorgensen. 1990. Comparative life histories of east Atlantic and other harbour seal populations. Ophelia 32:211-235.

Harvey, J. T., R. F. Brown, and B. R. Mate. 1990. Abundance and distribution of harbor seals (Phoca vitulina) in Oregon, 1975-1983. Northwest. Nat. 71:65-71.

Harwood, J. 1990. The 1988 seal epizootic. J. Zool., Lond. 222:349-351.

Heide-Jorgensen, M. P. and T. Harkonen. 1988. Rebuilding seal stocks in the Kattegat-Skagerrak. Mar. Mamm. Sci. 4:231-246.

Heimlich-Boran, J. R. 1988. Behavioral ecology of killer whales (Orcinus orca) in the Pacific Northwest. Can. J. Zool. 66:565-578.

Helle, E., M. Olsson, and S. Jensen. 1976. PCB levels correlated with pathological changes in seal uteri. Ambio 5:261-263.

Hes, A. D., and G. P. Rouse. 1983. Population increase in the sub-Antarctic fur seal Arctocephalus tropicalis at Amsterdam Island. S. Afr. J. Antarct. Res. 13:29-34.

Hinshaw, V. S., W. J. Bean, R. G. Webster, J. E. Rehg, P. Fiorelli, G. Early, J. R. Geraci, and D. J. St. Augin. 1984. Are seals frequently infected with avian influenza viruses? J. Virology 51:863-865.

Hoelzel, A. R., J. K. Ford, and G. A. Dover. 1991. A paternity test case for the killer whale (Orcinus orca) by DNA fingerprinting. Mar. Mamm. Sci. 7:35-43.

Hoover, A. A. 1988. Harbor seal. In: J. W. Lentfer (ed.). Selected marine mammals of Alaska. Marine Mammal Commission, Washington, D.C.

Kerley, G. I. H. 1983. Relative population sizes and trends, and hybridization of fur seals Arctocephalus tropicalis and A. gazella at the Prince Edward Islands, Southern Ocean. S. Afr. J. Zool. 18:388-392.

Kovacs, K. M., K. M. Jonas, and S. E. Welke. 1990. Sex and age segregation by Phoca vitulina concolor at haul-out sites during the breeding season in the Passamaquoddy

Bay region, New Brunswick. Mar. Mamm. Sci. 6:204-214.

Laws, R. M. 1992. History and present status of southern elephant seal populations. In: B. J. Le Boeuf and R. M. Laws (eds.). Elephant seals. University of California. In Press.

Laws, R. and R. J. F. Taylor. 1957. A mass dying of crabeater seals, Lobodon carcinophagus (Gray). Proceedings of the Zoological Society of London 129:315-324.

Leatherwood, S., C. O. Matkin, J. D. Hall, G. M. Ellis. 1990. Killer whales, Orcinus orca, photo-identified in Prince William Sound, Alaska, 1976 through 1987. Can. Field Nat. 104:362-371.

Loughlin, T. R. and R. V. Miller. 1989. Growth of the northern fur seal colony on Bogoslof Island, Alaska. Arctic 42:368-372.

Majluf, P. 1991. El Niño effects on pinnipeds in Peru. pp 55-74. In: F. Trillmich and K. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin.

McLaren, I. A. 1990. Pinnipeds and Oil: Ecologic Perspectives. In: J. R. Geraci and D. J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks. Academic Press, New York.

Merrick, R. L., T. R. Loughlin, and D. G. Calkins. 1987. Decline in abundance of the northern sea lion, Eumetopias jubatus, in Alaska, 1956-1986. U. S. Fish. Bull. 85:351-365.

Mitchell, E. and R. R. Reeves. 1988. Records of killer whales in the western North Atlantic, with emphasis on eastern Canadian waters. Rit Fiskideildr 11:161-193.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990a. Recent trends in the abundance of harbour seals, Phoca vitulina, in British Columbia. Can. J. Fish. Aquat. Sci. 47:992-1003.

Olesiuk, P. F., M. A. Bigg, G. M. Ellis, S. J. Crockford, and R. J. Wigen. 1990b. An assessment of the feeding habits of harbour seals (Phoca vitulina) in the Strait of Georgia, British Columbia, based on scat analysis. Can. Tech. Rept. Fish. Aquat. Sci. 1730:1-135.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990c. Life history and population dynamics of resident killer whales (Orcinus orca) in the coastal waters of British Columbia and Washington State. Rept. int. Whal. Commn., Special Issue 12:209-243.

Oritsland, T. and I. Christensen. 1982. A mass stranding of killer whales at Lofoten, northern Norway, in June 1981. Rep. int. Whal. Commn 323:642.

Payne, M. R. 1977. Growth of a fur seal population. Philos. Trans. Royal Soc. Lond. 279(Ser B):67-79.

Payne, P. M. and D. C. Schneider. 1984. Yearly changes in abundance of harbor seals, Phoca vitulina, at a winter haul-out site in Massachussetts. U. S. Fish. Bull. 82:440-442.

Payne, R., V. Rowntree, J. S. Perkins, J. G. Cooke, and K. Lankester. 1990. Population size, trends and reproductive parameters of right whales (Eubalaena australis) off Peninsula Valdes, Argentina. Rep. int. Whal. Commn Spec. Iss. 12:271-278.

Perry, A., C. S. Baker, L. M. Herman. 1990. Population characteristics of individually identified humpback whales in the central and eastern North Pacific: a summary and critique. Rep. int. Whal. Commn Spec. Iss. 12:307-317.

Pierce, G. J., P. M. Thompson, A. Miller, J. S. Diack, D. Miller, and P. R. Boyle. 1991. Seasonal variation in the diet of common seals (Phoca vitulina) in the Moray Firth area of Scotland. J. Zool., Lond. 223:641-652.

Pitcher, K. W. 1980a. Stomach contents and feces as indicators of harbor seal, Phoca vitulina, foods in the Gulf of Alaska. U. S. Fish. Bull. 78:797-798.

Pitcher, K. W. 1980b. Food of the harbor seal, Phoca vitulina richardsi, in the Gulf of Alaska. U. S. Fish. Bull. 78:545-549.

Pitcher, K. W. 1990. Major decline in number of harbor seals, Phoca vitulina richardsi, on Tugidak Island, Gulf of Alaska. Mar. Mamm. Sci. 6:121-134.

Pitcher, K. W. and D. C. McAllister. 1981. Movements and haulout behaviour of radio-tagged harbour seals, Phoca vitulina. Can. Field-Nat. 95:292-297.

Reijnders, P. J. H. 1978. Recruitment in the harbour seal (Phoca vitulina) population in Dutch Wadden Sea. Neth. J. Sea Res. 12:164-179.

Reilly, S. B. 1984. Assessing gray whale abundance: a review. pp. 203. In: M. L. Jones, S. L. Swartz, and S. Leatherwood. The Gray Whale, Eschrictius robustus. Academic Press, N. Y. 600 pp.

Reilly, S. B. and Barlow, J. 1986. Rates of increase in dolphin population size. U. S. Fish. Bull. 84:527-533.

Reilly, S. B., Rice, D. W. and A. A. Wolman. 1983. Population assessment of the gray whale, Eschrichtius robustus, from California shore censuses, 1967-1980. U. S. Fish. Bull. 81:267-281.

Schneider, P. M. and P. M. Payne. 1983. Factors affecting haul-out of harbor seals at a site in southeastern massachusetts. J. Mammal. 64:518-520.

Shaugnessy, P. D. and S. D. Goldsworthy. 1990. Population size and breeding season of the Antarctic fur seal Arctocephalus gazella at Heard Island--1987-1988. Mar. Mamm. Sci. 6:292-304.

Smith, A. W., R. J. Brown, D. E. Skilling, and R. L. DeLong. 1974. Leptospira pomona and reproductive failure in California sea lions (Zalophus californianus californianus). J. Amer. Vet. Med. Assoc. 165:996-998.

St. Aubin, D. J. 1990. Physiologic and toxic effects on pinnipeds. In: J. R. Geraci and D. J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks. Academic Press, New York.

Stewart, B. S. 1984. Diurnal hauling patterns of harbor seals at San Miguel Island, California. J. Wildl. Manage. 48:1459-1461.

Stewart, B. S. 1992. Population recovery of northern elephant seals on the southern California Channel Islands. In: D. R. McCullough and R. H. Barrett (eds.). Wildlife 2001. Elsevier Press. In Press.

Stewart, B. S., G. A. Antonelis, R. L. DeLong, and P. K. Yochem. 1988. Abundance of harbor seals on San Miguel Island, California, 1927 through 1986. Bull. So. Calif. Acad. Sci. 87:39-43.

Stewart, B. S. and P. K. Yochem. 1991. Northern elephant seals on the Southern California Channel Islands and El Niño. pp. 234-243. In: F. Trillmich and K. Ono (eds.). Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin.

Stewart, B. S., P. K. Yochem, R. L. DeLong, and G. A. Antonelis. 1992. Status and trends in abundance of pinnipeds on the Southern California Channel Islands. In: F. G. Hochberg (ed). Proceedings of the Third California Islands Symposium, Santa Barbara Museum of Natural History, Santa Barbara, CA. In Press.

Terhune, J. M., and M. Almon. 1983. Variability of harbor seals numbers on haul-out sites. Aquat. Mamm. 10:71-78.

Testa, J. W., G. Oehlert, D. G. Ainley, J. L. Bengtson, D. B. Siniff, R. M. Laws, and D. Rounsevell. 1991. Temporal variability in Antarctic marine ecosystems: Periodic fluctuations in the phocid seals. Can. J. Fish. Aquat. Sci. 48:631-639.

Thompson, P. M., M. A. Fedak, B. J. McConnell and K. Nicholas. 1989. Seasonal and sex-related variation in the activity patterns of common seals (Phoca vitulina). J. Appl. Ecol 26:521-536.

Thompson, P. M., G. J. Pierce, J. R. Hislop, D. Miller, and J. S. W. Diack. 1981. Winter foraging by common seals (Phoca vitulina) in relation to food availability in the inner Moray Firth, N. E. Scotland. J. Anim. Ecol. 60:283-294.

Trillmich, F. and D. Limberger. 1985. Drastic effects of El Niño on Galapagos pinnipeds. Oecol. 67:19-22.

Vedros, N. A., A. W. Smith, J. Schonewald, G. Migaki, and R. C. Hubbard. 1971. Leptospirosis epizootic among California sea lions. Science 172:12450-1251.

Wilkinson, I. S. and M. N. Bester. 1988. Is onshore human activity a factor in the decline of the southern elephant seal? S. Afr. J. Antarct. Res. 18:14-17.

Wursig, B. 1990. Cetaceans and oil: Ecologic Perspectives. In: J. R. Geraci and D. J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks. Academic Press, New York.

Yochem, P. K. 1987. Haul-out patterns and site fidelity of harbor seals at San Nicolas and San Miguel Islands, California. M.S. thesis, San Diego State University, San Diego, CA.

Yochem, P. K., B. S. Stewart, R. L. DeLong, and D. P. DeMaster. 1987. Diel hauling patterns and site fidelity of harbor seals (Phoca vitulina richardsi) on San Miguel Island, California, in autumn. Mar. Mamm. Sci. 3:323-332.

York, A. E. 1987. On comparing the population dynamics of fur seals. NOAA Tech. Rep. NMFS 51:133-140.

Zakharov, V. M. and A. V. Yablokov. 1990. Skull asymmetry in the Baltic grey seal: effects of environmental pollution. Ambio 19:266-269.

Zeh, J. E., J. C. George, A. E. Raftery, and G. M. Carroll. 1991. Rate of increase, 1978-1988, of bowhead whales, Balaena mysticetus, estimated from ice-based census data. Mar. Mamm. Sci. 7:105-122.

6.0. Tables

Table 1. A summary of growth rates expressed as percent increase per annum in various pinniped populations.

| SPECIES | AREA | RATE | PERIOD | NOTES | SOURCE |
|---|---|---|---|---|---|
| Phoca vitulina richardsi | Alaskan peninsula | -3.5 | 1976-85 | E | 1 |
| " | Tugidak I. | -19.0 | 1976-79 | E | 2 |
| " | " | -7.0 | 1982-88 | E | 2 |
| " | British Columbia | 12.5 | 1973-88 | E | 3 |
| " | Oregon | 8.1 | 1975-83 | E, I, D | 4 |
| " | Gulf of Farallones, Double Pt. | 7.6 | 1976-87 | E, I | 5 |
| " | Gulf of Farallones, S. Farallon I. | 17.0 | 1974-86 | E, I | 5 |
| " | San Miguel I. | 22.0 | 1958-76 | E, I | 6 |
| " | " | 5.0 | 1976-86 | E, I | 6 |
| Phoca vitulina concolor | Massachusetts | 11.9 | 1972-83 | E, D | 7 |
| " | Kattegat-Skagerrak | 12.0 | 1979-86 | E | 8 |
| Callorhinus ursinus | Pribilof Is. | 8.0 | 1911-24 | E | 9 |
| " | " | 0.0 | 1950-55 | E | 10 |

| | | | | | |
|---|---|---|---|---|---|
| " | " | -6.0 | 1955-65 | E | 10 |
| " | " | 0.0 | 1965-75 | E | 10 |
| " | " | -7.8 | 1975-81 | E | 10 |
| " | " | -1.8 | 1981-86 | E | 10 |
| " | Commander I. | 0.0 | 1974-82 | E | 10 |
| " | Robben I. | -5.8 | 1974-82 | E | 10 |
| " | Bogoslof I. | 57.0 | 1980-88 | E | 11 |
| Eumetopias jubatus | Alaska | -2.7 | 1956-86 | E | 12 |
| Arctocephalus tropicalis | Gough I. | 15.9 | 1955-77 | E | 13 |
| " | Marion I. | 10.5 | 1951-74 | E, I | 14 |
| " | " | 12.9 | 1974-89 | E, I | 15 |
| " | " | 15.0 | 1974-81 | E, I | 16 |
| " | Amsterdam I. | 11.0 | 1956-81 | E | 14 |
| " | " | 7.8 | 1955-69 | E | 17 |
| " | " | 16.5 | 1969-81 | E | 14 |
| " | Prince Edward I. | 9.7 | 1982-87 | E, I | 15 |

| | | | | | |
|---|---|---|---|---|---|
| Arctocephalus gazella | Heard I. | 20.7 | 1962-88 | I | 18 |
| " | Bird I. | 13.1 | 1958-75 | E | 19 |
| " | Marion Is. | 15.1 | 1974-81 | E | 16 |
| " | Prince Edward Is. | 11.3 | 1981-89 | E, I | 15 |
| Arctocephalus pusillus pusillus | Southern Africa, mainland colonies | 7.5 | 1971-83 | E | 20 |
| " | Southern Africa, island colonies | -3.5 | 1971-83 | E | 20 |
| " | Southern Africa | 5.8 | 1971-80 | E | 21 |
| Arctocephalus australis | All stocks | 11.0 | 1953-72 | E | 22 |
| Arctocephalus townsendi | Isla de Guadalupe | 7.5 | 1954-77 | E | 23 |
| Mirounga angustirostris | San Miguel I. | 13.6 | 1964-81 | E, I | 24 |
| " | San Nicolas I. | 16.5 | 1959-81 | E, I | 24 |
| " | Año Nuevo | 15.8 | 1968-80 | E, I | 24 |
| " | Farallon I. | 53.3 | 1974-80 | E, I | 24 |
| " | Isla de Guadalupe | 5.4 | 1965-77 | E | 24 |
| " | Islas San Benito | 5.9 | 1965-77 | E | 24 |

| SPECIES | AREA | RATE | PERIOD | NOTES | SOURCE |
|---|---|---|---|---|---|
| Mirounga leonina | South Georgia | 0.0 | 1951-85 | E | 25 |
| " | Patagonia | 5.1 | 1975-82 | E | 25 |
| " | " | 3.2 | 1982-90 | E | 25 |
| " | Iles Kerguelen | -4.6 | 1970-77 | E | 25 |
| " | Heard I. | -2.4 | 1949-85 | E | 25 |
| " | Marion I. | -4.8 | 1974-83 | E | 25 |
| " | " | -1.9 | 1983-89 | E | 25 |
| " | Macquarie I. | -2.1 | 1949-85 | E | 25 |
| Zalophus californianus | California | 8.7 | 1927-46 | E | 23 |
| " | " | 6.7 | 1947-70 | E | 23 |
| " | San Miguel I. | 5.0 | 1971-81 | E | 26 |
| Halichoerus grypus | United Kingdom | 7.0 | Early 1960s-late 1970s | E | 27 |

NOTES: D = Relaxation from disturbance; E = Exploited population; I = Immigration

SOURCE: 1 = Pitcher 1986, cited in Hoover 1988; 2 = Pitcher 1990; 3 = Olesiuk et al. 1990; 4 = Harvey et al. 1990; 5 = Allen et al. 1989; 6 = Stewart et al. 1988; 7 = Payne and Schneider 1984; 8 = Heide-Jorgensen and Harkonen 1988; 9 = Lander 1981; 10 = York 1987; 11 = Loughlin and Miller 1989;

Table 1, continued

12 = Merrick et al. 1987; 13 = Bester 1980; 14 = Condy 1978; 15 = Wilkinson and Bester 1990; 16 = Kerley 1983; 17 = Hes and Rouse 1983; 18 = Shaughnessy and Goldsworthy 1990; 19 = York 1987, after Payne 1977; 20 = Butterworth et al. 1987; 21 = Shaughnessy and Butterworth 1981, cited in York 1987; 22 = Vaz-Ferreira 1982, cited in York 1987; 23 = Chapman 1981; 24 = Cooper and Stewart 1983; 25 = Laws In Press; 26 = DeMaster et al. 1982; 27 = Harwood 1981

Table 2. A summary of growth rates expressed as percent increase per annum in various cetacean populations.

| SPECIES | AREA | RATE | PERIOD | NOTES | SOURCE |
|---|---|---|---|---|---|
| Balaenoptera musculus | Iceland | 4.8 | 1969-88 | E | 1 |
| " | " | 5.2 | 1979-90 | E | 2 |
| Megaptera noveangliae | Iceland | 11.5 | 1970-88 | E | 1 |
| " | " | 13.8 | 1979-88 | E | 1 |
| " | " | 14.8 | 1979-90 | E | 2 |
| " | Western Australia | 4.8 | 1963-88 | E | 1 |
| " | Eastern Australia | 10.0 | 1983-87 | E | 1 |
| " | NW Atlantic | 9.4 | 1979-86 | E | 1 |
| Eubalaena glacialis | Argentina | 7.6 | 1974-86 | E | 1 |
| " | Western Australia | 11.7 | 1977-87 | E | 3 |
| " | South Africa | 6.8 | 1971-87 | E | 1 |
| Balaena mysticetus | Bering/Beaufort/ Chuckchi Seas | 3.1 | 1978-88 | E | 4 |
| " | Bering/Chukchi Seas | 3.0-4.5 | 1978-89 | E | 1 |

| SPECIES | AREA | RATE | PERIOD | NOTES | SOURCE |
|---|---|---|---|---|---|
| <u>Balaenoptera</u> <u>musculus</u> | Iceland | 4.8 | 1969-88 | E | 1 |
| " | " | 5.2 | 1979-90 | E | 2 |
| <u>Megaptera</u> <u>noveangliae</u> | Iceland | 11.5 | 1970-88 | E | 1 |
| " | " | 13.8 | 1979-88 | E | 1 |
| " | " | 14.8 | 1979-90 | E | 2 |
| <u>Eschrichtius</u> <u>robustus</u> | California stock | 2.5 | 1967-80 | E | 5 |
| <u>Orcinus</u> <u>orca</u> | British Columbia | 3.01 | 1973-81 | E | 6 |
| " | " | 1.67 | 1973-81 | U | 6 |
| " | Puget Sound | 2.3 | 1973-81 | E | 7 |

NOTES: E = Exploited population; U = Unexploited population

SOURCE: 1 = Best 1990; 2 = Sigurjonsson and Gunnlaugsson 1990; 3 = Bannister 1990; 4 = Zeh et al. 1991; 5 = Reilly 1984; 6 = Bigg 1982; 7 = Balcomb et al. 1982.

RPWG
R

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Office of Oil Spill Damage
Assessment and Restoration
P.O. Box 210029
Auke Bay, Alaska 99821

RECEIVED JUN 29

DATE: June 25, 1990

MEMORANDUM FOR: Brian Ross

FROM: John Strand

SUBJECT: Review of Restoration Planning Work Group Document Entitled, "Ecological Restoration of Prince William Sound and the Gulf of Alaska - An Annotated Bibliography of Relevant Literature."

After reading the recently received (June 22nd) introduction section to the subject literature review, many of my initial comments regarding organization have been addressed. I do have a few additional comments with regard to organization, however, and I would add a few words to the list of representative key words shown on page 2. I would also add other criteria to the list of issues used in evaluating relevancy for inclusion in the bibliography presented in Appendix B. Finally, I have attached a bibliographic listing of other pertinent references that could/should be added to Appendix B.

ORGANIZATION - I find it very difficult to use the document in its present form. References pertaining to restoration are intermingled with those pertaining to biological effects and monitoring methods. Accordingly, the document should be organized by topic; for example, fate of petroleum hydrocarbons, biological effects, restoration alternatives, long-term ecological monitoring, etc. Each of these topics could also be broken-down into subtopics; for example, intertidal and subtidal habitats, fish and shellfish, marine and terrestrial mammals, etc.

KEY WORDS - What seems to be missing from the document are important papers and reports dealing with the fate of spilled petroleum. By fate, I mean the persistence or retention of oil in various ecological compartments; for example, water, sediment and/or biological tissue. The need for restoration is often based on the presence of an oil (hydrocarbon) residual. Accordingly, I would add the following key words: fate, persistence, retention, uptake, accumulation, and bioaccumulation.

Because many of the important reports on fate of oil deal with the most toxic, carcinogenic, or mutagenic fractions (the polynuclear aromatic hydrocarbons), I would like to see the first set of key words on page 2 starting with "oil" expanded to include: polynuclear aromatic hydrocarbon, aromatic hydrocarbon, and synthetic fuel oil. The addition of "synthetic fuel oil" is made because of the relatively large data base on this topic that exists at the U.S. Department of Energy, which is accessible through NTIS.

Although "approaches and techniques for long-term monitoring studies" is listed as a criterion of relevancy for listing of references in Appendix B (see page 3), the appropriate key words are not contained in the list used in the literature search (see page 2). The following key words should then be added: long-term monitoring, ecological monitoring, sampling design, and trend analysis.

RELEVANCY FOR INCLUSION IN APPENDIX B - To Criterion No 3 - Creation of new aquatic habitat (by dredge and fill techniques, construction of artificial reefs, etc.), I would add "capping." Capping is an alternative to dredge and fill in dealing with contaminated subtidal sediments.

To criterion No 5 - Toxicity of hydrocarbons in the aquatic environment, I would add the word "fate." Actually, I would re-word the criterion to read, "Fate and toxicity of hydrocarbons in the aquatic environment."

OTHER PERTINENT LITERATURE - Finally, attached is a bibliography of some other important papers/reports that could/should be added to Appendix B. Some of the references deal with the fate of spilled oil in either aquatic or terrestrial habitats. Others deal with spilled oil in the Pacific Northwest (Washington), which has both geographic and ecologic relevance to Prince William Sound. Still others deal with clean-up and restoration. Some of the references are found in the "gray" literature because of their recent publication date.

Attachment

cc: Byron Morris
    David Cantillon

**ATTACHMENT 1**

Jackson, J.B.C.; Cubit J.D.; Keller, B.D.; Batista, V.; Burns, K.; Caffey, H.M.; Caldwell, R.L.; Garrity, S.D.; Getter, C.D.; Gonzalez, C.; Guzman, H.M.; Kaufmann, K.W.; Knap, A.H.; Levings, S.C.; Marshall, M.J.; Steger, R.; Thompson, R.C.; Weil, E. (1989). *Ecological Effects of a Major Oil Spill on Panamanian Coastal Marine Communities.* Science, Vol. 243, pp. 37-44.

Krahn, Margaret M.; Rhodes, Linda D.; Myers, Mark S.; Moore, Leslie K.; MacLeod, William D. Jr.; Malins, Donald C. (1986). *Associations Between Metabolites of Aromatic Compounds in Bile and the Occurrence of Hepatic Lesions in English Sole (Parophrys vetulus) from Puget Sound, Washington.* Arch. Environ. Contam. Toxicol. Vol. 15, pp. 61-67.

Spaulding, Malcolm L.; Reed, Mark; Anderson, Eric; Isaji, Tatsusaburo; Swanson, J. Craig; Saila, Saul B.; Lorda, Ernesto; Walker, Henry. (1985). *Oil Spill Fishery Impact Assessment Model: Sensitivity to Spill Location and Timing.* Estuarine, Coastal and Shelf Science, Vol. 20, pp. 41-53.

Malins, D.C.; McCain, B.B.; Myers, M.S.; Brown, D.W.; Krahn, M.M.; Roubal, W.T.; Schiewe, M.H.; Landahl, J.T.; Chan, S.-L. (1987). *Field and Laboratory Studies of the Etiology of Liver Neoplasms in Marine Fish from Puget Sound.* Environmental Health Perspectives, Vol. 71, pp. 5-16.

Melzian, Brian D.; Lake, James. (1986/87). *Accumulation and Retention of No. 2 Fuel Oil Compounds in the Blue Crab, Callinectes sapidus Rathbun.* Oil & Chemical Pollution, Vol. 3 No. 5, p. 367.

Skalski, John R.; McKenzie, Daniel H. (1982). *A Design for Aquatic Monitoring Programs.* Journal of Environmental Management, Vol. 14, pp. 237-251.

Baker, J.M.. (1970). *The Effects of Oils on Plants.* Environ. Pollut. (1), pp. 27-44.

White, Donald H.; King, Kirke A.; Coon, Nancy C. (1979). *Effects of No. 2 Fuel Oil on Hatchability of Marine and Estuarine Bird Eggs.* Bull. Environm. Contam. Toxicol., Vol. 21, pp. 7-10.

Dibble, J.T.; Bartha, R. (1979). *Rehabilitation of Oil-Inundated Agricultural Land: A Case History.* Soil Science, Vol. 128, No. 1, pp. 56-60.

Szaro, Robert C. (1979). *Bunker C Fuel Oil Reduces Mallard Egg Hatchability*. Bull. Environm. Contam. Toxicol., Vol. 22, pp. 731-732.

Schwendinger, R.B. (1968). *Reclamation of Soil Contaminated with Oil*. Journal of the Institute of Petroleum, Vol. 54, No. 535, pp. 182-197.

Anderson, J.W.; Riley, R.G.; Bean, R.M. (1978). *Recruitment of Benthic Animals as a Function of Petroleum Hydrocarbon Concentrations in the Sediment*. Journal of the Fisheries Research Board of Canada, Vol. 35, No. 5, pp. 776-790.

Pearson, Walter H.; Sugarman, Peter C.; Woodruff, Dana L.; Blaylock, J.W. (1980). *Detection of Petroleum Hydrocarbons by the Dungeness Crab, Cancer Magister*. Fishery Bulletin, Vol. 78, No. 3, pp. 821-826.

Maynard, Desmond J.; Weber, Douglas D. (1981). *Avoidance Reactions of Juvenile Coho Salmon (Oncorhynchus kisutch) to Monocyclic Aromatics*. Can. J. Fish. Aquat. Sci., Vol. 38, pp. 772-778.

Herbes, S.E.; Southworth, G.R.; Shaeffer, D.L.; Griest, W.H.; Maskarinec, M.P. (1980). *Critical Pathways of Polycyclic Aromatic Hydrocarbons in Aquatic Environments*. The Scientific Basis of Toxicity Assessment, H. Witschi (ed.), Elsevier/North-Holland Biomedical Press, pp. 113-128.

Dauble, Dennis D.; Gray, Robert H.; Skalski, J.R.; Lusty, E.W.; Simmons, M.A. (1985). *Avoidance of a Water-Soluble Fraction of Coal Liquid by Fathead Minnows*. Transactions of the American Fisheries Society, Vol. 114, pp. 754-760.

Brannon, E.L.; Quinn, T.P.; Whitman, R.P.; Nevissi, A.E.; Nakatani, R.E. (1986). *Homing of Adult Chinook Salmon after Brief Exposure to Whole and Dispersed Crude Oil*. Transactions of the American Fisheries Society, Vol. 115, pp. 823-827.

Lauren, D.J.; Rice, S. (1985). *Significance of Active and Passive Depuration in the Clearance of Naphthalene from the Tissues of Hemigrapsus nudus (Crustacea: Decapoda)*. Marine Biology, Vol. 88, pp. 135-142.

Neff, Jerry M. (1985). *Use of Biochemical Measurements to Detect Pollutant-Mediated Damage to Fish*. Aquatic Toxicology and Hazard Assessment: Seventh Symposium, ASTM STP 854, pp. 155-183.

Thomas, Robert E.; Rice, Stanley D. (1981). *Excretion of Aromatic Hydrocarbons and Their Metabolites by Freshwater and Seawater Dolly Varden Char*. Biological Monitoring of Marine Pollutants, Academic Press, pp. 425-448.

Motohiro, T. (1983). *Tainted Fish Caused by Petroleum Compounds - A Review*. Wat. Sci. Tech. (Finland), Vol. 15, pp. 75-83.

Roubal, William T.; Collier, Tracy K.; Malins, Donald C. (1977). *Accumulation and Metabolism of Carbon-14 Labeled Benzene, Naphthalene, and Anthracene by Young Coho Salmon (Oncorhynchus Kisutch)*. Archives of Environmental Contamination and Toxicology, Vol. 5, pp. 513-529.

Whipple, Jeannette A.; Eldridge, Maxwell B.; Benville, Pete Jr. (1981). *An Ecological Perspective of the Effects of Monocyclic Aromatic Hydrocarbons on Fishes*. Biological Monitoring of Marine Pollutants, Academic Press, pp. 483-551.

Shaw, D.G.; Cheek, L.M.; Paul, A.J. (1977). *Uptake and Release of Petroleum by Intertidal Sediments at Port Valdez, Alaska*. Estuarine and Coastal Marine Science, Vol. 5, pp. 429-436.

Riley, R.G.; Thomas, B.L.; Anderson, J.W.; Bean, R.M. (1980/81). *Changes in the Volatile Hydrocarbon Content of Prudhoe Bay Crude Oil Treated Under Different Simulated Weathering Conditions*. Marine Environmental Research, Vol. 4, pp. 109-119.

Petty, S.E.; Wakamiya, W.; English, C.J.; Strand, J.A.; Mahlum, D.D. (1982). *Assessment of Synfuel Spill Cleanup Options*. PNL-4244. Pacific Northwest Laboratory Operated for the U.S. Department of Energy by Battelle Memorial Institute, Richland, WA.

Nakatani, R.E.; Salo, E.O.; Nevissi, A.E.; Whitman, R.P.; Snyder, B.P.; Kaluzny, S.P. (1985). *Effect of Prudhoe Bay Crude Oil on the Homing of Coho Salmon in Marine Waters*. Health and Environmental Sciences Department API Publication No. 4411, American Petroleum Institute, Washington, D.C.

Fickeisen, D.H.; Vaughan, B.E. (1984). *Behavior of Complex Mixtures in Aquatic Environments*. PNL-5135. Pacific Northwest Laboratory Operated for the U.S. Department of Energy by Battelle Memorial Institute, Richland, WA.

Strand, John A. III; Vaughan, Burton E. (1981). *Ecological Fate and Effects of Solvent Refined Coal (SRC) Materials: A Status Report*. PNL-3819. Pacific Northwest Laboratory Operated for the U.S. Department of Energy by Battelle Memorial Institute, Richland, WA.

Word, J.Q.; Pearson, W.H.; Skalski, J.R.; Gurtisen, J.M.; Lucke, R.B.; Strand, J.A. (1987). *Reconnaissance of Petroleum Contamination from the ARCO Anchorage Oil Spill at Port Angeles, Washington, and its Influence on Selected Areas of the Strait of Juan De Fuca*. Prepared for ARCO Marine, Inc. by Battelle, Pacific Northwest Laboratories, Richland, WA.

Word, J.Q.; Skalski, J.R.; Pearson, W.H.; Strand, J.A.; Lucke, R.B.; Ward, J.A. (1987). *Effectiveness of Cleaning Oiled Beach Sediments at Ediz Hook Following the ARCO Anchorage Oil Spill*. Prepared for ARCO Marine Inc. by Battelle, Pacific Northwest Laboratories, Richland, WA.

Pacific Northwest Laboratory. (1986). *Reconnaissance Survey of Eight Bays in Puget Sound*. Final Reports, Volume I and II. Prepared for U.S. Environmental Protection Agency Region 10, Seattle, WA, by Battelle, Marine Research Laboratory, Sequin, WA.

Gumtz, Garth D. (1972). *Restoration of Beaches Contaminated by Oil*. EPA-R2-72-045. Office of Research and Monitoring U.S. Environmental Protection Agency, Washington, D.C. 20460.

RPWG
R

FILE

# OIL SPILL RESTORATION PLANNING OFFICE

437 E Street, Suite 301 Anchorage, Alaska 99501
(907) 271-2461 FAX: (907) 271-2467

May 14, 1991

Daniel D. Roby
Assistant Professor
Cooperative Wildlife Research Laboratory
Southern Illinois University
Carbondale, Illinois 62901

Dear Dr. Roby:

The State-Federal Restoration Planning Work Group has completed its selection of contractors to perform the "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems Following Man-Induced and Natural Phenomena-Related Disturbances". I regret to inform you that your firm was not selected to do this work. Your efforts in preparing and submitting a proposal are appreciated.

Again, thank you for your interest. We will be sure to notify you of any future opportunities for technical assistance in the restoration planning effort.

Sincerely,

Stan

Stanley E. Senner
Co-Chair

Dan -
This is the official confirmation of what you know already.
Stan

# OIL SPILL RESTORATION PLANNING OFFICE

**437 E Street, Suite 301 Anchorage, Alaska 99501**
**(907) 271-2461 FAX: (907) 271-2467**

May 14, 1991

Jon K. Dueker
Vice President
Jones & Stokes Associates, Inc.
2820 Northup Way, Suite 100
Bellevue, WA 98004

Dear Mr. Dueker:

The State-Federal Restoration Planning Work Group has completed its selection of contractors to perform the "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems Following Man-Induced and Natural Phenomena-Related Disturbances". Although your proposal was well presented and sufficient, it did not address our needs as well as some of the other proposals. Therefore, I regret to inform you that your firm was not selected to do this work.

Your efforts in preparing and submitting a proposal are appreciated and we thank you for your interest. We will be sure to notify you of any future opportunities for technical assistance in the restoration planning effort.

Sincerely,

Stanley E. Senner
Co-Chair

We appreciated Rishi's efforts in putting together a Jones & Stokes proposal.

# OIL SPILL RESTORATION PLANNING OFFICE

**437 E Street, Suite 301 Anchorage, Alaska 99501**
**(907) 271-2461 FAX: (907) 271-2467**

May 14, 1991

Dr. William A. Richkus, Director
Ecological Sciences & Analysis
Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045-1934

Dear Dr. Richkus:

The State-Federal Restoration Planning Work Group has completed its selection of contractors to perform the "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems Following Man-Induced and Natural Phenomena-Related Disturbances". Although your proposal was well presented and sufficient, it did not address our needs as well as some of the other proposals. Therefore, I regret to inform you that your firm was not selected to do this work.

Your efforts in preparing and submitting a proposal are appreciated and we thank you for your interest. We will be sure to notify you of any future opportunities for technical assistance in the restoration planning effort.

Sincerely,

Stan Senner

Stanley E. Senner
Co-Chair

We appreciated Foster's efforts in putting together a VERSAR proposal.

PRWG
R


# KILKELLY ENVIRONMENTAL ASSOCIATES

P.O. Box 31265 • Raleigh, NC 27622 • 919-781-3150 • Telecopy 919-781-9524


June 7, 1990

Kirstan Ballard
U.S. Environmental Protection Agency
Anchorage, Alaska

Dear Kirstan:

As requested by Hal Kibby, I have enclosed information pertaining to the computer data-based literature review we have conducted for EPA-CERL. Specifically, I have included the summary information for each literature search we have conducted. The summary information includes the key words used in the search and the number of references located for each key word or combination of key words. I have also included a separate listing of each computer data base searched.

Please note that while we downloaded most of the references indicated by the search strategy, less than half of these were appropriate for the document we are compiling.

Please call me with any question you may have at (919) 781-3150.

Sincerely,

William Warren-Hicks, Ph.D

# COMPUTER DATA BASES

| | | |
|---|---|---|
| File 44: | Aquatic Science Abstracts: | 1978 - 1989 |
| File 5: | BIOSIS Previews: | 1969 - 1990 |
| File 55: | BIOSIS Previews: | 1981 - 1990 |
| File 68: | Environmental Bibliography: | 1974 - 1989 |
| File 40: | ENVIROLINE: | 1970 - 1989 |
| File 41: | Pollution Abstracts: | 1970 - 1990 |
| File 6: | NTIS: | 1964 - 1990 |

File(s) searched:

File 44:AQUATIC SCIENCE ABSTRACTS - 78-90/JAN

File 5:BIOSIS PREVIEWS 69-90/JAN BA8905;RRM3805
(C.BIOSIS 1990)
File 40:ENVIROLINE - 70-89/DEC
(COPR. R. R. BOWKER COMPANY 1989)
File 41:POLLUTION ABSTRACTS - 70-90/JAN
(C. CAMBRIDGE SCIENTIFIC ABSTRACTS)
File 6:NTIS - 64-90/ISSUE05
(COPR. 1990 NTIS)

Sets selected:

| Set | Items | Description |
|---|---|---|
| 1 | 108435 | OIL(3N)SPILL OR OIL OR PETROLEUM OR CRUDE(W)OIL OR GASOLINE OR FUEL(W)OIL |
| 2 | 57496 | REESTABLISH? OR RESTOR? OR REHABILITAT? |
| 3 | 692 | (S1 AND S2) NOT BIODEGRADAT? |

Prints requested ('*' indicates user print cancellation) :

| Date | Time | Description |
|---|---|---|
| 13feb | 18:09EST | P005: PR S3/7/ALL VIA DIALMAIL (items 1-692) |

Record - 1

<DIALOG File 44: >
1957898 219-07898
Environmental liability considerations in the valuation and appraisal of producing oil and gas properties.
Russell, R.M.
Assoc.
J. PET. TECHNOL., vol. 41, no. 1, pp. 55-58, (1989).
LANGUAGES: English
SUMMARY LANGUAGES: English
DOC TYPE: JOURNAL ARTICLE
JOURNAL ANNOUNCEMENT: 8910

Purchasing producing oil and gas properties without consideration of the potential environmental liabilities attendant to ownership and operation is a trap for the unwary. Changes in the law governing injection operations, toxic waste, and groundwater contamination are increasing dramatically the level of monitoring and reporting activities in the oil industry. The potential liability to restore and clean up damages caused by past operating practices exists. Those who purchase or appraise producing properties should appraise themselves of potential new business costs and ensure that economic projections reflect the change. When appraising engineers lack the expertise to evaluate or are directed by the client to ignore these aspects, engineering reports should disclose that these aspects have not been analyzed.

From: OS 6 File(s) 44,5,55,...
Date: 07feb90 04:23:06
P004: PR S4/7/ALL VIA DIALMAIL (items 1 -373)

Msg type: print
Msg id: 786612
Msg lines: 10494
Records: 373

File(s) searched:

File 44:AQUATIC SCIENCE ABSTRACTS - 78-89/NOV

File 5:BIOSIS PREVIEWS 69-90/JAN BA8904;RRM3804
(C.BIOSIS 1990)

File 55:BIOSIS PREVIEWS 81-90/JAN BA8904;RRM3804
(C.BIOSIS 1990)

File 68:ENVIRONMENTAL BIBLIOGRAPHY - 74-89/APR

File 40:ENVIROLINE - 70-89/DEC
(COPR. R. R. BOWKER COMPANY 1989)

File 41:POLLUTION ABSTRACTS - 70-90/JAN
(C. CAMBRIDGE SCIENTIFIC ABSTRACTS)

Sets selected:

| Set | Items | Description |
|---|---|---|
| 1 | 107262 | OIL(W)SPILL OR OIL OR PETROLEUM OR CRUDE(W)OIL OR GASOLINE OR FUEL(W)OIL |
| 2 | 271151 | ECOLOGIC(W)EFFECT OR ECOLOGIC(W)IMPACT OR BIOLOGICAL OR AQUATIC OR TERRESTRIAL OR ENVIRONMENTAL(W)IMPACT OR ENVIRONMENTAL(W)EFFECT |
| 3 | 203247 | RECOVER? OR SUCCESSION |
| 4 | 373 | S1 AND S2 AND S3 |

Prints requested ('*' indicates user print cancellation) :

| Date | Time | Description |
|---|---|---|
| 06feb | 19:01EST | P004: PR S4/7/ALL VIA DIALMAIL (items 1-373) |

```
System:OS - DIALOG OneSearch

   File 41:POLLUTION ABSTRACTS - 70-90/JAN
        (C. CAMBRIDGE SCIENTIFIC ABSTRACTS)

   File 44:AQUATIC SCIENCE ABSTRACTS - 78-90/JAN

     Set  Items  Description
     ---  -----  -----------
?exs td014

     S1     879  MITIGAT?
          18687  OIL
           2734  SPILL
           1955  OIL(N)SPILL
           5775  PETROLEUM
           3030  CRUDE
          18687  OIL
           1629  CRUDE(W)OIL
            856  GASOLINE
           5294  FUEL
          18687  OIL
            662  FUEL(W)OIL
          18687  OIL
     S2   21625  OIL(N)SPILL OR PETROLEUM OR CRUDE(W)OIL OR GASOLINE OR
                 FUEL(W)OIL OR OIL
Processing
          51024  MARINE
          13900  ESTUAR?
           6753  SALT
           2448  MARSH
           1134  SALT(W)MARSH
          28117  OCEAN
           4318  BEACH
           5599  SHORE
           7206  TIDAL
           1105  SUBTIDAL
           3752  INTERTIDAL
           3964  REEF
     S3   97846  MARINE OR ESTUARY OR SALT(W)MARSH OR OCEAN OR BEACH OR
                 SHORE OR TIDAL OR SUBTIDAL OR INTERTIDAL OR REEF
Processing
           0029  RESERVOIR?
          27606  LAKE?
          13769  STREAM?
           2448  MARSH
          29085  RIVER?
           1959  WETLAND?
           7653  FRESH
         116235  WATER
           3880  FRESH(W)WATER
          21031  FRESHWATER
```

| | | |
|---|---|---|
| S4 | 80482 | RESERVOIR? OR LAKE? OR STREAM? OR MARSH OR RIVER? OR WETLAND? OR FRESH(W)WATER OR FRESHWATER |
| | 879 | S1 |
| | 21625 | S2 |
| S5 | 87 | S1 AND S2 |
| | 879 | S1 |
| | 97846 | S3 |
| S6 | 159 | S1 AND S3 |
| | 879 | S1 |
| | 80482 | S4 |
| S7 | 298 | S1 AND S4 |
| | 879 | S1 |
| | 21625 | S2 |
| | 97846 | S3 |
| S8 | 29 | S1 AND S2 AND S3 |
| | 879 | S1 |
| | 21625 | S2 |
| | 80482 | S4 |
| S9 | 16 | S1 AND S2 AND S4 |

298
155
135
15
198

Results of an information search (conducted online in DIALINDEX) for articles using the strategy: RESTOR? AND (MARINE OR ESTUAR? OR SALT(W)MARSH OR SALT(W)MARSHES OR BEACH OR BEACHES OR SHORE OR SHORES OR TIDAL OR SUBTIDAL OR INTERTIDAL OR REEF OR REEFS OR OCEAN?) AND (HABITAT OR HABITATS). This parallels the previous searches conducted for OEPER using the words: CREAT? OR BUILD OR CONSTRUCT? OR ESTABLISH? OR REPLANT? in the place of RESTOR?. "?" means that any number of letters may follow the root.

| DATABASE | DATES COVERED | NUMBER OF CITATIONS |
|---|---|---|
| Biosis Previews | 1969 to April 1990 | 25 |
| NTIS (National Technical Information Service) | 1964 to 1990 | 95 |
| Enviroline | 1970 to March 1990 | 22 |
| Pollution Abstracts | 1970 to Feb 1990 | 9 |
| Aquatic Science Abstracts | 1978 to March 1990 | 58 |
| TOTAL | | 209 |

MARSH DESCRIPTION!

| DATABASE | Strategy A | Strategy B | A and B | Strategy C |
|---|---|---|---|---|
| BIOSIS 1981-1990 | 289 | 205 | 494 | 983 |
| Pollution Abstracts 1970-1990 | 12 | 27 | 39 | 51 |
| Aquatic Science Abstracts 1978-1990 | 299 | 262 | 561 | 1,102 |
| TOTAL | 600 | 494 | 1,094 | 2,136 |
| | | | | |
| BIOSIS 1985-1990 | 140 | 94 | 234 | |
| Pollution Abstracts 1985-1990 | 4 | 3 | 12 | |
| Aquatic Science Abstracts 1985-1990 | 102 | 53 | 155 | |
| TOTAL | 246 | 150 | 401 | |
| | | | | |
| BIOSIS 1987-1990 | 96 | | | |
| Pollution Abstracts 1987-1990 | 3 | | | |
| Aquatic Science Abstracts 1987-1990 | 59 | | | |
| TOTAL | 158 | | | |

grand total 5279

Strategy A = (ZOSTERA) AND (SEAGRASS? OR EELGRASS? OR EEL-GRASS? OR POTAMOGETONAC?)

Strategy B = (FUCUS) AND (ALGAE OR MACROALGAE OR PHAEOPHY?)

Strategy C = SEAGRASS? OR EELGRASS? OR EEL-GRASS

Pollution Abs + Aquatic Abs:
2448 marsh

1134 salt + marsh

# KILKELLY ENVIRONMENTAL ASSOCIATES

P.O. Box 31265 • Raleigh, NC 27622 • 919-781-3150 • Telecopy 919-781-9524


TO: Kirstan Ballard

DATE: 6/7

FIRM: EPA

FROM: Bill Warren-Hicks

TIME:

MESSAGE:

Number of pages following 8

In the event of a problem with this transaction, please call (919) 781-3150 and ask for Sherry.

Facsimile # (919) 781-9524

RPWG
R

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
**National Marine Fisheries Service**
**Office of Oil Spill Damage**
**Assessment and Restoration**
**P.O. Box 210029**
**Auke Bay, Alaska 99821**

September 18, 1992

Dr. John M. Boland
Pacific Estuarine Research Laboratory
San Diego State University
San Diego, CA 92182-0057

Dear John:

Please find enclosed our final comments on your report entitled Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems following Man-Induced and Natural-Phenomena-Related Disturbances: Marine Invertebrate Communities. I was hesitant to forward our reviews until your return to campus; I believe you said you would be in South Africa until mid-September. These comments are provided on behalf of the Restoration Planning Work Group (RPWG), but only represent comments provided by John Armstrong and myself.

General Comments:

Your revision is vastly improved when compared with your first draft. As you will see, most of our comments are minor and editorial in nature. Suggestions for change are called to your attention in the text margins, but most of these occur in the Executive Summary. There are no changes suggested for the Annotated Bibliography.

Specific Comments:

1) In the Executive Summary, I would suggest that you not write in the first person, that is, refrain from using a style that includes "First, I focused on the time the communities took to recover; Second, I discuss four abiotic factors that appear to affect recovery, etc." Perhaps you will want to use subheadings in the Executive Summary to cover these topics. You could easily introduce these topics in the first paragraph of the Executive Summary by indicating that "this document summarizes the readily available information on recovery for purposes of: 1) estimating the time frame of recovery, 2) identifying which indicators of species-, population-, community-, or ecosystem-recovery are the most practical to measure, 3) determining how important abiotic factors affect recovery, and 4) providing recommendations as to how these indicators can be monitored or tested in a practical way." If this is not clear, I can gladly provide a clarification over the telephone. You also write in the first person in Section 1.0 - INTRODUCTION, but no where else in the manuscript!

2) John Armstrong suggests that you consider introducing a definition for recovery earlier in the document. I am less inclined to do so, but I will leave this decision to you. The organization of your document generally follows the outline that was provided you in Seattle at our June 19, 1991 meeting. The need to explicitly define recovery is essentially a recommendation that results from of your review and synthesis and logically should be included in Section 4.0, which focuses on approaches to determine when recovery has occurred.

I would ask that you consider the suggested changes, make those that you think appropriate, and return the final manuscript (both hard and electronic copies) to me at either my Juneau address or the Anchorage RPWG address. At most, I think you have an hour or two of work.

John, your effort has resulted in a scholarly contribution. You have provided much useful information to the RPWG in their discussions and decision-making process dealing with the adequacy of natural recovery and the potential need to intervene on behalf of impacted intertidal and shallow subtidal resources. On behalf of the Trustees and RPWG, I would like to thank you for a job well done. I am sure you also will hear directly from the Environmental Protection Agency in this regard in the near future.

Yours very truly,

John A. Strand, Ph.D.
Restoration Manager

Enclosures: Manuscript reviewed by John Armstrong (includes cover letter)
Manuscript reviewed by John Strand
Manuscript (electronic copy)

cc: John Armstrong
Byron Morris (w/o enclosures)
Bruce Wright (w/o enclosures)
RPWG (w/o enclosures)

RPWG
R

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Office of Oil Spill Damage
Assessment and Restoration
P.O. Box 210029
Auke Bay, Alaska 99821

November 20, 1991

Dr. John M. Boland
Pacific Estuarine Research Laboratory
San Diego State University
San Diego, CA 92182-0057

Dear John:

Please find enclosed the recently completed peer reviews of your report entitled Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems following Man-Induced and Natural-Phenomena-Related Disturbances: Marine Invertebrate Communities. These comments are provided on behalf of the Restoration Planning Work Group (RPWG). You should find reviews conducted by Si Simonstadt, Pete Peterson, John Armstrong, and Art Weiner. My impressions and specific comments are provided below in this cover letter. I have also taken the liberty of enclosing a few relevant papers from the "gray" literature taken from my own library that may be of some interest and possible inclusion in your final report. There is also a short Bibliography of Ecosystem Recovery literature that may be of some help. Finally, I have enclosed a list of references from one of the chapters (Chapter 11) in Hood and Zimmerman (1986) The Gulf of Alaska, Physical Environment and Biological Resources that includes references dealing with intertidal community response to sudden land-level changes.

As to my own impressions and comments, I feel that your effort constitutes a contribution to RPWG's general understanding of recovery of marine invertebrate communities following oiling and other disturbances. I also believe that you have provided information useful to the RPWG in their future discussions and decision-making process dealing with the adequacy of natural recovery and the potential need to intervene (implement restoration) on behalf of impacted intertidal and shallow subtidal habitats. I also appreciate your discussion of what is meant by "recovery" and your pointing-out the need to adopt a more standardized definition. However, you should also know that the depth of your contribution did not come across during your oral presentation.

This is not to say that your report does not need improvement. I would have to agree with the other reviewers who suggest there is a need to include additional reference materials. I don't believe that there is a need to do an exhaustive search but I think that there is a need to include more of the relevant literature on recovery associated with dredging and dredge spoil disposal, disposal of drilling muds, other sources of natural disturbance (earthquake and land-level changes), and even nuclear testing (Amchitka Island test series). Additional references dealing with specific experiments to better understand recovery processes should also be sought and reviewed. Are you aware that some experimental studies of recovery are included in your annotated bibliography but are not reviewed in the synthesis document (e.g., Bakke {1986} and Zajac and Whitlatch {1982a,b})? Why not?

I also feel that, in general, you can extract more useful information from the references you included in the annotated bibliography. For example, I might have expected to see information from the two Zajac and Whitlatch (1982) papers in the section of the report dealing with the effects of abiotic factors on recovery. Are there other papers included in the annotated bibliography that are not used in your synthesis? Is the reciprocal of this question also true? Are there papers cited in the synthesis document that could be included in the annotated bibliography? I am not so sure that I would have excluded from your review any papers that treated the long-term recovery of a single species (see page 5).

Some effort should go into writing a better "synthesis" section extrapolating from the more general (basic) literature on recovery to the particular situation in Prince William Sound and the Gulf of Alaska. I think that if you were to review some of the relevant "Alaskan" literature that this could help you to draw some conclusions about the timebase of recovery in disturbed intertidal and subtidal communities in northern latitudes. The "Alaskan" literature might also improve our understanding of how important abiotic factors affect recovery rates.

As well, I was disappointed in how you responded to our need to identify the most practical and cost effective indicators of recovery to measure (Section 4.1), another key requirement of the synthesis. We were not looking for an endorsement of "indicator" species per se. Rather, we wanted recommendations for the best endpoints of recovery to measure, which really goes back to an appropriate definition of recovery. In other words, we want to know what to measure and how? Should we follow biomass, abundance, diversity, age structure, reproductive condition or what? Again this section was to have particular relevance to the spill zone.

One final comment, I would very much like to receive an estimate of the time and costs associated with revising your report as suggested by our peer reviewers. Obviously, how you approach this exercise will depend upon assumptions relating to what other literature sources you search and subsequently how many papers/reports would be available for review and synthesis. Maybe you could provide time and cost estimates for two or three different options, or levels of effort. For example, what would it cost to include an additional review/synthesis of the literature from the Gulf of Alaska on the response of intertidal and subtidal communities to sudden land-level changes (earthquake and nuclear testing)? What would it cost to include the relevant literature from the Proceedings of the International Oil Spill Conferences, 1972 to the present, and also the relevant literature published by the Minerals Management Service, Pacific Outer Continental Shelf Region? I am sure that with the suggestions of the individual peer reviewers, you could develop other possible options for which time and costs estimates could be generated.

I hope this is some help. I very much appreciate your efforts on our behalf and look forward to working with you to ensure a successful completion to our contract. I am available at your convenience to discuss any of the enclosed comments. I am certain you are also free to seek clarification from any of the peer reviewers.

Yours very truly,

John A. Strand, Ph.D.

Enclosures

cc: Susan MacMullin (w/o literature)
Byron Morris (w/o literature)
Joe Jehl, Jr. (w/o literature)
Stan Senner (w/o literature)
Joy Zedler (w/o literature)

6 November 2001

To: John Strand
From: Si Simenstad

Please excuse the haphazard review of the Boland report; it is on the airplane @ the end of the day and I knew that there would be no *way*, with my schedule that I can summarize it lucidly tomorrow!

I will have to say that I think that they did make a contribution, although they probably got so terrified by the amount of literature out there that they over-reacted in limiting their scope. I would make three critical suggestions for the report that *may* be acceptable by John & Joy: (1) expand the literature *at least* to cover experimental evidence of recovery, if not some of the more gray literature on dredge material disposal, tectonic/nuclear test uplift, etc; (2) categorize the studies by relevant determinants of recovery, e.g., type of insult, e.g., pollution vs. natural disturbance, frequency & intensity, in addition to size, of disturbance; and (3) provide a real synthesis section relevant to Prince William Sound and the Gulf of Alaska (*all* contractors should be required to do this!).

I acknowledge that this was not an easy task, and suggest that the RFP did not provide complete guidance. Thus, I'm not sure I disagree per se, with anything substantial in the report; they just didn't go far enough w/ it, either in scope or evaluation.

b. WHY NOT OTHER, e.g. "INTENTIONAL" DISTURBANCE — EXPERIMENTAL, TECTONIC UPLIFT, DREDGING, ARTIFICIAL REEF IMPLACEMENT, ETC. — OR NUCLEAR TEST!
c. WHAT ABOUT ABUNDANT LITERATURE ON SETTLING PLATE COLONIZATION?

(2) READING OF 54 PAPERS, ~~HOWEVER, APPEARED TO BE~~ EXCEEDINGLY THOROUGH.

# COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: MARINE INVERTEBRATE COMMUNITIES

(3) IGNORED TOPIC OF HABITAT PROTECTION

(4) WHERE IS ACTUAL SYNTHESIS? — RECOMMENDATIONS FOR INDICATORS AND METHODOLOGIES?

by

**John M. Boland**, Postdoctoral Research Associate.

Project supervision:

**Joy B. Zedler**, Professor of Biology

Pacific Estuarine Research Laboratory (PERL)

Biology Department

San Diego State University

San Diego, CA 92182-0057

FIRST DRAFT - CONFIDENTIAL

10 OCTOBER 1991

Project sponsored by:

The Oil Spill Restoration Planning Office

Environmental Protection Agency

U.S. Departments of Agriculture, Commerce and Interior

437 E Street, Suite 301

Anchorage, Alaska 99501

## EXECUTIVE SUMMARY


This paper is a comprehensive review and critical synthesis of the readily available literature on recovery of benthic invertebrate communities following disturbances. It was commissioned by the staff of the Oil Spill Restoration Planning Office to assist them in their management of Alaska's Prince William Sound area following the oil spill of the *Exxon Valdez*.

Benthic invertebrate communities are very productive, rich in species and support food webs that include commercially and ecologically important species. These communities are vulnerable to disturbances, including storm damage, sewage pollution and oil pollution. Many scientific studies have described the recovery of these communities after a disturbance and I review 54 of these studies here.

First, I focused on the time the communities took to recover and had six general conclusions:

1. Most of the studies (65%) reported that recovery did not occur.
2. Recovery was more likely after a small disturbance than after a large disturbance.
3. Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.
4. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates. After a large oil spill, recovery of the invertebrate communities on hard substrates may take less than 10 years whereas the recovery of the invertebrate communities on soft substrates will take longer than 10 years.
5. One can estimate recovery time by using the rule of thumb: recovery time is at least as long as the maximum age of the organisms killed.
6. The review of this recovery literature by the Exxon Corporation biologists, Baker, Clark, Kingston and Jenkins, was inadequate.

Second, I discuss four abiotic factors that appear to effect recovery. Recovery is generally slower (a) after a large oil spill than after a small oil spill, (b) in soft sediments than on hard sediments, (c) in the high intertidal zone than in the low intertidal zone, and (d) at high latitudes than at temperate latitudes.

Third, I discuss the management practises that may influence recovery. In particular, I point out the problems associated with clean-up methods and bioremediation, and suggest that transplantation of some species should be considered.

Finally, I recommend an approach to determine when recovery has occurred. I think that the following six points are crucial to a successful study.

1. A definition of recovery is necessary. I suggest: "Complete recovery after an oil spill occurs when (a) all the species that were present before the oil spill are again present; (b) each of these species has reached their original abundances and biomasses, (c) each of these species has reached their original age distributions, and (d) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.
2. The hypotheses being tested should be clearly stated. The following hypotheses are appropriate: that there are no significant differences in (a) the species that are present in oiled and unoiled areas; (b) the abundances and biomasses of the species in oiled and

unoiled areas; (c) the age distributions of the species in oiled and unoiled areas; and (d) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

3. None of the papers cited in Table 1 provides a good example of how to conduct a recovery study. It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem.

4. Natural communities are spatially heterogenous. This means (a) that it is necessary to study many unoiled and many oiled sites so that the range of natural variability can be determined, (b) that a large area should be covered at each site, and (c) that a large number of samples are required for reliable estimates of population densities.

5. All the results that are necessary and sufficient to test the hypotheses should be presented in the report.

6. Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the community.

## ACKNOWLEDGEMENTS

I thank Jeff Crooks and Stacey Baczkowski for searching for papers, reading papers and helping compile Table 1; Joy Zedler for helpful comments on early drafts of this manuscript; and Bruce Nyden, Dawn Makis and Bric Standish for typing most of the Bibliography.

# 1.0 INTRODUCTION

## 1.1 Background

On 24 March 1989 the tanker *Exxon Valdez* ran aground in Alaska's Prince William Sound causing the largest oil spill in U.S. history. Approximately 11 million gallons of North Slope crude was lost at sea. The oil spread over an area of >900 square miles and oiled 1, 244 miles of the shorelines in the Prince William Sound, and on the Kenai Peninsula, Alaska Peninsula and Kodiak Island (Alaska Department of Environmental Conservation, 1989).

A tremendous clean-up and restoration effort has followed the spill and the managers of this effort would like to know what to expect in the recovery of these habitats. In particular, they would like answers to questions such as: How long will recovery take? What factors are likely to affect recovery? What indicators of recovery should the biologists be measuring? In an attempt to answer these questions for invertebrate communities, I have reviewed the literature on recovery of invertebrate communities after various disturbances, including oil spills.

Benthic invertebrate communities in the intertidal and shallow subtidal zones are particularly vulnerable to oil spills because much of the oil is deposited and concentrated in these habitats (National Research Council 1985) and, because invertebrates are relatively immobile, they are unable to escape the toxic and smothering effects of oiling. The recovery of these communities is relatively slow and the damage caused by an oil spill can still be detected several years after a major spill (e.g., Southward and Southward 1978).

Benthic invertebrate communities are very productive, rich in species and support complex food webs that frequently include commercially and ecologically important species. For instance, the benthic invertebrates in Alaska support many species of bottom feeding fish (e.g., black rockfish), birds (e.g., oystercatchers), and mammals (e.g., gray whale, sea otter, brown bear, black bear, even man -- subsistence harvesting of mussels and clams). Also many benthic invertebrates have planktonic larvae and these become important components of planktonic food webs which include pelagic fishes (e.g., salmon, herring), birds (e.g., puffins, kittiwakes, murres, bald eagles), and mammals (e.g., harbor seals). Damages to the benthic invertebrate communities can therefore have wide-spread effects.

The **effects** of disturbances on benthic invertebrate communities have been quite well studied, particularly during the past 20 years (e.g., Kvitek et al. in press, see Connell and Keough 1985, and Sousa 1985, for reviews). However, long-term studies of **recovery** in these communities are quite rare -- I have found only 54 papers that deal with recovery and most of these (72%) followed recovery for a rather short time -- less than 6 years. Our review of these recovery studies expands upon earlier reviews by Mann and Clark (1978), Thistle (1981), and Ganning et al. (1984), and provides a different perspective to the review by Baker et al. (1990).

## 1.2 Objectives

There are two objectives to this paper:

1. To review the readily available literature on recovery of invertebrate communities after a disturbance. I will focus on the rate of recovery and factors that may affect recovery.

2. To extrapolate the information obtained in the review to the injured Alaskan ecosystem. In particular, to identify the most practical indicators of recovery to measure, and to recommend an approach to determine when recovery has occurred.

## 2.0 TECHNICAL APPROACH

### 2.1 Information Retrieval and Sources of Data

Among the sources searched were:

1. Aquatic Sciences and Fisheries Abstracts -- 1982 to 1990. Using the key words: oil-spills-benthic; intertidal-recruitment; intertidal-succession; subtidal-succession; disturbance-recovery-invertebrates; disturbance-recovery-marine; and oil-invertebrates.

2. Oil Spill Public Information Center's Collection List -- June 1991.

3. The reference list in: National Research Council. 1985. Oil in the Sea; Inputs, Fates and Effects. National Academy Press, Washington Press, Washington, D.C.

4. The reference list in: W.P. Sousa. 1984. The role of disturbance in natural communities. Ann. Rev. Ecol. Syst. 15: 353-391.

5. Marine Pollution Bulletin for the years 1985 through 1990.

### 2.2 Analysis and Synthesis

Papers were excluded from the review if: (1) they dealt with the effect of disturbances and not recovery after disturbances (e.g., Maki 1991, see Teal and Howarth 1984, and National Research Council 1985 for reviews); (2) they dealt with the recovery of a single species rather than the recovery of the whole community (e.g., Krebs and Burns 1978); (3) they dealt with the effect of oil on the physiology, biochemistry or behavior of species (e.g., Percy 1977, see National Research Council 1985 for review); and (4) they were not in English (e.g., NOAA-CNEXO 1982). Thus the papers that are included in this review deal with the population and community level recovery after many kinds of disturbances (from whale feeding excavations to oil and sewage spills), in several different habitats (from subtidal soft sediments to rocky shores), and from many parts of the world (from Straits of Magellan to Norway).

Organic pollution and oil spills have similar effects on the biota and these are different to the effects of non-organic disturbances (Glémarec 1986). I therefore searched thoroughly for papers dealing with the recovery of invertebrate communities after oils spills and organic pollution but less thoroughly for papers dealing with recovery after non-organic disturbances.

I grouped the papers according to the nature of the habitat (soft substrates and hard substrates), the size of the disturbance (small, if less than square meters; medium if square meters; and large if square kilometers), and the type of disturbance (non-organic, organic, and oil pollution).

# 3.0 REVIEW OF READILY AVAILABLE INFORMATION ON RECOVERY

## 3.1 Benthic Invertebrates

### 3.1.1 Rate, Duration, and Degree of Recovery Following Disturbance

It is important to define what I mean by the terms disturbance and recovery. Disturbance is "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established" (Sousa 1984). Typical disturbances in benthic invertebrate communities are oil pollution, sewage pollution, the shearing force of large waves, and the foraging activities of animals, such as whales.

The majority of the papers discussed below do not define recovery, however their implied definition was usually the return of all population densities to pre-disturbance levels or to undisturbed levels. For the purposes of this review I have chosen to keep to this definition. However, in Section 4.2 I discuss further the definition of recovery.

Here I review many different types of disturbances and deal with soft and hard sediments separately because there are some differences in the recovery of their benthic invertebrate communities.

SOFT SUBSTRATES

**A) Succession model**

The effects of organic pollution on infaunal invertebrate communities have been studied for many years and a general model has emerged of the succession that occurs in these communities during recovery (Pearson and Rosenberg 1978, Rhoads and Germano 1982). Figure 1A describes part of this model. In general, a heavy input of organic material (e.g., sewage, pulp-mill effluent) onto the sediment reduces the oxygen content of the sediment and a black anaerobic layer rises to the sediment surface. The combination of high sulphide, low pH, and low oxygen concentrations in anaerobic sediment may cause complete defaunation. With no further input of organic material, currents carry away some of the organic material, conditions improve and a few macroinvertebrate species invade. These opportunistic species are usually small tubiculous polychaetes that are able to tolerate the conditions and take advantage of the rich organic material available. As conditions improve further and oxygen penetrates farther into the sediment, other species invade. These species, called "equilibrium" species or late succession species, include sub-surface deposit feeders whose burrowing activities result in further aeration of the sediment. Finally, these late succession species grow large, other late succession species invade, some (or all) of the opportunists drop out, and the community is indistinguishable from an undisturbed community.

Notice that the succession began when the area was invaded by relatively small, abundant, surface dwelling polychaete opportunists and ended when the area was inhabited by a suite of relatively large, rare, deep dwelling late succession species that include polychaetes, mollucs, crustaceans and echinoderms. Not only does the diversity of phyla increase but the number of foraging modes also increases, from non-selective sub-surface deposit feeders (e.g., *Capitella*) and carnivores, to suspension-feeders, omnivores, carnivores, and selective surface deposit feeders (Pearson and Rosenberg 1978).

The second part of the model describes how three important community characteristics (total number of species, total number of individuals, and total biomass) change during recovery of the community following an organic pollution event (Pearson and Rosenberg 1978; Figure 2). The total number of species increases steadily but then declines slightly because the opportunistic species tend to drop out. The total number of individuals rises very rapidly because the opportunists can be very dense but as the opportunists are replaced by late succession species the number of individuals drops quickly and eventually levels off at a relatively low number. The total biomass tends to increase steadily to a plateau usually with two peaks -- one early in the succession when opportunists are abundant and the other in the middle of succession when the greatest number of species are present in the community.

The end point of the succession is termed the "climax." This climax may only exist as an average condition on a relatively large spatial scale because frequent disturbances will prevent all parts of the habitat from reaching the climax state at the same time (Sousa 1984). The habitat will appear spatially heterogenous, i.e., many small patches at different stages of succession will be scattered in the large climax community.

The successional patterns described here also occur in space (Figure 1B). As one proceeds from a point source of organic pollution one will find in turn: an afaunal area, an area dominated by surface dwelling polychaetes, an area where there is a mixture of opportunistic and late succession species (transitional), and finally an area dominated by late succession species. This spatial pattern has been studied more than the temporal pattern (e.g., Pearson 1975, Swartz et al. 1986).

An important aspect of this model is that the composition of the early and late communities are quite predictable. The opportunistic species that invade during the initial stages of recovery from enrichment are distributed world-wide and the composition of the community they form is usually very similar from place to place (Pearson and Rosenberg 1978). It is therefore predictable. The late succession species that form the community during the final stage of recovery are more locally distributed and the "normal" communities they form differ from site to site depending on the habitat and the faunal region. However, the composition of these "normal" communities is predictable from undisturbed areas nearby. Only the transitional community is unpredictable. This is because both the recruitment of the late succession species and the elimination of the opportunistic species is unpredictable.

Another important aspect of this succession is that a large number of species at a site does not indicate a recovered community. Actually a fully recovered site has fewer species, fewer individuals and less biomass than a partially recovered site! It will probably have the following characteristics: the anaerobic layer will be deep, several phyla will be present and several feeding modes will be present. However, a site can be considered to have fully recovered only when it is structurally and functionally indistinguishable from undisturbed reference sites.

### B) Recovery times

I reviewed 42 papers that dealt with the recovery of invertebrate communities in soft bottom habitats (Table 1). Recovery criteria were not always the same (see Section 4.2.1); in this section I adopt the terminology of each author, i.e., if the author determined that the area had not recovered then I repeat that it had not recovered. In general, the recovery times varied with the type and scale of the disturbance.

a. Non-organic disturbances

A few papers dealt with the recovery of invertebrate communities after they were disturbed by animals. These disturbances tended to be on a relatively small scale -- even the excavations made by the gray whales are usually less than 50m$^2$ in size (Oliver and Slattery 1985). Recovery of these communities was relatively rapid -- some recovery had occurred in just a few days and in most cases full recovery was expected to occur within one year.

Recovery of the community occurred relatively quickly in other small scale disturbances, e.g., experimentally defaunated areas (e.g., Zajac and Whitlatch 1982a). Most authors attributed this to the small size of the experimentally disturbed area.

Recovery from other more extensive natural disturbances, such as following a red tide and a hurricane, were slower -- recovery had not been completed after more than two years in either case (Dauer and Simon 1976, Boesch et al. 1976).

None of these disturbances is similar to that created by oil spills, i.e., these disturbances do not involve the addition of organic material to the sediment surface.

b. Anthropogenic pollution

Organic pollution and oil pollution have been described as similar -- both forms of pollution are frequently extensive and affect the sediment and its inhabitants in similar ways (Glémarec 1986). Several papers dealt with the recovery of invertebrate communities following an organic pollution event (Table 1). Most commonly the authors reported that recovery was not complete, but recovery was found in one case (Rosenberg 1976).

Rosenberg (1976) monitored the subtidal benthic community in the Saltkallefjord before and after a paper mill stopped dumping organic material. He found that recovery of the community was slowest in the most polluted sites; after approximately six years these sites had partially recovered -- they had the same number of species as the less polluted sites but the species compositions were not similar. After eight years, however, the compositions of the most polluted and least polluted sites were similar, and they were similar to that recorded prior to the establishment of the paper mill, forty years earlier.

c. Oil pollution

Many papers dealt with the recovery of benthic infaunal communities after being oiled (Table 1). The scale of the oil pollution ranged from small experimental oilings to major oil spills.

The recovery of invertebrates after a small scale oiling was quite slow. Above I pointed out that recovery in small areas is usually fast, but when oil is applied to the sediment the recovery is slower. For example, in the study by Vanderhorst et al. (1980), recovery was still not complete after 16 months. Although the species lists were similar in the control and oiled sites, the abundances of the species were significantly lower in the oiled sites.

Only three of the 21 papers describing the recovery of invertebrate communities after large scale oiling found full recovery (Blaylock and Houghton 1989, Glémarec 1986, Ibanez and Dauvin 1988). The recovery times for these studies were 1.5 years, 5.5 years, and 10 years, respectively. In several cases recovery was reported to be "partial" or "close to fully recovered" and in these cases partial recovery time was also between one and ten years (e.g., Dauvin 1987). More typically the researchers return to a site three to seven years after an oil spill, and determine that recovery still has not occurred (e.g., Thomas 1977).

I suspect that insufficient time has been allowed for full recovery to occur at most of these study sites and I conclude that the recovery of soft sediment invertebrate communities after an oil spill can take longer than ten years.

WHAT ABOUT OTHER PURELY EXPERIMENTAL EVIDENCE?? THERE'S MORE THAN A FEW PAPERS OUT THERE ON RECRUITMENT TO "NEW" SUBSTRATES

## HARD SUBSTRATES

### A) Succession

Succession on rocky shores has been well studied in temperate zones (e.g., Dayton 1971, Lubchenco 1983, Sousa 1984, Farrell 1991) and a general view of the process has emerged (Paine and Levin 1981). In the absence of disturbance, the competitive dominant species spreads out and occupies 100% of the space. For example, mussels are the competitive dominant on exposed Washington shores and they can form beds that cover 100% of the rock surface (Dayton 1971). Disturbance by waves, logs or starfish predation opens gaps in the beds of the competitive dominant. These gaps are relatively small, usually less than $1m^2$ (Paine and Levin 1981). Small gaps are filled by the growth or movement of animals from the surrounding area. Large gaps are invaded by these means and by the settlement of species out of the plankton. The first settlers are usually small algal species, followed by barnacles and worms, and finally by the dominant large algae and/or mussels. Thus a succession generally occurs, but this succesion is not particularly predictable -- the rates at which species invade depend upon the presence of their larvae in the water column and inhibition can occur. Frequently a shoreline looks like a mozaic where gaps at different stages of succession are scattered about the matrix of the competitive dominant.

ISN'T THERE EVIDENCE FOR THIS IN SOFT-BOTTOM COMMUNITIES? MAYBE AT A LARGER SCALE?

An important principle has come out of these studies -- the intermediate disturbance principle: the highest number of species is found in a system with an intermediate degree of disturbance (Paine 1966, Connell 1978). If the combined disturbance from all sources (e.g., predation, wave action) is low, then the system becomes dominated by the competitive dominant and its attendant species (i.e., a relatively low number). If the combined disturbance is high, then few opportunities arise for most species to recruit successfully -- therefore the total number of species is again low. Only when the combined disturbance is intermediate do conditions favour a large number of species. This pattern is usually studied in space but is also observed in the recovery of invertebrate communities after a disturbance (Connell 1978). In this respect recovery on hard sediments is similar to that in soft sediments -- the greatest number of species occur before full recovery. Therefore, again, the presence of a large number of species does not indicate that a site has recovered.

An important feature of the studies that have led to these generalizations about succession on rocky shores is that the disturbances examined are unlike oil pollution -- the gaps are relatively small and organic enrichment is rarely involved. However, Southward and Southward (1978) found that the general sequence of recolonization after the Torrey Canyon oil spill was similar to that described above for small-scale experiments where the rocks were scraped clean.

SO, WHY NOT SYNTHESIZE THESE EXPERIMENTAL RESULTS?

B) Recovery times

I reviewed 17 papers that dealt with the recovery of invertebrate communities on hard substrates (Table 1). Recovery criteria were not always the same (see Section 4.2.1); in this section , as above, I adopt the terminology of each author, i.e., if the author determined that the area had not recovered then I repeat that it had not recovered.

a. Non-organic disturbances

A few papers in Table 1 deal with the recovery of rocky shore invertebrate communities after non-organic disturbances. Recovery was relatively common and rapid -- between 1.75 years and 5.5 years (e.g., Paine and Levin 1981).

Boulder beaches are common in Alaska and the recovery of the communities on boulder beaches is therefore of special interest. In a series of experimental studies of succession on boulder beaches Sousa (1979a, 1979b, 1980) showed that the recovery of early successional assemblages takes approximately 5 months, middle successional assemblages 2.5 years, and late successional assemblages a minimum of 4 years.

However, it must be remembered that these disturbances are not similar to oil spills because they are relatively small and do not involve the addition of toxic organic material.

b. Oil pollution

Many papers have dealt with the recovery of rocky shore invertebrate communities after oiling (Table 1). In general, recovery was common and occurred relatively quickly (five years or less) after small and medium sized oil spills, but recovery was less common and occurred relatively slowly after large spills (even after ten years a site may not be fully recovered).

Southward and Southward (1978) noted that "heavily oiled places that received repeated application of dispersants have taken nine to ten years and may not be completely normal yet." Thomas (1978) found that, seven years after an oil spill, the oiled communities still did not resemble the unoiled communities. The fucoid algae (e.g., *Fucus*), in particular, were slow to recover.

CONCLUSIONS

- **Most of the studies report that recovery did not occur.** Recovery occurred in only 35% of the studies (Table 2). This means that either: recovery was going to occur in all cases but the assessment of recovery was conducted too early, i.e. prior to recovery (Teal 1990, Harding 1990); or recovery was not going to occur in all cases because the systems were irreparably damaged and will never recover to their pre-disturbance conditions.

- **Recovery was more likely after a small disturbance than after a large disturbance.** Recovery was reported in 65% of the studies following a small disturbance, 38% of the studies following a medium disturbance, and in only 18% of the studies following a large disturbance (Table 2). This suggests that recovery times are relatively fast after a small disturbance but slow after a large disturbance.

- **Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.** Recovery was reported in 46% of the stuidies following a non-oiling disturbance and in only 26% of the studies following an oiling disturbance (Table 2). This suggests that recovery times are relatively fast after a non-oiling disturbance but slow after an oiling disturbance. One reason for these trends is that oil persists longer than other disturbances (e.g., sewage); Ganning et al. (1984) estimated that the minimum residence time of oil on mud flats was 10 years.

- **Recovery was more likely after oiling of hard substrates than after oiling of soft substrates.** Recovery was reported in 45% of the studies of oiling of hard substrates and in only 17% of the studies of oiling of soft substrates (Table 2). Again, this suggests that recovery times are relatively fast on hard substrates but slow in soft substrates.

- **One can estimate recovery time by using the rule of thumb: recovery time is at least as long as the maximum age of the organisms killed.** For instance, if a mussel bed consisting of 1 to 20 year old mussels, is destroyed then it will take at least 20 years to recover. This provides only a rough estimate of the recovery time because some species are slow to recruit new individuals, particularly if the disturbed area is large and the source of colonists is far away (Sousa 1984). Also, if the disturbance is the result of an oil spill, residual hydrocarbons can reduce the fertility of the surviving adults. For example, oiled individuals of the the barnacle *Pollicipes polymerus* brooded fewer young than unoiled individuals (Straughan 1972). However, this rule of thumb provides a useful rough estimate of the recovery time.

- **The review of this literature by Baker et al. (1990) was inadequate.** Exxon Corporation biologists reviewed the literature on recovery of cold water marine environments after oil spills (Baker et al. 1990). Their paper covers the same topics as ours -- it includes a section on the benthic environment and a table (their Table 7) which is much like our Table 1. When a comparison is made of the two tables it is obvious that theirs is short of some important references -- the relatively long-term studies of soft sediments that found that recovery was not complete (e.g., Elmgren et al. 1983, Sanders 1978, Sanders et al. 1980, Thomas 1977, Dauvin 1987). In addition, in some cases, they chose to present the rosiest picture. For example, Southward and Southward (1978) state that "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 years; heavily oiled places that received repeated application of dispersants have taken 9-10 years and may not be completely normal yet." Baker et al. (1990) describe these results in their table as "good recovery after 2 years." It is clear that the research of Baker, Clark, Kingston and Jenkins must be read with some skeptism.

### 3.1.2 Effects of Abiotic Factors on Recovery

Because recovery was completed in so few of the studies, it is extremely difficult to make correlations between abiotic factors and recovery times. However, drawing on the data and observations presented in the papers, I conclude that four abiotic factors influence recovery.

## NATURE OF THE OIL SPILL

In general, the severity of the oil spill and the areal extent of the oil spill will affect the recovery time; high concentrations of oil will kill more of the resident species, making recovery slower, and large areas to be recolonized will also slow recovery (Straughan 1972, Southward and Southward 1978, Sanders et al. 1980, Sousa 1984).

WHAT ABOUT KIND OF OIL!?!

## HABITAT

Recovery is faster on rocky shores than soft sediments (Vandermeulen 1977, Table 2). The main reason for this appears to be the lingering effects of oil. The time taken for oil to disperse after an oil spill depends on the water flow in the habitat. Ganning et al. (1984) reported that the estimated minimum residence time of oil spilled in the following habitats was: 6 months on rocky shores, 4 years on sandy shores, and 10 years on mud flats. Factors that promote oil retention are weak tidal action, weak currents and fine sediments (Vandermeulen 1977, Gundlach 1987). Although recovery starts as soon as organisms can tolerate the conditions, which is well before all the oil has dissappeared, it appears that the residual hydrocarbons retard the recovery of the invertebrate communities by taking up space, by killing individuals, and by reducing their reproductive output (Southward and Southward 1978).

The effects of the oil spill may be delayed up to three years after the spill and are difficult to demonstrate. Conan (1982) gives two examples: was the death of all the intertidal individuals of the species *Tellina fabula* (a clam) several months after an oil spill due to oil? Also was the poor recruitment of *Tellina fabula* and *Donax vittatus* for the two years following a spill due to oil?

The NATURAL disturbance level in the habitat will also influence the recovery time because a frequently disturbed habitat will have younger adults than an infrequently disturbed habitat. For instance, intertidal boulders are frequently disturbed by large waves that cause the boulders to roll over and thereby crush or smother the organisms growing on them (Sousa 1979a, b); stable rocky shores are also affected by the large waves but less so (Dayton 1971). Thus stands of old organisms are rare on boulder beaches but common on stable rocky shores. One would therefore predict that recovery would be faster on boulders than on stable rocky shores.

## TIDAL HEIGHT

Position in the intertidal zone is important to the recovery of the community after a disturbance -- mid-tidal communities recover more quickly than high-tidal communities (e.g., Farrell 1991). Describing the recovery of the intertidal communities five years after the Arrow oil spill, Thomas (1977) stated that "recolonization has proceeded from lower to higher levels but has not yet occurred in the high tide zone." Position in the intertidal zone is also important to the natural self-cleaning of stranded oil -- oil stranded half-way up the shore is removed more quickly than oil stranded at the top of the shore (Vandermeulen 1977, Thomas 1977, and 1978). It is likely that the recovery of the high intertidal species is naturally slower than that of the mid-tidal species and that oil stranded in the high intertidal zone slows the process still further.

BUT "BATHTUB RING" EFFECT TYPICALLY CONCENTRATES OIL AROUND MLLW?!

TEMPERATURE

Cool temperatures slow biological processes. Oil is more persistent at high latitudes than at low latitudes because photochemical and microbial degradation occur more slowly in colder temperatures and diminished light (Roberts 1989). Cold water organisms are longer lived and have longer generation times than their warm water counterparts (Roberts 1989). Also, cold water organisms tend to have lower fecundity and slower growth rates (Southward and Southward 1978). Recovery of invertebrate communities is therefore expected to proceed more slowly at high latitudes (Dunbar 1968, Southward and Southward 1978, Clarke 1979).

### 3.1.3 Dependency of Recovery on Habitat Protection, Changes in Management Practices, and Other Restoration Approaches

THE CLEAN-UP

Stranded oil disperses very slowly and so cleaning up as much of the stranded oil as possible is an important first step on the road to recovery of the system. However, many of the methods used to clean-up oil spills appear to be more harmful than the oil itself For instance, in 1967 after the Torrey Canyon spill off England, 10,000 tons of toxic dispersants (also called detergents) were used in the cleaning operations, and most of the invertebrate mortalities could be attributed to the dispersants rather than the oil (Southward and Southward 1978). More recently hot water has been used to clean oiled shores, but hot water also kills many organisms (Broman et al. 1983, Houghton et al. 1991).

These studies show that the short-term effects of the cleaning are detrimental but they do not evaluate the long-term effects, i.e., the recovery of the habitats. However, I predict that recovery will be slower in cleaned areas because, in general, very large clearings take longer to recover than patches that have some of the original inhabitants intact (Sousa 1984, Smith and Brumsickle 1989).

Thomas (1978) agreed that some clean-up methods on rocky shores do more harm than good, but suggested that clean-up of oil from soft sediments would promote recovery. He stated that "if clean-up methods for lagoons could be improved so that oil could be removed without sediment penetration or disturbance, clean-up should help to minimize oil pollution effects" (Thomas 1978).

BIOREMEDIATION

In bioremediation a nitrogen-phosphorus fertilizer is sprayed onto the stranded oil. This fertilizer provides extra nutrients for naturally occurring micro-organisms (i.e., bacteria and fungi) that break down oil. This technique, long employed against toxic wastes, can more than double the speed of oil removal (EPA 1990). The micro-organisms feed on the oil and leave behind asphalt hydrocarbons that are unsightly but not toxic. One problem with this approach is that bacteria may not be active below the top few inches of soft sediments. Another problem is that micro-organisms are relatively slow to break-down oil in cold marine habitats (Cretney et al. 1978, Atlas et al. 1978). The first large-scale use of bioremediation took place in Prince William Sound during 1989 as a series of experiments. The preliminary results of the experiments look promising (EPA 1990), but the effects on long-term recovery of the communities are not known.

RESTORATION

Given sufficient time, full recovery after an oil spill is likely to occur naturally. It will probably take a long time in areas that were heavily oiled, heavily oiled and destructively cleaned, where the sediments are soft, and/or where the disturbance was extensive (see Section 3.1.2). In order to speed recovery, managers will want to consider restoration options.

One option is to do nothing. Teal (1990) advises against active restoration. He states that it is best to leave the area alone after picking up as much oil as possible. He believes that we know so little about the ecosystems we are trying to restore that we could do more harm than good.

Another option is to transplant species into the disturbed sites. Species' recovery rates will depend on life-history characteristics and tolerance of oil. The species that have larvae in the plankton all, or most, of the year will recruit quickly into large disturbed spaces. On the other hand, the species whose larvae are rarely found in the plankton or whose larvae have extremely short-range dispersal, will recruit slowly into the same patches. Examples of species with short-range dispersal are soft corals (Gerrodette 1981), amphipods (Cabioch 1980), some *Octopus* (Hochberg and Fields 1980), many of the snails in the order Neogastropoda (Abbott and Haderlie 1980), and several species of algae (Dayton 1973, Paine 1979, Sousa 1984). Most of these propagules disperse less than 2m from the adult. Recruitment of such species to disturbed patches will correlate with the abundance of propagule-releasing adults in the immediate vicinity of the clearing. Thus the recolonization of large bare areas by these types of species will take a very long time. These short-range dispersal species would be the most likely to benefit from transplantation. Short-range dispersal is also more common in the Arctic than in temperate waters (Thorson 1950).

The alga, *Fucus*, is a short-range dispersal species that is an important species on hard substrates in Alaska -- it is common and provides cover and food for many invertebrate species. The recovery of *Fucus* may well determine the pattern of recovery for the community as a whole. To speed the recovery of *Fucus*, particularly in large disturbed areas, managers may consider transplanting plants into the area.

Unfortunately there is little information on how to conduct the restoration of marine communities. The restoration of kelp beds in southern California may provide an example for the restoration of the damaged ecosystems in Alaska. *Macrocystis pyrifera*, the giant kelp, forms the main component of southern California's kelp forests. Although an adult plant produces millions of spores, and although the spores and gametes are planktivorous, colonization of disturbed areas can be slow. Population declines of this species around sewer outfalls and power plants, and during warm water years, have stimulated many attempts at restoration (see Foster and Schiel 1985 for review). Transplants have been made of three stages in the life-cycle of the plant -- adult sporophytes, juvenile sporophytes and microscopic sporophytes. Most restoration attempts using these methods have not had suitable controls, so their success rates are difficult to determine (Foster and Schiel 1985). However, *Macrocystis* has returned to some of the transplanted areas.

I recommend that care be taken to not damage the areas from which the transplants are taken. In addition, I recommend that any major restoration project begin with an experimental phase so that the success rates of different methods can be evaluated. This will help rule out techniques that don't work and will help identify promising approaches that can be developed further (see PERL 1990). This research will provide valuable information on restoration techniques (a subject about which little is known) as well as further our knowledge of the Alaskan ecosystems. All major projects should be continually evaluated with a long-term monitoring program that will allow managers to take advantage of unforeseen benefits and to address unexpected problems quickly.

// ibid

## 4.0 EXTRAPOLATION TO THE INJURED ALASKAN ECOSYSTEM

### 4.1 Identification of Most Practical and Cost Effective Indicators of Recovery to Measure

Indicator species have been used extensively in pollution studies. Indicator species are those species which, by their presence and abundance, provide some indication of the prevailing environmental conditions. The best indicator species are those that have narrow and specific environmental tolerances, because they will show a marked response to quite small changes in environmental quality (Abel 1989).

However, indicator species provide only a general overview of the approximate position of the community in the successional process, i.e., whether the community is generally in the early or the late successional stage. What is needed to ~~determine whether~~ recovery has occurred is an extensive study that includes all ~~of the~~ macroinvertebrate species. Only then can one be sure of one's conclusions. See ~~below for~~ details.

WHY JUST MACRO INVERTEBRATE, MEIOFAUNA, FOR INSTANCE, ARE PROBABLY MORE SENSITIVE INDICATOR

### 4.2 Recommended Approach to Determine When Recovery has Occurred

#### 4.2.1 Definition of recovery

It is important that in a study of recovery that one state one's objectives clearly and define what one will or will not accept as a fully recovered ecosystem. The objectives will guide the entire project, including the sampling design, statistical tests and conclusions. Without clear objectives, the work will end up with a poorly directed sampling design and weak conclusions.

If one's objective is to determine whether an area has fully recovered from an oil spill then one must define what one will accept as recovered. Most of the researchers in Table 1 did not explicitly define recovery but their implicit definition was:

- "the return of all population densities to pre-disturbance levels or undisturbed levels."

However, there are many other possible definitions of recovery.

- American Heritage Dictionary (1973): "return to a normal condition; the getting back of something lost."

- Ganning et al. (1984): "the restoration to original functional and structural conditions with original species present in original numbers."

- Ganning et al. (1984): "returning the ecosystem to within the limits of natural variability."

- Lewis (1982): "complete recovery (has occurred when) there are no discernable after-effects."

- Boesch et al. (1987): "complete recovery is the time required for a disturbed community to exhibit variation that is within the bounds of variation seen in undisturbed, control areas."

- Conan (1982): "a new stable age distribution and equilibrium species assemblages attained".

- National Research Council (1975; page 91): "Complete recovery means that (1) the faunal and floral constituents that were present before the oil spill are again present and (2) they have their full complement of constituent age classes."

- Committee on Restoration of Aquatic Ecosystems, National Research Council (in press) " the return of an ecosytem to a close approximation of its condition prior to disturbance."

None of these definitions is completely satisfactory. They give a general description of the term but few specifics. I suggest the following definition of recovery -- it is a combination of the definitions:

- Boland (this report): "Complete recovery after an oil spill occurs when (1) all the species that were present before the oil spill are again present; (2) each of these species has reached their original abundances and biomasses, (3) each of these species has reached their original age distributions, and (4) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.

Prespill data on species abundances, biomasses, age distributions, growth rates and reproductive conditions are necessary for determining when recovery has occurred, however these data are usually unavailable. In these cases, studies of many unoiled sites must be conducted instead. These unoiled sites should be chosen carefully and should include all the habitats that were oiled. All the appropriate data should be collected in the unoiled sites soon after the oil spill and used as the baseline data representing the prespill conditions in the oiled sites.

Therefore, when one is testing for recovery one is testing the hypotheses that there are no significant differences in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that our definition, like those above, focuses on the structure of the community rather than its functioning. Too little is known about the functioning of marine communities to include it in the definition. One hopes that when the structure returns the functioning will return too. However, also notice that the recovered community does not have to be identical to the undisturbed community, only not statistically different from the undisturbed community.

Our definition of recovery is based upon that used by many researchers and the dictionary definition. However, the biologists working for The Exxon Corporation have recently proposed a different definition of recovery and this is:

- Baker et al. (1990): "the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and functioning normally. It may not have the same composition or age structure as that which was present before the damage, and will continue to show further change and development." This definition is very different to all the others outlined above in that it will consider a community recovered when it is only on the road to recovery. This is unacceptable. For instance, using this definition one may consider a mussel bed to have recovered if the rocks are completely covered with healthy opportunistic species such as green algae.

The difference between the definitions of Baker et al. (1990) and the others can be illustrated in an analogy. Say a train jumped the tracks and destroyed my house. The railroad company apologized and agreed to rebuild the house. After six months, the rubble has been removed, the new foundations have been laid and the workmen are starting to erect the wooden frame. Someone using Baker et al.'s definition would be impressed with the progress and probably state that "recovery has occurred!" But a house on the road to being built cannot be lived in; it is neither structurally nor functionally the same as a completed house. The other definitions of recovery require that further work be done on the house and only when it is completed will it be considered to have "recovered." In the same way, a community is recovered not when it is on the road to recovery but when it is fully recovered, i.e., structurally and functionally the same as it was before the disturbance.

The defintion of recovery of Baker et al. (1990) leads them to estimate recovery times that are relatively fast. "Rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." In subtidal sand and mud systems "recovery times are 1 to 5 years, but they can be 10 years or longer in exceptional cases" (Baker et al. 1990). Our literature survey suggests that recovery times are longer than these, and in general, these numbers should be doubled to obtain true estimates of recovery times (Section 3.1.1).

In conclusion, the definition of recovery is an extremely important part of the study.

### 4.2.2. Methods

We are testing the hypotheses that there is no significant difference in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that no mention has been made of the summarizing statistics like species diversity, total number of species, total biomass or total number of individuals -- as we have seen in Section 3.1.1, these numbers cannot be used to show when recovery has occurred. Also, notice that identifications need to be made to the species level. Some research has shown that little information is lost when identifications are made to the family level (Warwick 1988) but this applies to only some analyses, and too little is known about the Alaskan invertebrates to support this view.

Sanders et al. (1980) critized past research on recovery by saying that they arrived at "conclusions that are, at best, equivocal interpretations of insufficient and ambiguous data. Such inadequacies are usual in many pollution-related studies of benthic ecology, including those in which important decisions are based."

None of the papers cited in Table 1 provides a good example of how to conduct a recovery study. It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study be planned by competant statisticians and biologists familiar with the Alaskan ecosystem. Many books and papers describe appropriate sampling programs and methods to be used for studying marine benthos (e.g., Green 1979, Gauch 1982, Holme and McIntyre 1984, Mead 1988, Underwood 1981, Hurlbert 1984, Stewart-Oaten et al. 1986, Gray et al. 1988, Krebs 1989, PERL 1990), and these sources should be consulted.

Natural communities are spatially heterogenous. This means (1) that it is necessary to study many sites nearby that were not oiled and many sites within the oiled area so that the range of natural variability can be determined (Mann 1978, Ganning et al. 1984), (2) that a large area should be covered at each site, and (3) that a large number of samples are required for reliable estimates of population densities. Even to estimate population densities to within 20-40% of their true value may require several hundred samples at each site (Abel 1989). Because communities change with depth, a useful design is the stratified random sampling inwhich one blocks with depth (Gray et al. 1988).

### 4.2.3. Results

All the results that are necessary and sufficient to test the hypotheses should be presented. Frequently researchers collect a lot of information but report only diversity. Some also report, total biomass and total abundance, but very rarely do papers go beyond these summarizing statistics and describe the abundances of individual species. This is a weakness because, as we have seen above (Figure 2), "climax" communities do not have the greatest number of species, biomasses, or individuals. Also, these summarizing statistics cannot be used to test the hypotheses.

Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the functioning of the community.

### 4.2.4. Conclusions

Finally, the conclusions should be clearly presented.

## 5.0 LIST OF INDIVIDUALS CONTACTED DURING STUDY

Mr. Dennis C. Lees,
ERC Environmental and Energy Services Co. (ERCE),
5510 Morehouse Drive,
San Diego, CA 92121.

Dr. John S. Oliver,
Moss Landing Marine Laboratories,
Moss Landing, CA 95039.

## 6.0 REFERENCES


Abbot, D.P., and E.C. Haderlie. 1980. Prosobranchia: marine snails. In R.H. Morris, D.P. Abbott and E.C. Haderlie (eds.) Intertidal invertebrates of California. Stanford University Prerss, Stanford, California.

Abel, P.D. 1989. Water pollution biology. Ellis Horwood Limited Publishers, Chichester, England.

American Heritage Dictionary. 1973. The American Heritage Dictionary of the English Language. American Heritage Publishing Co., Boston, Mass.

Atlas, R.M., A. Horowitz and M. Busdosh. 1978. Prudhoe crude oil in Arctic marine ice, water, and sediment ecosystems: degradation and interactions with microbial and benthic communities. J. Fish. Res. Board Can. 35: 585-590.

Baker, J.M., R.B. Clark, P.F. Kingston and R.H. Jenkins. 1990. Natural recovery of cold water marine environments after an oil spill. Thirteenth annual Arctic and marine oil spill program technical seminar.

Blaylock, W.M., and J.P. Houghton. 1989. Infaunal recovery at Ediz Hook following the *Arco Anchorage* oil spill. Proceedings of the 1989 oil spill conference: 421-426.

Boesch, D.F., R.J. Diaz and R.W. Virnstein. 1987. Effects of tropical storm Agnes on soft-bottom macrobenthic communities of the James and York Estuaries and the Lower Chesapeake Bay. Chesapeake Science 17: 246-259.

Broman, D., B. Ganning and C. Lindblad. 1983. Effects of high pressure, hot water shore cleaning after oil spills on shore ecosystems in the northern Baltic proper. Marine Environmental Research 10: 173-187.

Cabioch, L. 1980. Pollution of subtidal sediments and disturbance of benthic animal communities. Ambio 9: 294-296.

Committee on Restoration of Aquatic Ecosystems (in press). Restoration of aquatic ecosystems. National Academy Press, Washington, D.C.

Conan, G. 1982. The long-term effects of the *Amoco Cadiz* oil spill. Phil. Trans. R. Soc. Lond. 297: 323-333.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. Science 199: 1302-1310.

Connell, J.H., and M.J. Keough. 1985. Disturbance and patch dynamics of subtidal marine animals on hard substrata. Pages 125-151 in S.T.A. Pickett and P.S. White, editors. The ecology of natural disturbance and patch dynamics. Academic Press, Orlando, Florida.

Cretney, W.J., C.S. Wong, D.R. Green and C.A. Bawden. 1978. Long-term fate of a heavy oil in a spill-contaminated B.C. coastal bay. J. Fish. Res. Board Can. 35: 521-527.

Dauer, D.M., and S.L. Simon. 1976. Repopulation of the polychaete fauna of an intertidal habitat following natural defaunation: species equilibrium. Oecologia 22: 99-117.

Dauvin, J-C. 1987. Evolution å long terme (1978-1986) des populations d'amphipodes des sables fins de la Pierre Noire (Baie de Morlaix, Manche Occidentale) apres la catastrophe de l'Amoco Cadiz. Marine Environmental Research 21: 247-273.

Dayton, P.K. 1971. Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecological Monographs 41: 351-389.

Dayton, P.K. 1973. Dispersion, dispersal, and persistence of the annual intertidal alga, *Postelsia palmaeformis*. Ecology 54: 433-438.

Elmgren, R., S. Hansson, U. Larsson, B. Sundelin and P.D. Boehm. 1983. The *Tsesis* oil spill: acute and long-term impact on the benthos. Marine Biology 73: 51-65.

EPA. 1990. Alaskan oil spill bioremediation project. Report from Office of Research and Development, Washington, D.C.

Farrell, T.M. 1991. Models and mechanisms of succession: an example from a rocky intertidal community. Ecological Monographs 61: 95-113.

Foster, M.S., and D.R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85 (7.2). 152 pp.

Ganning, B., D.J. Reish and D. Straughan. 1984. Recovery and restoration of rocky shores, sandy beaches, tidal flats and shallow subtidal bottoms impacted by oil spills. From J. Cairns and A. Buikema (eds.). Restoration of habitats impacted by oil spills. Butterworth Publishers, Boston, Mass.

Gauch, H.G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge, England.

Gerodette, T. 1981. Dispersal of the solitary coral *Balanophyllia elegans* by demersal planular larvae. Ecology 62: 611-619.

Glémarec, M. 1986. Ecological impact of an oil spill: utilization of biological indicators. Water Science and Technology 18: 203-211.

Gray, J.S., M. Aschan, M.R. Carr, K.R. Clarke, R.H. Green, T.H. Pearson, R. Rosenberg and R.M. Warwick. 1988. Analysis of community attributes of the benthic macrofauna of Frierfjord/Langesundfjord and in a mesocosm experiment. Marine Ecology Progress Series 46: 151-165.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, New York.

Gundlach, E. 1987. Oil-holding capacities and removal coefficients for different shoreline types to computer simulate spills in coastal waters. Proceedings of the 1987 oil spill conference: 451-457.

Harding, L. 1990. Panel presentation to Restoration Planning Work Group. Proceedings of the public symposium, July, 1990.

Hochberg, F.G., and W.G. Fields. 1980. Cephalopoda: the squids and octopuses. In R.H. Morris, D.P. Abbott and E.C. Haderlie (eds.) Intertidal invertebrates of California. Stanford University Prerss, Stanford, California.

Holme, N.A. and A.D. McIntyre (eds.). 1984. Methods for the study of marine benthos. Blackwell Scientific Publications, Oxford, England.

Houghton, J.P., D.C. Lees, H. Teas, H.L. Cumberland, S. Landino, W. Driskell, and T.A. Ebert. 1991. Evaluation of the condition of intertidal and shallow subtidal biota in Prince William Sound following the *Exxon Valdez* oil spill and subsequent shoreline treatment. Report to National Oceanic and Atmospheric Administration, Seattle, Washington.

Hurlbert , S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54: 187-211.

Ibanez, F., and J-C. Dauvin. 1988. Long-term changes (1977 to 1987) in a muddy fine sand *Abra alba-Melinna palmata* community from the western English Channel: multivariate time-series analysis. Marine Ecology progress Series 49: 65-81.

Krebs, C.J. 1989. Ecological methodology. Harper and Row, Publishers, New York.

Krebs, C.T., and K.A. Burns. 1978. Long-term effects of an oil spill on populations of the salt-marsh crab *Uca pugnax*. J. Fish. Res. Board Can. 35: 648-649.

Kvitek, R.G., J.S. Oliver, A.R. DeGrange and B.S. Anderson. (in press). Changes in Alaskan soft-bottom prey communities along a gradient in sea otter predation. Ecology.

Lewis, J.R. 1982. The composition and functioning of benthic ecosystems in relation to the assessment of long-term effects of oil pollution. Phil. Trans. R. Soc. Lond. 297: 257-267.

Lubchenco, J. 1983. *Littorina* and *Fucus*: effects of herbivores, substratum heterogeneity, and plant escapes during succession. Ecology 64: 1116-1123.

Maki, A.W. 1991. The *Exxon Valdez* oil spill: initial environmental impact assessment. Environ. Sci. Technol. 25: 24-29.

Mann, K.H. 1978. A biologist looks at oil in the sea. Shore and beach 46: 27-29.

Mann, K.H., and R.B. Clark. 1978. Session III. Summary and overview: long-term effects of oil spills on marine intertidal communities. J. Fish. Res. Board Can. 35: 791-795.

Mead, R. 1988. The design of experiments. Cambridge University Press, Cambridge, England.

National Research Council. 1975. Petroleum in the marine environment. National Academy Press, Washington Press, Washington, D.C.

National Research Council. 1985. Oil in the Sea; Inputs, Fates and Effects. National Academy Press, Washington Press, Washington, D.C.

NOAA-CNEXO. 1982. Ecological study of the Amoco Cadiz oil spill. Report to National Oceanic and Atmospheric Administration and Centre National pour l'Exploitation des Oceans.

Oliver, J.S., and P.N. Slattery. 1985. Destruction and opportunity on the sea floor: effects of gray whale feeding. Ecology 66: 1965-1975.

Paine, R.T. 1966. Food web complexity and species diversity. American Naturalist 100: 65-75.

Paine, R.T. 1979. Disaster, catastrophe and local persistence of the sea palm *Postelsia palmaeformis*. Science 205: 685-687.

Paine, R.T., and S.A. Levin. 1981. Intertidal landscapes: disturbance and the dynamics of patterns. Ecological Monographs 51: 145-178.

Pearson, T.H. 1975. Benthic ecology of Loch Linnhe and Loch Eil, a sea loch system on the west coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment. J. Exp. Mar. Biol. Ecol. 20: 1-41.

Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review 16: 229-311.

Percy, J.A. 1977. Response of arctic marine benthic crustaceans to sediments contaminated with crude oil. Environ. Pollut. 13: 1-10.

PERL. 1990. A manual for assessing restored and natural coastal wetlands with examples from southern California. California Sea Grant Report No. T-CSGCP-021. La Jolla, California.

Rhoads, D.C., and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method of remote ecological monitoring of the seafloor. Mar. Ecol. Prog. Ser. 8: 115-128.

Roberts, L. 1989. Long, slow recovery predicted for Alaska. Science 244: 22-24.

Rosenberg, R. 1976. Benthic faunal dynamics during succession following pollution abatement in a Swedish estuary. Oikos 27: 414-427.

Sanders, H.L. 1978. *Florida* oil spill impact on the Buzzards Bay benthic fauna: West Falmouth. J. Fish. Res. Board Can. 35: 717-730.

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth, Mass. J. Mar. Res. 38: 265-380.

Smith, G.R., and S.J. Brumsickle. 1989. The effects of patch size and substrate location on colonization modes and rates in intertidal sediment. Limnology and Oceanography 34: 1263-1277.

Sousa, W.P. 1979a. Disturbance in marine intertidal boulder fields: the nonequilibrium maintenance of species diversity. Ecology 60: 1225-1239.

Sousa, W.P. 1979b. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. Ecological Monographs 49: 227-254.

Sousa, W.P. 1980. The responses of a community to disturbance: the importance of successional age and species' life histories. Oecologia 45: 72-81.

Sousa, W.P. 1984. The role of disturbance in natural communities. Annual Review of Ecology and Systematics 15: 353-391.

Sousa, W.P. 1985. Disturbance and patch dynamics rocky intertidal shores. Pages 101-124 in S.T.A. Pickett and P.S. White, editors. The ecology of natural disturbance and patch dynamics. Academic Press, Orlando, Florida.

Southward, A.J., and E.C. Southward. 1978. Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. J. Fish. Res. Board Can. 35: 682-706.

Stewart-Oaten, A., W.W. Murdoch and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67: 929-940.

Straughan, D. 1972. Factors causing environmental changes after an oil spill. Journal of Petroleum Technology, Offshore Issue 1972: 250-254.

Swartz, R.C., F.A. Cole, D.W. Schults and W.A. DeBen. 1986. Ecological changes in the southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series 31: 1-13.

Teal, J.M. 1990. Panel presentation to Restoration Planning Work Group. Proceedings of the public symposium, July, 1990.

Teal, J.M., and R.W. Howarth. 1984. Oil spill studies: a review of ecological effects. Environmental Management 8: 27-44.

Thistle, D. 1981. Natural physical disturbances and communities of marine soft bottoms. Marine Ecology Progress Series 6: 223-228.

Thomas, M.L.W. 1977. Long term biological effects of bunker C oil in the intertidal zone. Proceedings of symposium, Seattle, Washington.

Thomas, M.L.W. 1978. Comparison of oiled and oiled intertidal communities in Chedabucto Bay, Nova Scotia. J. Fish. Res. Board Can. 35: 707-716.

Thorson, G. 1950. Reproductive and larval ecology of marine bottom invertebrates. Biol. revs. Cambridge Philos. Soc. 25: 1-45.

Underwood, A.J. 1981. Techniques of analysis of variance in experimental marine biology and ecology. Oceanogr. Mar. Biol. Annu. Rev. 19: 513-605.

Vanderhorst, J.R., J.W. Blaylock, P. Wilkinson, M. Wilkinson, and G. Fellingham. 1980. Recovery of Strait of Juan de Fuca intertidal habitat following experimental contamination with oil. Second annual report to the U.S. Environmental Protection Agency, Washington, D.C.

Vandermeulen, J.H. 1977. The Chedabucto Bay spill - *Arrow*, 1970. Oceanus 20: 31-39.

Warwick, R.M. 1988. The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. Marine Pollution Bulletin 19: 259-268.

Zajac, R.N., and R.B. Whitlatch. 1982a. Responses of estuarine infauna to disturbance. I. Spatial and temporal variation of intial recolonization. Marine Ecology Progress Series. 10: 1-14.

## 7.0 ANNOTATED BIBLIOGRAPHY

Here follows a detailed description of each of the recovery papers reviewed in Table 1. It includes the abstracts of each paper taken verbatim from the original papers. Three papers (Flower 1983, Glémarec 1986, Guzman and Campodonico 1981) did not have abstracts and for these I wrote a brief summary of their findings.

United States
Environmental Protection
Agency

Region 10
1200 Sixth Avenue
Seattle WA 98101

Alaska
Idaho
Oregon
Washington

EPA

NOV 15 1991

MEMORANDUM

SUBJECT: Critique of the draft report: "Comprehensive Review and Critical Synthesis of the Literature on Recovery of Ecosystems Following Man-Induced and Natural-Phenomena-Related Disturbances: Marine Invertebrate Communities"

FROM: John Armstrong *John Armstrong*
Office of Coastal Waters

TO: John Strand
Restoration Planing Work Group

I have enclosed a critiqued copy of the above draft report. I've written numerous, substantial comments in the margins of the report. A few additional, more general comments are listed below.

The term "recovery" is used in various ways throughout this report. I suggest the Restoration Planning Work Group (RPWG) provide the author with a definition or at least a concept of recovery which will meet RPWG's needs. If RPWG is not prepared to do this, I believe the author should select definitions for "recovering", "partially recovered" and "recovered" (or substantially completely recovered) and provide these definitions at the start of the report. After defining recovery, the author should address the literature with these definition in mind.

I believe RPWG should tell the author precisely what they would like to get from his report and how RPWG intends to use it. This instruction or direction will help the author provide something useful to RPWG and not just a report which will be put on the shelf.

The report lacks a table of contents and many of the headings are too brief to be useful (i.e., P .13 - The Clean-Up, p. 17 - Methods, P. 18 - Results, Conclusions).

The section on Restoration (p. 14) is very brief and lacks both insights gained from the literature as well as imagination. I believe RPWG should be given a list of restoration options to choose from, even if some are not necessarily proven or practical. For example, mussels could be transported to beaches from which they have all been removed, predators (starfish) could be removed from certain areas, beaches could be posted to keep people off, beaches could be fenced or otherwise "altered" to keep wildlife off (i.e., loud noises to keep birds off the beaches).

The recent NOAA report by Houghton et. al. should be used and referenced more often in this report.

The Principal Investigator should conduct a more careful review of the next draft before it's presented to the RPWG.

Please don't hesitate to give me a call at FTS 399-1368 if you have any questions on my review comments John.

cc: Stan Senner
Susan Mac Mullin

# COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING MAN-INDUCED AND NATURAL-PHENOMENA-RELATED DISTURBANCES: MARINE INVERTEBRATE COMMUNITIES

by

**John M. Boland**, Postdoctoral Research Associate.

Project supervision:

**Joy B. Zedler**, Professor of Biology

Pacific Estuarine Research Laboratory (PERL)

Biology Department

San Diego State University

San Diego, CA 92182-0057

FIRST DRAFT - CONFIDENTIAL

10 OCTOBER 1991

Project sponsored by:

The Oil Spill Restoration Planning Office

Environmental Protection Agency

U.S. Departments of Agriculture, Commerce and Interior

437 E Street, Suite 301

Anchorage, Alaska 99501

## EXECUTIVE SUMMARY

This paper is a comprehensive review and critical synthesis of the readily available literature on recovery of benthic invertebrate communities following disturbances. It was commissioned by the staff of the Oil Spill Restoration Planning Office to assist them in their management of Alaska's Prince William Sound area following the oil spill of the *Exxon Valdez*.

Benthic invertebrate communities are very productive, rich in species and support food webs that include commercially and ecologically important species. These communities are vulnerable to disturbances, including storm damage, sewage pollution and oil pollution. Many scientific studies have described the recovery of these communities after a disturbance and I review 54 of these studies here.

First, I focused on the time the communities took to recover and had six general conclusions:

1. Most of the studies (65%) reported that recovery did not occur.
2. Recovery was more likely after a small disturbance than after a large disturbance.
3. Recovery was ~~more likely~~ after a non-oiling disturbance than after an oiling disturbance.
4. Recovery was more likely after oiling of hard substrates than after oiling of soft substrates. After a large oil spill, recovery of the invertebrate communities on hard substrates may take less than 10 years whereas the recovery of the invertebrate communities on soft substrates will take longer than 10 years.
5. ~~One can estimate recovery time by using the rule of thumb: recovery time is at least as long as the maximum age of the organisms killed.~~
6. The review of this recovery literature by the Exxon Corporation biologists, Baker, Clark, Kingston and Jenkins, was inadequate.

Second, I discuss four abiotic factors that appear to effect recovery. Recovery is generally slower (a) after a large oil spill than after a small oil spill, (b) in soft sediments than on hard sediments, (c) in the high intertidal zone than in the low intertidal zone, and (d) at high latitudes than at temperate latitudes.

Third, I discuss the management practises that may influence recovery. In particular, I point out the problems associated with clean-up methods and bioremediation, and suggest that transplantation of some species should be considered.

Finally, I recommend an approach to determine when recovery has occurred. I think that the following six points are crucial to a successful study.

1. A definition of recovery is necessary. I suggest: "Complete recovery after an oil spill occurs when (a) all the species that were present before the oil spill are again present; (b) each of these species has reached their original abundances and biomasses, (c) each of these species has reached their original age distributions, and (d) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments.
2. The hypotheses being tested should be clearly stated. The following hypotheses are appropriate: that there are no significant differences in (a) the species that are present in oiled and unoiled areas; (b) the abundances and biomasses of the species in oiled and

? reword

unoiled areas; (c) the age distributions of the species in oiled and unoiled areas; and (d) the growth rates ~~and reproductive~~ condition of individuals in oiled and unoiled areas.

3. None of the papers cited in Table 1 provides a good example of how to conduct a recovery study. It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem.

– how about Houghton et al, 1991 cited in your references

4. Natural communities are spatially heterogenous. This means (a) that it is necessary to study many unoiled and many oiled sites so that the range of natural variability can be determined, (b) that a large area should be covered at each site, and (c) that a large number of samples are required for reliable estimates of population densities.

5. All the results that are necessary and sufficient to test the hypotheses should be presented in the report. – what report?

6. ~~Details about~~ "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the community.

## ACKNOWLEDGEMENTS

I thank Jeff Crooks and Stacey Baczkowski for searching for papers, reading papers and helping compile Table 1; Joy Zedler for helpful comments on early drafts of this manuscript; and Bruce Nyden, Dawn Makis and Bric Standish for typing most of the Bibliography.

# 1.0 INTRODUCTION

## 1.1 Background

On 24 March 1989 the tanker *Exxon Valdez* ran aground in Alaska's Prince William Sound causing the largest oil spill in U.S. history. Approximately 11 million gallons of North Slope crude was lost at sea. The oil spread over an area of >900 square miles and oiled 1, 244 miles of the shorelines in the Prince William Sound, and on the Kenai Peninsula, Alaska Peninsula and Kodiak Island (Alaska Department of Environmental Conservation, 1989).

A tremendous clean-up and restoration effort has followed the spill and the managers of this effort would like to know what to expect in the recovery of these habitats. In particular, they would like answers to questions such as: How long will recovery take? What factors are likely to affect recovery? What indicators of recovery should the biologists be measuring? In an attempt to answer these questions for invertebrate communities I have reviewed the literature on recovery of invertebrate communities after various disturbances, including oil spills.

Benthic invertebrate communities in the intertidal and shallow subtidal zones are particularly vulnerable to oil spills because much of the oil is deposited and concentrated in these habitats (National Research Council 1985) and, because invertebrates are relatively immobile, they are unable to escape the toxic and smothering effects of oiling. The recovery of these communities is relatively slow and the damage caused by an oil spill can still be detected several years after a major spill (e.g., Southward and Southward 1978).

Benthic invertebrate communities are very productive, rich in species and support complex food webs that frequently include commercially and ecologically important species. For instance, the benthic invertebrates in Alaska support many species of bottom feeding fish (e.g., black rockfish), birds (e.g., oystercatchers), and mammals (e.g., gray whale, sea otter, brown bear, black bear, even man -- subsistence harvesting of mussels and clams). Also many benthic invertebrates have planktonic larvae and these become important components of planktonic food webs which include pelagic fishes (e.g., salmon, herring), birds (e.g., puffins, kittiwakes, murres, bald eagles), and mammals (e.g., harbor seals). Damages to the benthic invertebrate communities can therefore have wide-spread effects.

The **effects** of disturbances on benthic invertebrate communities have been quite well studied, particularly during the past 20 years (e.g., Kvitek et al. in press, see Connell and Keough 1985, and Sousa 1985, for reviews). However, long-term studies of **recovery** in these communities are quite rare -- I have found only 54 papers that deal with recovery and most of these (72%) followed recovery for a rather short time -- less than 6 years. Our review of these recovery studies expands upon earlier reviews by Mann and Clark (1978), Thistle (1981), and Ganning et al. (1984), and provides a different perspective to the review by Baker et al. (1990).

## 1.2 Objectives

There are two objectives to this paper:

1. To review the readily available literature on recovery of invertebrate communities after a disturbance. I will focus on the rate of recovery and factors that may affect recovery.

2. To extrapolate the information obtained in the review to the injured Alaskan ecosystem. In particular, to identify the most practical indicators of recovery to measure, and to recommend an approach to determine when recovery has occurred.

## 2.0 TECHNICAL APPROACH

### 2.1 Information Retrieval and Sources of Data

Among the sources searched were:

1. Aquatic Sciences and Fisheries Abstracts -- 1982 to 1990. Using the key words: oil-spills-benthic; intertidal-recruitment; intertidal-succession; subtidal-succession; disturbance-recovery-invertebrates; disturbance-recovery-marine; and oil-invertebrates.

2. Oil Spill Public Information Center's Collection List -- June 1991.

3. The reference list in: National Research Council. 1985. Oil in the Sea; Inputs, Fates and Effects. National Academy Press, Washington Press, Washington, D.C.

4. The reference list in: W.P. Sousa. 1984. The role of disturbance in natural communities. Ann. Rev. Ecol. Syst. 15: 353-391.

5. Marine Pollution Bulletin for the years 1985 through 1990.

### 2.2 Analysis and Synthesis

Papers were excluded from the review if: (1) they dealt with the effect of disturbances and not recovery after disturbances (e.g., Maki 1991, see Teal and Howarth 1984, and National Research Council 1985 for reviews); (2) they dealt with the recovery of a single species rather than the recovery of the whole community (e.g., Krebs and Burns 1978); (3) they dealt with the effect of oil on the physiology, biochemistry or behavior of species (e.g., Percy 1977, see National Research Council 1985 for review); and (4) they were not in English (e.g., NOAA-CNEXO 1982). Thus the papers that are included in this review deal with the population and community level recovery after many kinds of disturbances (from whale feeding excavations to oil and sewage spills), in several different habitats (from subtidal soft sediments to rocky shores), and from many parts of the world (from Straits of Magellan to Norway).

Organic pollution and oil spills have similar effects on the biota and these are different to the effects of non-organic disturbances (Glémarec 1986). I therefore searched thoroughly for papers dealing with the recovery of invertebrate communities after oils spills and organic pollution but less thoroughly for papers dealing with recovery after non-organic disturbances.

I grouped the papers according to the nature of the habitat (soft substrates and hard substrates), the size of the disturbance (small, if less than square meters; medium if square meters; and large if square kilometers), and the type of disturbance (non-organic, organic, and oil pollution).

# 3.0 REVIEW OF READILY AVAILABLE INFORMATION ON RECOVERY

## 3.1 Benthic Invertebrates

### 3.1.1 Rate, Duration, and Degree of Recovery Following Disturbance

It is important to define what I mean by the terms disturbance and recovery. Disturbance is "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established" (Sousa 1984). Typical disturbances in benthic invertebrate communities are oil pollution, sewage pollution, the shearing force of large waves, and the foraging activities of animals, such as whales.

The majority of the papers discussed below do not define recovery, however their implied definition was usually the return of all population densities to pre-disturbance levels or to undisturbed levels. For the purposes of this review I have chosen to keep to this definition. However, in Section 4.2 I discuss further the definition of recovery.

Here I review many different types of disturbances and deal with soft and hard sediments separately because there are some differences in the recovery of their benthic invertebrate communities.

SOFT SUBSTRATES

**A) Succession model**

The effects of organic pollution on infaunal invertebrate communities have been studied for many years and a general model has emerged of the succession that occurs in these communities during recovery (Pearson and Rosenberg 1978, Rhoads and Germano 1982). Figure 1A describes part of this model. In general, a heavy input of organic material (e.g., sewage, pulp-mill effluent) onto the sediment reduces the oxygen content of the sediment and a black anaerobic layer rises to the sediment surface. The combination of high sulphide, low pH, and low oxygen concentrations in anaerobic sediment may cause complete defaunation. With no further input of organic material, currents carry away some of the organic material, conditions improve and a few macroinvertebrate species invade. These opportunistic species are usually small tubiculous polychaetes that are able to tolerate the conditions and take advantage of the rich organic material available. As conditions improve further and oxygen penetrates farther into the sediment, other species invade. These species, called "equilibrium" species or late succession species, include sub-surface deposit feeders whose burrowing activities result in further aeration of the sediment. Finally, these late succession species grow large, other late succession species invade, some (or all) of the opportunists drop out, and the community is indistinguishable from an undisturbed community.

Notice that the succession began when the area was invaded by relatively small, abundant, surface dwelling polychaete opportunists and ended when the area was inhabited by a suite of relatively large, rare, deep dwelling late succession species that include polychaetes, mollucs, crustaceans and echinoderms. Not only does the diversity of phyla increase but the number of foraging modes also increases, from non-selective sub-surface deposit feeders (e.g., *Capitella*) and carnivores, to suspension-feeders, omnivores, carnivores, and selective surface deposit feeders (Pearson and Rosenberg 1978).

The second part of the model describes how three important community characteristics (total number of species, total number of individuals, and total biomass) change during recovery of the community following an organic pollution event (Pearson and Rosenberg 1978; Figure 2). The total number of species increases steadily but then declines slightly because the opportunistic species tend to drop out. The total number of individuals rises very rapidly because the opportunists can be very dense but as the opportunists are replaced by late succession species the number of individuals drops quickly and eventually levels off at a relatively low number. The total biomass tends to increase steadily to a plateau usually with two peaks -- one early in the succession when opportunists are abundant and the other in the middle of succession when the greatest number of species are present in the community.

The end point of the succession is termed the "climax." This climax may only exist as an average condition on a relatively large spatial scale because frequent disturbances will prevent all parts of the habitat from reaching the climax state at the same time (Sousa 1984). The habitat will appear spatially heterogenous, i.e., many small patches at different stages of succession will be scattered in the large climax community.

The successional patterns described here also occur in space (Figure 1B). As one proceeds from a point source of organic pollution one will find in turn: an afaunal area, an area dominated by surface dwelling polychaetes, an area where there is a mixture of opportunistic and late succession species (transitional), and finally an area dominated by late succession species. This spatial pattern has been studied more than the temporal pattern (e.g., Pearson 1975, Swartz et al. 1986).

An important aspect of this model is that the composition of the early and late communities are quite predictable. The opportunistic species that invade during the initial stages of recovery from enrichment are distributed world-wide and the composition of the community they form is usually very similar from place to place (Pearson and Rosenberg 1978). It is therefore predictable. The late succession species that form the community during the final stage of recovery are more locally distributed and the "normal" communities they form differ from site to site depending on the habitat and the faunal region. However, the composition of these "normal" communities is predictable from undisturbed areas nearby. Only the transitional community is unpredictable. This is because both the recruitment of the late succession species and the elimination of the opportunistic species is unpredictable.

Another important aspect of this succession is that a large number of species at a site does not indicate a recovered community. Actually a fully recovered site has fewer species, fewer individuals and less biomass than a partially recovered site! It will probably have the following characteristics: the anaerobic layer will be deep, several phyla will be present and several feeding modes will be present. However, a site can be considered to have fully recovered only when it is structurally and functionally indistinguishable from undisturbed reference sites.

## B) Recovery times

I reviewed 42 papers that dealt with the recovery of invertebrate communities in soft bottom habitats (Table 1). Recovery criteria were not always the same (see Section 4.2.1); in this section I adopt the terminology of each author, i.e., if the author determined that the area had not recovered then I repeat that it had not recovered. In general, the recovery times varied with the type and scale of the disturbance.

a. Non-organic disturbances

A few papers dealt with the recovery of invertebrate communities after they were disturbed by animals. These disturbances tended to be on a relatively small scale -- even the excavations made by the gray whales are usually less than $50m^2$ in size (Oliver and Slattery 1985). Recovery of these communities was relatively rapid -- some recovery had occurred in just a few days and in most cases full recovery was expected to occur within one year.

Recovery of the community occurred relatively quickly in other small scale disturbances, e.g., experimentally defaunated areas (e.g., Zajac and Whitlatch 1982a). Most authors attributed this to the small size of the experimentally disturbed area.

Recovery from other more extensive natural disturbances, such as following a red tide and a hurricane, were slower -- recovery had not been completed after more than two years in either case (Dauer and Simon 1976, Boesch et al. 1976).

None of these disturbances is similar to that created by oil spills, i.e., these disturbances do not involve the addition of organic material to the sediment surface.

b. Anthropogenic pollution

Organic pollution and oil pollution have been described as similar -- both forms of pollution are frequently extensive and affect the sediment and its inhabitants in similar ways (Glémarec 1986). Several papers dealt with the recovery of invertebrate communities following an organic pollution event (Table 1). Most commonly the authors reported that recovery was not complete, but recovery was found in one case (Rosenberg 1976).

Rosenberg (1976) monitored the subtidal benthic community in the Saltkallefjord before and after a paper mill stopped dumping organic material. He found that recovery of the community was slowest in the most polluted sites; after approximately six years these sites had partially recovered -- they had the same number of species as the less polluted sites but the species compositions were not similar. After eight years, however, the compositions of the most polluted and least polluted sites were similar, and they were similar to that recorded prior to the establishment of the paper mill, forty years earlier.

c. Oil pollution

Many papers dealt with the recovery of benthic infaunal communities after being oiled (Table 1). The scale of the oil pollution ranged from small experimental oilings to major oil spills.

The recovery of invertebrates after a small scale oiling was quite slow. Above I pointed out that recovery in small areas is usually fast, but when oil is applied to the sediment the recovery is slower. For example, in the study by Vanderhorst et al. (1980), recovery was still not complete after 16 months. Although the species lists were similar in the control and oiled sites, the abundances of the species were significantly lower in the oiled sites.

Only three of the 21 papers describing the recovery of invertebrate communities after large scale oiling found full recovery (Blaylock and Houghton 1989, Glémarec 1986, Ibanez and Dauvin 1988). The recovery times for these studies were 1.5 years, 5.5 years, and 10 years, respectively. In several cases recovery was reported to be "partial" or "close to fully recovered" and in these cases partial recovery time was also between one and ten years (e.g., Dauvin 1987). More typically the researchers return to a site three to seven years after an oil spill, and determine that recovery still has not occurred (e.g., Thomas 1977).

I suspect that insufficient time has been allowed for full recovery to occur at most of these study sites and I conclude that the recovery of soft sediment invertebrate communities after an oil spill can take longer than ten years.

## HARD SUBSTRATES

### A) Succession

Succession on rocky shores has been well studied in temperate zones (e.g., Dayton 1971, Lubchenco 1983, Sousa 1984, Farrell 1991) and a general view of the process has emerged (Paine and Levin 1981). In the absence of disturbance, the competitive dominant species spreads out and occupies 100% of the space. For example, mussels are the competitive dominant on exposed Washington shores and they can form beds that cover 100% of the rock surface (Dayton 1971). Disturbance by waves, logs or starfish predation opens gaps in the beds of the competitive dominant. These gaps are relatively small, usually less than 1m$^2$ (Paine and Levin 1981). Small gaps are filled by the growth or movement of animals from the surrounding area. Large gaps are invaded by these means and by the settlement of species out of the plankton. The first settlers are usually small algal species, followed by barnacles and worms, and finally by the dominant large algae and/or mussels. Thus a succession generally occurs, but this succesion is not particularly predictable -- the rates at which species invade depend upon the presence of their larvae in the water column and inhibition can occur. Frequently a shoreline looks like a mozaic where gaps at different stages of succession are scattered about the matrix of the competitive dominant.

An important principle has come out of these studies -- the intermediate disturbance principle: the highest number of species is found in a system with an intermediate degree of disturbance (Paine 1966, Connell 1978). If the combined disturbance from all sources (e.g., predation, wave action) is low, then the system becomes dominated by the competitive dominant and its attendant species (i.e., a relatively low number). If the combined disturbance is high, then few opportunities arise for most species to recruit successfully -- therefore the total number of species is again low. Only when the combined disturbance is intermediate do conditions favour a large number of species. This pattern is usually studied in space but is also observed in the recovery of invertebrate communities after a disturbance (Connell 1978). In this respect recovery on hard sediments is similar to that in soft sediments -- the greatest number of species occur before full recovery. Therefore, again, the presence of a large number of species does not indicate that a site has recovered.

An important feature of the studies that have led to these generalizations about succession on rocky shores is that the disturbances examined are unlike oil pollution -- the gaps are relatively small and organic enrichment is rarely involved. However, Southward and Southward (1978) found that the general sequence of recolonization after the Torrey Canyon oil spill was similar to that described above for small-scale experiments where the rocks were scraped clean.

## B) Recovery times

I reviewed 17 papers that dealt with the recovery of invertebrate communities on hard substrates (Table 1). Recovery criteria were not always the same (see Section 4.2.1); in this section , as above, I adopt the terminology of each author, i.e., if the author determined that the area had not recovered then I repeat that it had not recovered.

a. Non-organic disturbances

A few papers in Table 1 deal with the recovery of rocky shore invertebrate communities after non-organic disturbances. Recovery was relatively common and rapid -- between 1.75 years and 5.5 years (e.g., Paine and Levin 1981).

Boulder beaches are common in Alaska and the recovery of the communities on boulder beaches is therefore of special interest. In a series of experimental studies of succession on boulder beaches Sousa (1979a, 1979b, 1980) showed that the recovery of early successional assemblages takes approximately 5 months, middle successional assemblages 2.5 years, and late successional assemblages a minimum of 4 years.

However, it must be remembered that these disturbances are not similar to oil spills because they are relatively small and do not involve the addition of toxic organic material.

b. Oil pollution

Many papers have dealt with the recovery of rocky shore invertebrate communities after oiling (Table 1). In general, recovery was common and occurred relatively quickly (five years or less) after small and medium sized oil spills, but recovery was less common and occurred relatively slowly after large spills (even after ten years a site may not be fully recovered).

Southward and Southward (1978) noted that "heavily oiled places that received repeated application of dispersants have taken nine to ten years and may not be completely normal yet." Thomas (1978) found that, seven years after an oil spill, the oiled communities still did not resemble the unoiled communities. The fucoid algae (e.g., *Fucus*), in particular, were slow to recover.

## CONCLUSIONS

- **Most of the studies report that recovery did not occur.** Recovery occurred in only 35% of the studies (Table 2). This means that either: recovery was going to occur in all cases but the assessment of recovery was conducted too early, i.e. prior to recovery (Teal 1990, Harding 1990); or recovery was not going to occur in all cases because the systems were irreparably damaged and will never recover to their pre-disturbance conditions.

- **Recovery was more likely after a small disturbance than after a large disturbance.** Recovery was reported in 65% of the studies following a small disturbance, 38% of the studies following a medium disturbance, and in only 18% of the studies following a large disturbance (Table 2). This suggests that recovery times are relatively fast after a small disturbance but slow after a large disturbance.

- **Recovery was more likely after a non-oiling disturbance than after an oiling disturbance.** Recovery was reported in 46% of the stuidies following a non-oiling disturbance and in only 26% of the studies following an oiling disturbance (Table 2). This suggests that recovery times are relatively fast after a non-oiling disturbance but slow after an oiling disturbance. One reason for these trends is that oil persists longer than other disturbances (e.g., sewage); Ganning et al. (1984) estimated that the minimum residence time of oil on mud flats was 10 years.

- **Recovery was more likely after oiling of hard substrates than after oiling of soft substrates.** Recovery was reported in 45% of the studies of oiling of hard substrates and in only 17% of the studies of oiling of soft substrates (Table 2). Again, this suggests that recovery times are relatively fast on hard substrates but slow in soft substrates.

- **One can estimate recovery time by using the rule of thumb: recovery time is at least as long as the maximum age of the organisms killed.** For instance, if a mussel bed consisting of 1 to 20 year old mussels, is destroyed then it will take at least 20 years to recover. This provides only a rough estimate of the recovery time because some species are slow to recruit new individuals, particularly if the disturbed area is large and the source of colonists is far away (Sousa 1984). Also, if the disturbance is the result of an oil spill, residual hydrocarbons can reduce the fertility of the surviving adults. For example, oiled individuals of the the barnacle *Pollicipes polymerus* brooded fewer young than unoiled individuals (Straughan 1972). However, this rule of thumb provides a useful rough estimate of the recovery time.

- **The review of this literature by Baker et al. (1990) was inadequate.** Exxon Corporation biologists reviewed the literature on recovery of cold water marine environments after oil spills (Baker et al. 1990). Their paper covers the same topics as ours -- it includes a section on the benthic environment and a table (their Table 7) which is much like our Table 1. When a comparison is made of the two tables it is obvious that theirs is short of some important references -- the relatively long-term studies of soft sediments that found that recovery was not complete (e.g., Elmgren et al. 1983, Sanders 1978, Sanders et al. 1980, Thomas 1977, Dauvin 1987). In addition, in some cases, they chose to present the rosiest picture. For example, Southward and Southward (1978) state that "lightly oiled, wave-beaten rocks that received light dispersant treatment showed the most complete return to normal, taking about 5-8 years; heavily oiled places that received repeated application of dispersants have taken 9-10 years and may not be completely normal yet." Baker et al. (1990) describe these results in their table as "good recovery after 2 years." It is clear that the research of Baker, Clark, Kingston and Jenkins must be read with some skeptism.

### 3.1.2 Effects of Abiotic Factors on Recovery

Because recovery was completed in so few of the studies, it is extremely difficult to make correlations between abiotic factors and recovery times. However, drawing on the data and observations presented in the papers, I conclude that four abiotic factors influence recovery.

## NATURE OF THE OIL SPILL

In general, the severity of the oil spill and the areal extent of the oil spill will affect the recovery time; high concentrations of oil will kill more of the resident species, making recovery slower, and large areas to be recolonized will also slow recovery (Straughan 1972, Southward and Southward 1978, Sanders et al. 1980, Sousa 1984).

## HABITAT

Recovery is faster on rocky shores than soft sediments (Vandermeulen 1977, Table 2). The main reason for this appears to be the lingering effects of oil. The time taken for oil to disperse after an oil spill depends on the water flow in the habitat. Ganning et al. (1984) reported that the estimated minimum residence time of oil spilled in the following habitats was: 6 months on rocky shores, 4 years on sandy shores, and 10 years on mud flats. Factors that promote oil retention are weak tidal action, weak currents and fine sediments (Vandermeulen 1977, Gundlach 1987). Although recovery starts as soon as organisms can tolerate the conditions, which is well before all the oil has dissappeared, it appears that the residual hydrocarbons retard the recovery of the invertebrate communities by taking up space, by killing individuals, and by reducing their reproductive output (Southward and Southward 1978).

The effects of the oil spill may be delayed up to three years after the spill and are difficult to demonstrate. Conan (1982) gives two examples: was the death of all the intertidal individuals of the species *Tellina fabula* (a clam) several months after an oil spill due to oil? Also was the poor recruitment of *Tellina fabula* and *Donax vittatus* for the two years following a spill due to oil?

The disturbance level in the habitat will also influence the recovery time because a frequently disturbed habitat will have younger adults than an infrequently disturbed habitat. For instance, intertidal boulders are frequently disturbed by large waves that cause the boulders to roll over and thereby crush or smother the organisms growing on them (Sousa 1979a, b); stable rocky shores are also affected by the large waves but less so (Dayton 1971). Thus stands of old organisms are rare on boulder beaches but common on stable rocky shores. One would therefore predict that recovery would be faster on boulders than on stable rocky shores.

## TIDAL HEIGHT

Position in the intertidal zone is important to the recovery of the community after a disturbance -- mid-tidal communities recover more quickly than high-tidal communities (e.g., Farrell 1991). Describing the recovery of the intertidal communities five years after the Arrow oil spill, Thomas (1977) stated that "recolonization has proceeded from lower to higher levels but has not yet occurred in the high tide zone." Position in the intertidal zone is also important to the natural self-cleaning of stranded oil -- oil stranded half-way up the shore is removed more quickly than oil stranded at the top of the shore (Vandermeulen 1977, Thomas 1977, and 1978). It is likely that the recovery of the high intertidal species is naturally slower than that of the mid-tidal species and that oil stranded in the high intertidal zone slows the process still further.

TEMPERATURE

Cool temperatures slow biological processes. Oil is more persistent at high latitudes than at low latitudes because photochemical and microbial degradation occur more slowly in colder temperatures and diminished light (Roberts 1989). Cold water organisms are longer lived and have longer generation times than their warm water counterparts (Roberts 1989). Also, cold water organisms tend to have lower fecundity and slower growth rates (Southward and Southward 1978). Recovery of invertebrate communities is therefore expected to proceed more slowly at high latitudes (Dunbar 1968, Southward and Southward 1978, Clarke 1979).

### 3.1.3 Dependency of Recovery on Habitat Protection, Changes in Management Practices, and Other Restoration Approaches

THE CLEAN-UP

Stranded oil disperses very slowly and so cleaning up as much of the stranded oil as possible is an important first step on the road to recovery of the system. However, many of the methods used to clean-up oil spills appear to be more harmful than the oil itself For instance, in 1967 after the Torrey Canyon spill off England, 10,000 tons of toxic dispersants (also called detergents) were used in the cleaning operations, and most of the invertebrate mortalities could be attributed to the dispersants rather than the oil (Southward and Southward 1978). More recently hot water has been used to clean oiled shores, but hot water also kills many organisms (Broman et al. 1983, Houghton et al. 1991).

These studies show that the short-term effects of the cleaning are detrimental but they do not evaluate the long-term effects, i.e., the recovery of the habitats. However, I predict that recovery will be slower in cleaned areas because, in general, very large clearings take longer to recover than patches that have some of the original inhabitants intact (Sousa 1984, Smith and Brumsickle 1989).

Thomas (1978) agreed that some clean-up methods on rocky shores do more harm than good, but suggested that clean-up of oil from soft sediments would promote recovery. He stated that "if clean-up methods for lagoons could be improved so that oil could be removed without sediment penetration or disturbance, clean-up should help to minimize oil pollution effects" (Thomas 1978).

BIOREMEDIATION

In bioremediation a nitrogen-phosphorus fertilizer is sprayed onto the stranded oil. This fertilizer provides extra nutrients for naturally occurring micro-organisms (i.e., bacteria and fungi) that break down oil. This technique, long employed against toxic wastes, can more than double the speed of oil removal (EPA 1990). The micro-organisms feed on the oil and leave behind asphalt hydrocarbons that are unsightly but not toxic. One problem with this approach is that bacteria may not be active below the top few inches of soft sediments. Another problem is that micro-organisms are relatively slow to break-down oil in cold marine habitats (Cretney et al. 1978, Atlas et al. 1978). The first large-scale use of bioremediation took place in Prince William Sound during 1989 as a series of experiments. The preliminary results of the experiments look promising (EPA 1990), but the effects on long-term recovery of the communities are not known.

## RESTORATION

Given sufficient time, full recovery after an oil spill is likely to occur naturally. It will probably take a long time in areas that were heavily oiled, heavily oiled and destructively cleaned, where the sediments are soft, and/or where the disturbance was extensive (see Section 3.1.2). In order to speed recovery, managers will want to consider restoration options.

One option is to do nothing. Teal (1990) advises against active restoration. He states that it is best to leave the area alone after picking up as much oil as possible. He believes that we know so little about the ecosystems we are trying to restore that we could do more harm than good.

Another option is to transplant species into the disturbed sites. Species' recovery rates will depend on life-history characteristics and tolerance of oil. The species that have larvae in the plankton all, or most, of the year will recruit quickly into large disturbed spaces. On the other hand, the species whose larvae are rarely found in the plankton or whose larvae have extremely short-range dispersal, will recruit slowly into the same patches. Examples of species with short-range dispersal are soft corals (Gerrodette 1981), amphipods (Cabioch 1980), some *Octopus* (Hochberg and Fields 1980), many of the snails in the order Neogastropoda (Abbott and Haderlie 1980), and several species of algae (Dayton 1973, Paine 1979, Sousa 1984). Most of these propagules disperse less than 2m from the adult. Recruitment of such species to disturbed patches will correlate with the abundance of propagule-releasing adults in the immediate vicinity of the clearing. Thus the recolonization of large bare areas by these types of species will take a very long time. These short-range dispersal species would be the most likely to benefit from transplantation. Short-range dispersal is also more common in the Arctic than in temperate waters (Thorson 1950).

The alga, *Fucus*, is a short-range dispersal species that is an important species on hard substrates in Alaska -- it is common and provides cover and food for many invertebrate species. The recovery of *Fucus* may well determine the pattern of recovery for the community as a whole. To speed the recovery of *Fucus*, particularly in large disturbed areas, managers may consider transplanting plants into the area.

Unfortunately there is little information on how to conduct the restoration of marine communities. The restoration of kelp beds in southern California may provide an example for the restoration of the damaged ecosystems in Alaska. *Macrocystis pyrifera*, the giant kelp, forms the main component of southern California's kelp forests. Although an adult plant produces millions of spores, and although the spores and gametes are planktivorous, colonization of disturbed areas can be slow. Population declines of this species around sewer outfalls and power plants, and during warm water years, have stimulated many attempts at restoration (see Foster and Schiel 1985 for review). Transplants have been made of three stages in the life-cycle of the plant -- adult sporophytes, juvenile sporophytes and microscopic sporophytes. Most restoration attempts using these methods have not had suitable controls, so their success rates are difficult to determine (Foster and Schiel 1985). However, *Macrocystis* has returned to some of the transplanted areas.

I recommend that care be taken to not damage the areas from which the transplants are taken. In addition, I recommend that any major restoration project begin with an experimental phase so that the success rates of different methods can be evaluated. This will help rule out techniques that don't work and will help identify promising approaches that can be developed further (see PERL 1990). This research will provide valuable information on restoration techniques (a subject about which little is known) as well as further our knowledge of the Alaskan ecosystems. All major projects should be continually evaluated with a long-term monitoring program that will allow managers to take advantage of unforeseen benefits and to address unexpected problems quickly.

## 4.0 EXTRAPOLATION TO THE INJURED ALASKAN ECOSYSTEM

### 4.1 Identification of Most Practical and Cost Effective Indicators of Recovery to Measure

Indicator species have been used extensively in pollution studies. Indicator species are those species which, by their presence and abundance, provide some indication of the prevailing environmental conditions. The best indicator species are those that have narrow and specific environmental tolerances, because they will show a marked response to quite small changes in environmental quality (Abel 1989).

However, indicator species provide only a general overview of the approximate position of the community in the successional process, i.e., whether the community is generally in the early or the late successional stage. What is needed to determine whether recovery has occurred is an extensive study that includes all of the macroinvertebrate species. Only then can one be sure of one's conclusions. See below for details.

### 4.2 Recommended Approach to Determine When Recovery has Occurred

#### 4.2.1 Definition of recovery

It is important that in a study of recovery that one state one's objectives clearly and define what one will or will not accept as a fully recovered ecosystem. The objectives will guide the entire project, including the sampling design, statistical tests and conclusions. Without clear objectives, the work will end up with a poorly directed sampling design and weak conclusions.

If one's objective is to determine whether an area has fully recovered from an oil spill then one must define what one will accept as recovered. Most of the researchers in Table 1 did not explicitly define recovery but their implicit definition was:

- "the return of all population densities to pre-disturbance levels or undisturbed levels."

However, there are many other possible definitions of recovery.

- American Heritage Dictionary (1973): "return to a normal condition; the getting back of something lost."

- Ganning et al. (1984): "the restoration to original functional and structural conditions with original species present in original numbers."

- Ganning et al. (1984): "returning the ecosystem to within the limits of natural variability."

- Lewis (1982): "complete recovery (has occurred when) there are no discernable after-effects."

- Boesch et al. (1987): "complete recovery is the time required for a disturbed community to exhibit variation that is within the bounds of variation seen in undisturbed, control areas."

- Conan (1982): "a new stable age distribution and equilibrium species assemblages attained".

- National Research Council (1975; page 91): "Complete recovery means that (1) the faunal and floral constituents that were present before the oil spill are again present and (2) they have their full complement of constituent age classes."

- Committee on Restoration of Aquatic Ecosystems, National Research Council (in press) " the return of an ecosytem to a close approximation of its condition prior to disturbance."

None of these definitions is completely satisfactory. They give a general description of the term but few specifics. I suggest the following definition of recovery -- it is a combination of the definitions:

- Boland (this report): "Complete recovery after an oil spill occurs when (1) all the species that were present before the oil spill are again present; (2) each of these species has reached their original abundances and biomasses, (3) each of these species has reached their original age distributions, and (4) all individuals are as healthy (as measured by growth rates) and productive (as measured by reproductive condition) as the individuals that were present at the time of the oil spill." In the absence of pre-spill data, original conditions should be estimated from several unoiled communities in similar physical/chemical environments. good

Prespill data on species abundances, biomasses, age distributions, growth rates and reproductive conditions are necessary for determining when recovery has occurred; however these data are usually unavailable. In these cases, studies of many unoiled sites must be conducted instead. These unoiled sites should be chosen carefully and should include all the habitats that were oiled. All the appropriate data should be collected in the unoiled sites soon after the oil spill and used as the baseline data representing the prespill conditions in the oiled sites. ?

Therefore, when one is testing for recovery one is testing the hypotheses that there are no significant differences in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that our definition, like those above, focuses on the structure of the community rather than its functioning. Too little is known about the functioning of marine communities to include it in the definition. One hopes that when the structure returns the functioning will return too. However, also notice that the recovered community does not have to be identical to the undisturbed community, only not statistically different from the undisturbed community.

Our definition of recovery is based upon that used by many researchers and the dictionary definition. However, the biologists working for The Exxon Corporation have recently proposed a different definition of recovery and this is:

- Baker et al. (1990): "the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and functioning normally. It may not have the same composition or age structure as that which was present before the damage, and will continue to show further change and development." This definition is very different to all the others outlined above in that it will consider a community recovered when it is only on the road to recovery. This is unacceptable. For instance, using this definition one may consider a mussel bed to have recovered if the rocks are completely covered with healthy opportunistic species such as green algae.

The difference between the definitions of Baker et al. (1990) and the others can be illustrated in an analogy. Say a train jumped the tracks and destroyed my house. The railroad company apologized and agreed to rebuild the house. After six months, the rubble has been removed, the new foundations have been laid and the workmen are starting to erect the wooden frame. Someone using Baker et al.'s definition would be impressed with the progress and probably state that "recovery has occurred!" But a house on the road to being built cannot be lived in; it is neither structurally nor functionally the same as a completed house. The other definitions of recovery require that further work be done on the house and only when it is completed will it be considered to have "recovered." In the same way, a community is recovered not when it is on the road to recovery but when it is fully recovered, i.e., structurally and functionally the same as it was before the disturbance.

The defintion of recovery of Baker et al. (1990) leads them to estimate recovery times that are relatively fast. "Rocky shores usually recover in 2 to 3 years. Other shorelines show substantial recovery in 1 to 5 years with the exception of sheltered, highly productive shores (e.g., salt marshes), which may take 10 years or more to recover." In subtidal sand and mud systems "recovery times are 1 to 5 years, but they can be 10 years or longer in exceptional cases" (Baker et al. 1990). Our literature survey suggests that recovery times are longer than these, and in general, these numbers should be doubled to obtain true estimates of recovery times (Section 3.1.1).

In conclusion, the definition of recovery is an extremely important part of the study.

### 4.2.2. Methods

We are testing the hypotheses that there is no significant difference in (1) the species that are present in oiled and unoiled areas; (2) the abundances and biomasses of the species in oiled and unoiled areas; (3) the age distributions of the species in oiled and unoiled areas; and (4) the growth rates and reproductive condition of individuals in oiled and unoiled areas.

Notice that no mention has been made of the summarizing statistics like species diversity, total number of species, total biomass or total number of individuals -- as we have seen in Section 3.1.1, these numbers cannot be used to show when recovery has occurred. Also, notice that identifications need to be made to the species level. Some research has shown that little information is lost when identifications are made to the family level (Warwick 1988) but this applies to only some analyses, and too little is known about the Alaskan invertebrates to support this view.

Sanders et al. (1980) critized past research on recovery by saying that they arrived at "conclusions that are, at best, equivocal interpretations of insufficient and ambiguous data. Such inadequacies are usual in many pollution-related studies of benthic ecology, including those in which important decisions are based."

None of the papers cited in Table 1 provides a good example of how to conduct a recovery study. It is clear that if a study is to stand up to scrutiny it will have to be a careful and thorough study planned by competant statisticians and biologists familiar with the Alaskan ecosystem. Many books and papers describe appropriate sampling programs and methods to be used for studying marine benthos (e.g., Green 1979, Gauch 1982, Holme and McIntyre 1984, Mead 1988, Underwood 1981, Hurlbert 1984, Stewart-Oaten et al. 1986, Gray et al. 1988, Krebs 1989, PERL 1990), and these sources should be consulted.

Natural communities are spatially heterogenous. This means (1) that it is necessary to study many sites nearby that were not oiled and many sites within the oiled area so that the range of natural variability can be determined (Mann 1978, Ganning et al. 1984), (2) that a large area should be covered at each site, and (3) that a large number of samples are required for reliable estimates of population densities. Even to estimate population densities to within 20-40% of their true value may require several hundred samples at each site (Abel 1989). Because communities change with depth, a useful design is the stratified random sampling inwhich one blocks with depth (Gray et al. 1988).

### 4.2.3. Results

All the results that are necessary and sufficient to test the hypotheses should be presented. Frequently researchers collect a lot of information but report only diversity. Some also report, total biomass and total abundance, but very rarely do papers go beyond these summarizing statistics and describe the abundances of individual species. This is a weakness because, as we have seen above (Figure 2), "climax" communities do not have the greatest number of species, biomasses, or individuals. Also, these summarizing statistics cannot be used to test the hypotheses.

Details about "important species" (e.g., those that are numerically dominant, provide much of the structure to the community, or play an important role in the dynamics of the system) should also be presented. An analysis of the recovery of the community therefore requires a detailed knowledge of the functioning of the community.

### 4.2.4. Conclusions

Finally, the conclusions should be clearly presented.

THE UNIVERSITY OF NORTH CAROLINA
AT
CHAPEL HILL

RECEIVED
NOV 08 1991
OIL SPILL OFFICE

Institute of Marine Sciences
919/726-6841
FAX: 919-726-2426

The University of North Carolina at Chapel Hill
3407 Arendell Street
Morehead City, North Carolina 28557

# TELECOPY TRANSMITTAL FORM

To: John A. Strand

Location: U.S. Dept. Commerce, NOAA, Office of Oil Spill Damage Assessment and Restoration, Auke Bay, AK 99821

FAX No.: (907) 789-6608

From: Dr. Charles H. Peterson

FAX No.: (919) 726-2426

Total No. of Pages, including this page 3

Date: 8 November 1991 Time: ______ a.m. 5:10 p.m.

If you do not receive all pages, please contact our office at (919) 726-6841.

COMMENTS:

**Review of Boland Draft Report on Marine Invertebrate Recovery by Charles H. Peterson - Peer Reviewer**

---

The written report is better than the oral presentation on Nov. 5 in Anchorage. There are useful components to the written report, especially (1) the assembly of abstracts of papers describing recovery from oil and organic pollution of marine benthic communities, (2) the presentation of a suite of alternative definitions of recovery, (3) the implicit raising of several important questions about factors that may influence the rate of recovery, and (4) the partial review of the Baker et al. (1990) report.

As a guide to the literature on recovery of marine invertebrate communities, this report has several shortcomings:

(1) The review of recovery literature is grossly incomplete and highly selective. Even if one argues that recovery from oil pollution differs from recovery from natural disturbance because of the injection of organic enrichment and toxic components, the natural disturbance literature is still relevant and included in the RFP. Recovery from oil disturbance should take at least as long as recovery from disturbance that adds no toxic components and recovery sequences following natural disturbances provide valuable insight into the mechanisms, process, and rate of natural recovery processes. Furthermore, these studies of natural recovery are, in general, much more rigorous and more process-based science than the oil spill studies.

(2) Much of a vast and relevant grey literature on recovery of marine benthic communities, especially from oil-related disturbances, is overlooked. There is a large literature from the North Sea (Norway, Holland, U.K., etc.). The NRC report on drilling muds and cuttings includes numerous relevant sources. The frequent international oil spill symposium volumes represent an additional readily available source of grey literature that should be incorporated into the review.

(3) The review mentions the need to consider the demography of component species (especially the longevity and the scale of dispersal of propagules) in evaluating potential recovery rates. This is true, yet the report includes no such review of demographic parameters by taxon of marine invertebrates. This greatly limits the value of the report.

(4) The conceptual understanding of successionary mechanisms is better understood for marine rocky shore communities than for perhaps any other ecosystem. This understanding permits some well-founded predictions about the course and rate of recovery of such communities. This insight is not adequately incorporated into the report. Similarly, there is brief mention

# MEMORANDUM

# State of Alaska

**DEPARTMENT OF NATURAL RESOURCES** **DIVISION OF LAND**

**OIL SPILL PROJECT OFFICE**

TO: John Strand
NOAA/RPWG

DATE: November 19, 1991

FROM: Art Weiner [ ARW ]
Natural Resource Manager

TELEPHONE: 907/278-8012

FAX: 907/276-7178
FAXMODEM: 907/272-6683

SUBJECT: **Review of Boland Report**

The following are my comments on the Boland report following a rather hasty review of the text and my meeting notes.

1. A rather limited volume of literature was reviewed. Gray literature on oil spills should have been considered.
2. Substrate manipulation experimental work should have been reviewed to some extent.

3. Review of single species recovery may have revealed some interesting information on, at least, dominant elements of the intertidal fauna, e.g. *Fucus*.

4. Review of the literature describing recovery of temperate and sub-arctic intertidal communities from *non-organic* disturbance might have been useful.

5. There is a relevant and growing literature on bioremediation. There are several reports and journal articles that reported on the effects of this technique on EVOS that were not reviewed.

6. The report missed the *Pentec* study and its bibliography that contains a number of relevant citations.

7. There is a literature on the effects of the 1964 Alaska earthquake on the EVOS affected area. There may be papers on the recovery of the intertidal community from this earthquake.

8. There is a literature on various treatment technologies and their effects on the intertidal community impacted by oil spills, e.g. Pentec study.

9. There is no differentiation between intertidal and subtidal effects in the table.

10. The inclusion and discussion of recovery definitions is most helpful.

RECEIVED
NOV 19 1991
OIL SPILL OFFICE

11/19/91

Post-It™ brand fax transmittal memo 7671 | # of pages ▸ 1

| To JOHN STRAND | From ART WEINER |
|---|---|
| Co. NOAA/RPWG | Co. DNR/RPWG |
| Dept. | Phone # 278-8012 |
| Fax # 789-6608 | Fax # 276-7178 |

of the (rather more speculative) literature on soft-sediment succession but this literature is not then used to develop the needed predictions of recovery rates.

(5) The efforts to address the influences of various abiotic and biotic factors on recovery rates are not sufficiently complete. In particular, water depth (tidal elevation), sediment type (cobble vs. sand vs. mud), energy regime, and community type (sessile bivalves, etc. vs. gastropod-dominated on rocky shores; suspension feeders vs. deposit feeders on soft bottoms) should be evaluated in the review of potential influences or the rate of community recovery.

(6) A more comprehensive review of the Baker et al. (1990) report would have been useful.

I do not mean to imply by my inclusion of six major issues in this review of the draft report that all these concerns should be addressed in revision. The adequate attention to all these issues would involve a major additional effort, doubtless in excess of funds remaining on the contract.