OCS Study
MMS 2003-075

Species-level identification of infaunal samples and the relationship between taxonomic aggregation and the Before-After/Control-Impact Paired Series assessment design

Final Technical Summary

Final Study Report

MMS
U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

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FINAL TECHNICAL SUMMARY

STUDY TITLE: Detecting Ecological Impacts: Effects of Taxonomic Aggregation in the Before-After/Control-Impact Paired Series Design

REPORT TITLE: Species-level identification of infaunal samples and the relationship between taxonomic aggregation and the Before-After/Control-Impact Paired Series assessment design

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PROJECT MANAGER: Russell J. Schmitt

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KEY WORDS: Santa Barbara Channel; produced water; infauna, taxonomy; BACIPS; assessment design; statistical power

BACKGROUND: Traditional studies of environmental impacts are notoriously expensive, due in part, to the cost of species-level identification in systems that are extremely speciose (e.g., as exemplified by infaunal marine communities). However, less expensive studies using higher taxonomic levels of identification (e.g., family or class) are typically chided as inadequate. Such criticism is often unsubstantiated: e.g., Carney (1996) concluded that studies of the effects of taxonomic aggregation are critically needed

before we can best design future assessments. Importantly, any critical evaluation must occur in the context of an appropriate design. For example, previous attempts to address this issue (e.g., Ferraro and Cole 1992) have been based on simple, Control-Impact designs that confound spatial variation driven by other processes with the effects of the anthropogenic activity being studied (Osenberg and Schmitt 1996). Instead, we require an evaluation of taxonomic aggregation in the context of a sampling design that can reliably separate a putative impact from other sources of temporal and spatial variability. Therefore, effects of taxonomic aggregation should be explored in the context of the Before-After/Control-Impact Paired Series assessment design (Stewart-Oaten et al. 1986; Schmitt and Osenberg 1996).

OBJECTIVES: Our main objective was to obtain species-level identification of organisms that were archived in previously collected MMS/UC SCEI samples (a portion of these samples formed the basis of the previous analyses of produced water by Osenberg et al. 1992a,b, 1994, 1996). We also aimed to obtain data on size-frequency distributions, which could prove to be a more sensitive indicator of environmental impacts (e.g., Osenberg et al. 1996). Finally, we updated the taxonomic designations for another comprehensive dataset collected for a study of the effects of a nuclear power plant so that all datasets used an identical taxonomic scheme and could therefore be analyzed similarly. We selected these previous studies because they offered the opportunities to examine taxonomic aggregation in the context of BACIPS assessment designs. Finally, we had hoped to conduct analyses of these data, but the species-level identification took significantly more time and resources than anticipated (further highlighting a limitation of species level data). As a result, we are making the resulting data available to the scientific community via the internet (e.g., on the web page for the UCSB led Long Term Ecological Research program) to facilitate subsequent analyses (e.g., to quantify the effect of taxonomic pooling on the error variance in BACIPS designs and thus the power of assessment studies). While the species level identifications were being completed, we also continued our application of BACIPS to new environmental contexts, including the design of MPAs and the study of artificial reefs.

DESCRIPTION: Scientifically based policy decisions are often difficult to make given the uncertainty associated with the documentation of environmental impacts. This uncertainty has at least two key sources: (i) the extreme expense of doing field assessments (which typically require species-level identification, which therefore limits the number of studies that can be adequately funded), and (ii) the application of inappropriate assessment designs. Species-level identification is costly in time and money and requires the work of a few highly trained specialists. Such detailed taxonomic resolution may not be necessary. Indeed high statistical power might be achieved even with studies using crude levels of taxonomic resolution. Unfortunately, most studies of the effects of taxonomic resolution have relied on ineffective assessment designs. In contrast to these commonly used designs, the Before-After/Control-Impact Paired Series (BACIPS) design is more likely to be able to separate effects of a perturbation from other sources of spatial and temporal variation in environmental parameters (Stewart-Oaten et al. 1986, Osenberg and Schmitt 1996). However, to date, there has been little study of the effects of taxonomic aggregation (i.e., the effect of identifying organisms to differ levels of taxonomic resolution) within the context of BACIPS assessment designs.

In a BACIPS design, the efficacy of taxonomic aggregation will depend on the pattern of temporal and spatial variation in density as well as the covariance (in space and time) of species that are pooled into higher units and their relative abundance. It has been argued that pooling could reduce error variance and thus increase power of a statistical test of an impact (e.g., Carney 1996). This could occur if species negatively covary in their responses to natural processes that drive spatial and temporal variation. However, this assertion ignores the sensitivity of different species to the impact. If species within a pooled taxonomic group exhibit opposite responses to the impact (e.g., some increase in abundance while other decrease), as suggested by the assumption about their response to natural processes, then pooling is likely to inhibit the detection of impacts by reducing the "strength of the signal". The overall effect of taxonomic pooling (or resolution) can only be assessed by simultaneous consideration of species' responses to natural variation and to the putative impact.

It is vital that these more sophisticated analyses based on a BACIPS assessment design be conducted. The results not only have important implications for the management of produced water discharge, but may also fundamentally change the way in which field assessments are conducted. In these times of limited finances, it is vital that scientifically defensible decisions be made with regard to the allocation of funds among competing needs. Enormous expenditures on species-level identification might be a poor use of funds (if it adds little to the power of an assessment); on the other hand, using crude levels of taxonomic resolution might yield a large number of equivocal studies (if higher resolution is necessary to document the impacts). Answers to these issues require a comparison of the effect of taxonomic resolution in the context of a BACIPS design. This requires species-level identification of organisms sampled in a BACIPS design, and subsequent exploration of the effects of taxonomic aggregation on the statistical inferences derived from the BACIPS design.

STUDY RESULTS: Our project produced detailed databases that includes high level taxonomic resolution on over 250,000 organisms collected in four different sampling schemes as part of previous MMS-sponsored studies: 1) infaunal cores collected at 20 different sites representing a gradient of distances from a produced water discharge in Carpenteria, California; 2) infaunal cores collected at three study sites near and far from a proposed produced water outfall near Gaviota, California; 3) emergence traps deployed at these same three sites near Gaviota, and used to sample infauna as they emerged from bottom sediments during the night; and 4) re-entry traps used to sample infauna as they returned to the sediments at night. Between 54 and 86% of all organisms were identified to the species level, depending on the study (Table 1). Overall, only 12.1% of organisms could not be identified to at least the genus level.

Table 1. Summary of sampling results in which organisms in each of four different studies were identified to the lowest possible taxonomic level (i.e., to Phylum, Class, Order, Family, Genus, or Species).

Site:	CARPENTERIA	GAVIOTA	GAVIOTA	GAVIOTA	TOTAL
Sample type:	Infaunal cores	Infaunal cores	Emergence traps	Re-entry traps	
total number of organisms identified:	124,101	104,317	16,010	6,287	250,715
Percent identified to Genus or Species:	93.3%	84.7%	66.4%	87.7%	87.9%
Percent identified to Species:	86.2%	69.8%	54.4%	77.4%	77.1%

In addition to the creation of the species-level databases, we also trained students, disseminated the results of the MMS/SCEI program to other scientists, and extended the BACIPS design to coastal resource management, in particular the assessment of marine reserves and artificial reefs. We presented the application of the BACIPS sampling design and analytical framework, which is the focus of our MMS project, at numerous scientific venues. Many of these talks discussed the application of BACIPS in evaluating the effectiveness of marine reserves and artificial reef programs for management of coastal resources. The theoretical framework developed in the context of artificial reefs also has relevance to the recent discussion of the "rigs-to-reef" programs, which is of considerable interest to MMS.

SIGNIFICANT CONCLUSIONS: The BACIPS design continues to be underutilized in environmental assessments. For example, we have found that no studies of artificial reefs and marine protected areas have used a properly executed BACIPS and thus are unable to unequivocally separate effects of these activities from other sources of variation. The same continues to hold for the study of taxonomic aggregation, where conclusions have been based on incomplete designs, such as the Control-Impact and the Before-After designs. To this end, we have 1) extended the application of the BACIPS assessment design to new contexts; and 2) completed an extensive database giving species-level identification for previously collected MMS samples. Over 250,000 organisms were individually identified and counted to generate four different databases that provide spatial, temporal, and spatiotemporal variation in densities of infauna. These databases are being made available to the public in the hope that they will facilitate future analysis of the effects of taxonomic aggregation in the context of BACIPS assessment designs.

STUDY PRODUCTS:

1) *Talks at national and international meetings that directly benefited from MMS/SCEI support (e.g., and highlighted SCEI projects or the BACIPS assessment design):*

Carr, M.H. Evaluating the effectiveness of marine reserves. California and the World Ocean '02 Conference, Santa Barbara, CA, October 2002.

Carr, M.H. Science and Marine Protected Areas. Federal Marine Protected Areas Education Workshop, Morro Bay, CA, September, 2002.

Carr, M.H. Science and Marine Reserves. United States Commission on Marine Policy – Monterey, CA, April, 2002.

Carr, M.H. The Ecological Basis of the Design and Evaluation of Marine Reserves. Fisherman's Forum on Marine Protected Areas, sponsored by the Pacific Marine Conservation Council – Portland, OR, January, 2002.

Osenberg, C.W., C.M. St. Mary, and B. Bolker. 2002. Assessing the efficacy of ecosystem management and marine reserves: the need for new approaches. The Fourth Mote International Symposium in Fisheries Ecology: *Confronting Tradeoffs in the Ecosystem Approach to Fisheries Management*, Sarasota, Florida, November 2002.

Osenberg, C.W. and C.M. St. Mary. 2002. Marine reserves: a tentative and cautionary evaluation of a powerful tool. Annual meeting of the Florida Chapter of the American Fisheries Society. Brooksville, FL. February 2002 (invited).

Osenberg, C.W. 2002. Marine protected areas: a critique of current assessment approaches. International Workshop: *Restoring and Sustaining Diversity of Tropical Pacific Coral Reef Fish*. Mo'orea, French Polynesia. April 2002 (invited).

Carr, M.H. and C. Syms. Evaluating the Effectiveness of MPAs: The Whys and Hows. Invited Plenary talk for the Fisheries, Oceanography and Society Symposium Series presented by the Ocean Life Institute of the Woods Hole Oceanographic Institute. Woods Hole, Mass. August, 2001.

Carr, M.H. and C. Syms. Natural Science and Marine Protected Areas: Moving Forward. Invited Plenary talk for the Pacific Marine Protected Areas Science and Coordination Workshop convened by the NOAA Marine Protected Areas Science Institute – Monterey, CA, August, 2001.

Carr, M.H. and C. Syms. Setting Conservation Targets in a Changing World: Evaluating Effectiveness of MPAs. Building Linkages for Marine Protected Areas in North America II: A Workshop of the North American Marine Protected Areas Network. NOAA Marine Protected Areas Science Institute – Monterey, May, 2001.

Carr, M.H. Science and the Design and Evaluation of Marine Reserves. Invited talk to the Alliance for Communities of Sustainable Fisheries – Monterey, CA, November, 2001.

Wilson, J.A., C.W. Osenberg, C.M. St. Mary, C.A. Watson, and W.J. Lindberg. 2001. Artificial reefs, the attraction-production issue, and density-dependence in coral reef fishes. Larry McEdward Memorial Symposium. Gainesville, FL. December 2001. (invited)

Wilson, J.A., C.W. Osenberg, C.M. St. Mary, C.A. Watson, and W.J. Lindberg. Artificial reefs, the attraction-production issue, and density-dependence in coral reef fishes. Annual meeting of the American Society of Ichthyologists and Herpetologists, La Paz, Mexico, June 2000.

Carr, M.H., P. Raimondi, C. Syms. 1999. Effectiveness of Marine Reserve: Approaches to Evaluation and Need for Adaptive Management. Invited

Symposium talk at the 80th Annual Meeting of the Western Society of Naturalists. Monterey, CA, December, 1999.

Carr, M.H. Sustainable Ecosystems, Fisheries and Marine Protected Areas" Invited Speaker, National Research Council (NRC), Ocean Studies Board. Committee on the Evaluation, Design and Monitoring of Marine Reserves and Protected Areas in the United States. Monterey, CA, May, 1999.

Osenberg, C.W., C.M. St. Mary, J.A. Wilson, and W.J. Lindberg. A quantitative framework to evaluate the attraction-production controversy, with application to marine ornamental fisheries. Seventh International Conference on Artificial Reefs and Related Aquatic Habitats. Sanremo, Italy, October 1999.

Osenberg, C.W., C.M. St. Mary, W.J. Lindberg, and T.K. Frazer. Marine reserves: implications of stage-structured fish populations and density dependence. Annual meeting of the Ecological Society of America, Spokane, Washington, August 1999.

Osenberg, C.W., C.M. St. Mary, W.J. Lindberg, and T.K. Frazer. The application of ecological models to the design of marine reserves: what are the effects of population stage-structure and density dependence? Florida Ecological and Evolutionary Symposium, Achbold Biological Station, Lake Placid, FL, April 1999. (invited by graduate student organizers)

Wilson, J.A., C.W. Osenberg, C.M. St. Mary, C.A. Watson, and W.J. Lindberg. Artificial reefs, the attraction-production issue, and density-dependence in marine ornamental fishes. First International Conference on Marine Ornamentals. Kailua - Kona, Hawaii, November 1999.

Lindberg, W.J., C.M. St. Mary, T.K. Frazer, and C.W. Osenberg. Marine reserves, complex life histories, and the meaning of essential fish habitat: the importance of closing the life cycle. The Second Mote International Symposium in Fisheries Ecology: *Essential Fish Habitat and Marine Reserves*, Sarasota, Florida, November 1998.

Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, C.M. St. Mary, and T.W.-M. Fan. Effects of produced water on mussel growth and production: application of the BACIPS design. 27th Benthological Ecology Meetings, Melbourne, Florida, March 1998.

2) *Invited seminars that included data or approaches developed in MMS/SCEI projects.*

Carr, M.H.

- Monterey Institute of International Studies, Monterey, CA, March 2003.

Holbrook, S.J.

- (previously reported in Reed and Holbrook Final Report).

Osenberg, C.W:

- Bodega Marine Laboratory, Bodega Bay, CA, Jan 2002
- Department of Biology, University of California, Santa Cruz, March 2002.
- Department of Zoology, University of Florida, September 2002.

- Ecology & Evolution Seminar Series, University of California, Davis, CA, Jan 2002
- National Marine Fisheries Service (Northwest Fisheries Science Center), Seattle, WA, May 2002
- Department of Zoology, University of Washington, Seattle, March 2001 (Invited as the first W.T. Edmondson Memorial lecturer).
- Department of Ecology and Environmental Science, Umeå University, Sweden, March 2000.
- Department of Zoology, University of Florida, September 1998.
- Department of Wildlife Ecology and Conservation, University of Florida, March 1997.

3) *Invited participation in workshops that benefited from MMS/SCEI projects (e.g., the application of BACIPS to environmental assessments).*

Annual workshop of the UC Toxic Substances Research and Teaching Program (Coastal Toxicology Component). Bodega Marine Laboratory, September, 2002. (Holbrook, Osenberg).

Restoring and Sustaining Diversity of Tropical Pacific Coral Reef Fish. Mo'orea, French Polynesia. April 2002 (Holbrook, Osenberg).

Springs Coast Technical Advisory Meeting, Southwest Florida Water Management District. Crystal River, FL. January 2002. (Osenberg)

Steinhatchee Reef Ecosystem Workshop. Steinhatchee, FL, November, 2002. (Osenberg)

Annual symposium of the UC Toxic Substances Research and Teaching Program. Tahoe, California. April, 2001 (Holbrook, Osenberg).

Development of an integrated research plan for analyzing the viability of a marine reserve network in the Bahamas. Lee Stocking Island, Bahamas. December 2000 (Osenberg).

Annual workshop of the UC Toxic Substances Research and Teaching Program (Coastal Toxicology Component). Bodega Marine Laboratory, September, 1999. (Holbrook, Osenberg).

Southwest Florida Water Management District assembly concerning *Ecological effects of nutrient loading along the Gulf coast of Florida*. Crystal River, Florida, May 1998. (Osenberg)

Florida Big Bend coastal research workshop: toward a scientific basis for ecosystem management. Sponsored by Florida Sea Grant, UF Department of Fisheries and Aquatic Sciences, USGS (Florida Caribbean Science Center), and Suwannee River Water Management District. Steinhatchee, Florida, May 1997. (Osenberg)

4) *Publications and technical reports for research that directly benefited from MMS/SCEI support (e.g., and highlighted SCEI projects or the environmental assessment designs):*

Carr, M.H., M.V. McGinnis, G.E. Forrester, J. Harding and P.T. Raimondi Consequences of Alternative Decommissioning Options To Reef Fish Assemblages and Implications for Decommissioning Policy. MMS OCS

Study 2003-0XX. Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, California. MMS Cooperative Agreement Number 14-35-0001-30758. 140 pages.

Osenberg, C.W., C.M. St. Mary, J.A. Wilson, and W.J. Lindberg. 2002. A quantitative framework to evaluate the attraction-production controversy, with application to marine ornamental fisheries. ICES Journal of Marine Science 59S:212-219.

Syms, C. and M. H. Carr. 2001. Marine protected areas: evaluating MPA effectiveness in an uncertain world. (30 pp.) Available at Marinet: North American Commission for Environmental Cooperation site: http://www.orchestrabycrossdraw.com/30/Posting.cfm?2B07183C303E151A01097F505D546A

Wilson, J.A., C.W. Osenberg, C.M. St. Mary, C.A. Watson, and W.J. Lindberg. 2001. Artificial reefs, the attraction-production issue, and density dependence in marine ornamental fishes. Aquarium Sciences and Conservation 3:95-105.

Osenberg, C.W., O. Sarnelle, S.D. Cooper, and R.D. Holt. 1999. Resolving ecological questions through meta-analysis: goals, metrics and models. Ecology 80:1105-1117.

5) *New Funding Stimulated by MMS support:*

Florida Sea Grant Program: "Pilot studies to assess the use of artificial reefs in marine ornamental fisheries" (C.W. Osenberg, C. St. Mary). $6,000. [This was seed money to initiate the above project, based on the application of BACIPS to artificial reefs]

National Sea Grant Program: "Fisheries habitat: a field assessment of the effects of artificial reefs and its role in fisheries management" (C.W. Osenberg, C. St. Mary and B. Bolker). $294,088. [This is a novel application of BACIPS to artificial reefs]

6) *Other Significant Accomplishments*:

SCEI projects and the BACIPS design are highlighted in lectures in several courses taught at UCSB, UCSC and UF.

UCSB:

Fall 1998	EEMB 595P	Graduate seminar in Coastal Toxicology
Fall 1999	EEMB 595P	Graduate seminar in Coastal Toxicology
Fall 2000	EEMB 595P	Graduate seminar in Coastal Toxicology
Fall 2001	EEMB 595P	Graduate seminar in Coastal Toxicology

UCSC:

Spring 1999	Biol 80-M	Conservation in the Sea
Spring 2000	Biol 80-M	Conservation in the Sea
Spring 2001	Biol 80-M	Conservation in the Sea
Spring 2002	Biol 80-M	Conservation in the Sea

UF:

Spring 1998	Zoo 6927/5205	Quantitative Methods and Ecological Inference
Spring 1998	Zoo 6927/4884	Topics in Quantitative Methods
Fall 1999	PCB 4044C	General Ecology
Fall 2000	Zoo 6927	Integrative Principles I
Spring 2001	PCB 4044C	General Ecology
Fall 2001	Zoo 6927	Integrative Principles I
Fall 2002	Zoo 6927/0503	Quantitative Methods and Ecological Inference
Fall 2002	Zoo 6927	Integrative Principles
Spring 2003	PCB 4044C	General Ecology

FINAL STUDY REPORT

Motivation

Traditional studies of environmental impacts are notoriously expensive, due in part, to the cost of species-level identification in systems that are extremely speciose (e.g., as exemplified by infaunal marine communities). However, less expensive studies using higher taxonomic levels of identification (e.g., family or class) are typically chided as inadequate. Such criticism is often unsubstantiated and in a recent review, Carney (1996) has concluded that studies of the effects of taxonomic aggregation are critically needed before we can best design future assessments. Importantly, any critical evaluation must occur in the context of an appropriate design. For example, previous attempts to address this issue (e.g., Ferraro and Cole 1992) have been based on simple designs that are unsuitable for the detection of environmental impacts (Osenberg and Schmitt 1996). Instead, we require an evaluation of taxonomic aggregation in the context of a sampling design that can reliably separate a putative impact from other sources of temporal and spatial variability. Therefore, we will evaluate the effects of taxonomic aggregation using the Before-After-Control-Impact Paired Series (BACIPS) assessment design (Stewart-Oaten et al. 1986).

In a BACIPS design, the efficacy of taxonomic aggregation will depend on the pattern of temporal and spatial variation in density as well as the covariance (in space and time) of species that are pooled into higher units and their relative abundance. It has been argued that pooling could reduce error variance and thus increase power of a statistical test of an impact (e.g., Carney 1996). This could occur if species negatively covary in their responses to natural processes that drive spatial and temporal variation. However, this assertion ignores the sensitivity of different species to the impact. If species within a pooled taxonomic group exhibit opposite responses to the impact (e.g., some increase in abundance while other decrease), as suggested by the assumption about their response to natural processes, then pooling is likely to inhibit the detection of impacts by reducing the "strength of the signal". The overall effect of taxonomic pooling (or resolution) can only be assessed by simultaneous consideration of species' responses to natural variation and to the putative impact.

Previous studies of taxonomic aggregation

The ability of a study to detect impacts of anthropogenic activities is often evaluated in the context of statistical power (e.g., Ferraro and Cole 1990, Osenberg et al. 1994). The power of any test of an environmental impact is simultaneously constrained by (i) the variability of the data, (ii) the magnitude of the putative impact and (iii) the number of independent sampling events. However, the meaning of these components will vary depending on the assessment design being applied. The effect of taxonomic aggregation will also depend on the assessment design, because it will depend on the patterns of spatial and temporal variation in the densities of units that comprise the higher taxonomic levels and how the chosen assessment design uses different sources of variation.

Table 1. Sources of variance considered in some previous studies of taxonomic aggregation of macrobenthos data. When explicit statistical models were not stated, they were inferred by the form of data presentation. When multiple types of comparisons were conducted in a single paper, they are distinguished by a) and b). 'Error' indicates the variance component used as the error term, and 'Effect' indicates the source used to estimate of the size of the effect.

Source	Sample (within site or among subsites within regions)	Among sites (Control, Impact)	Time (within Periods)	Period (Before, After)	Site x Time	Site x Period
Previous Analyses:						
Ferraro and Cole (1990)	b) Error	a) Effect b) Effect	a) Error			
Ferraro and Cole (1992)	Error	Effect				
Ferraro and Cole (1995)	Error	Effect				
Heip et al. (1988)	Error	Effect				
Herman and Heip (1988)	Error	Effect				
James et al. (1995)	Error	Effect				
Marchant et al. (1995)	Error	Effect				
Warwick (1988a)	b) Error	b) Effect	a) Error	a) Effect		
Warwick (1988b)	Error	Effect				
Wright et al. (1995)	Error	Effect				
Analyses Based on BACIPS Design (no published studies)					Error	Effect

Effects of taxonomic aggregation on the detection of anthropogenic impacts on the macrobenthos has been explored in a number of previous studies (Ferraro and Cole 1990, 1992, 1995, Herman and Heipp 1988, James et al. 1995, Marchant et al. 1995, Warwick 1988a, b, Wright et al. 1995). However, these studies have focused almost exclusively on *spatial* variation (Table 1: see also Frost et al. 1992 for an example of temporal variation). Thus, these studies examine the ability to detect the difference in infaunal density between two sites amid within site spatial variability in density. These studies have typically shown that aggregation has little effect on the patterns revealed at the species level. There are several problems with the general approach that has been applied in many of these studies: (1) it assumes that the anthropogenic activity is the only factor producing between-site differences in density; (2) as a result, it assumes that the within site spatial variation is the only source of error that obscures the detection of the impact (i.e., that the within site variation can be used as an error term in a test of the difference between two sites); (3) it often relies on qualitative assessment of the resulting patterns, or lacks quantitative estimates of the magnitude of variation and the magnitude of the impact; and (4) most of the studies have focused on community measures (such as species diversity), which may have little value in impact assessment (Carney 1996)

The first two problems are directly related to the application of a "Control-Impact" assessment design (i.e., comparison of a Control and Impact site after an intervention has occurred). The Control-Impact design is predicated on the tenuous assumption that there are no other sources of large-scale spatial variation: i.e., that the difference between a Control site and Impact site is due only to the effects of the impact. Such an assumption is unlikely to be satisfied (Underwood 1991, Osenberg and Schmitt 1996); no two sites (even two that are very "similar" and unaffected by an activity) will have identical densities. Likewise, application of a Before-After design (sampling at an Impact site Before and After an intervention), can confound some sources of temporal variation with the impact (Osenberg and Schmitt 1996, Stewart-Oaten 1996a,b). In contrast, the BACIPS design explicitly accounts for many sources of spatial and temporal variation, and uses different sources of variation to isolate the effect of an anthropogenic activity from background variation (Table 1). Unfortunately, there are no existing studies that examine the effect of taxonomic aggregation on the ability to detect environmental impacts using the BACIPS design. This information vacuum is particularly troublesome because the BACIPS design is the most powerful field assessment tool available, and its application is becoming more widespread (Schmitt and Osenberg 1996). Yet, we have virtually no information to guide the selection of taxonomic resolution in BACIPS studies.

The BACIPS design

In the basic BACIPS design, a Control and an Impact site (or multiple sites) are sampled simultaneously several times Before and After the perturbation. The metric of interest is the difference (hereafter referred to as "delta", Δ, or D for its estimate) in density (or other suitable variable) between the Control and Impact sites as estimated on each sampling date (e.g., $D_{P,i} = N_{I,P,i} - N_{C,P,i}$, where $N_{I,P,i}$ and $N_{C,P,i}$ are estimates of the parameter at the Control and Impact sites on the i^{th} date of Period P: i.e., Before or After). The average delta in the Before period ($D_{P\bullet}$) is an estimate of the spatial variation between the two sites (Δ_B),which provides an estimate of the expected delta that should exist in the After period in the absence of an environmental impact. The difference between the average Before and After deltas ($D_{B\bullet}$-$D_{A\bullet}$) provides a measure of the magnitude of the environmental impact. Confidence in this estimate is determined by the variance in deltas (among sampling dates within a period, s^2_D), as well as the number of sampling dates (i.e., replicates) in each of the Before and After periods ($n_B + n_A = n$).

For the purposes of this study, we follow the convention of Osenberg et al. (1994) and define

$$\text{Effect Size: } E = D_{B\bullet} - D_{A\bullet} \quad (1)$$

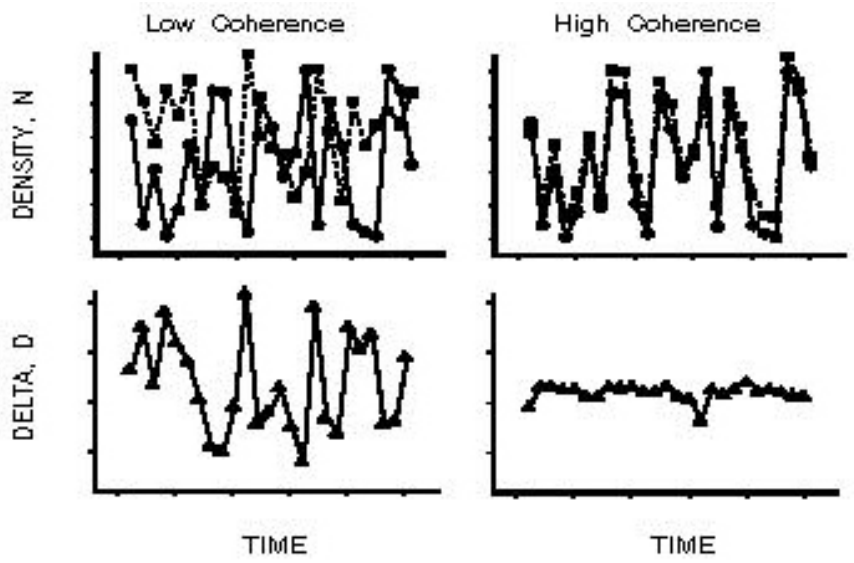
$$\text{Variability: } s^2_P = [\Sigma(D_{P,i} - D_{P\bullet})^2] / (n_P - 1) \quad (2)$$

In calculations of statistical power (Cohen 1977, Osenberg et al. 1994), the effect size should be standardized by dividing by the standard deviation of deltas (which can be averaged between the two periods, to yield s_D):

$$\text{Standardized Effect Size} = E_s = | D_{B\bullet} - D_{A\bullet} | / (2s_D) \quad (3)$$

We double the standard deviation in the denominator of Equation 3 based on the assumption that the resulting test will be two-tailed (Gill 1978).

Figure 1. Patterns of spatial and temporal variation in population densities that lead to high and low variation in deltas. Simulated data (top panels) are from two pairs of sites. In both panels temporal variation in density (at a site) and the average difference between the sites are similar. The panels differ in the degree to which the estimated densities at the paired sites track one another through time. On the left, poor tracking (i.e., low coherence: Magnuson *et al*. 1990) leads to a low correlation between densities at the two sites (r=-0.25), while on the right, good tracking (i.e., high coherence) leads to a stronger correlation in densities (r=0.98). The bottom graphs show the resulting differences in density (deltas). Low temporal coherence leads to high variability in deltas and thus low statistical power, while high coherence leads to low variability and higher power. From Osenberg et al. (1996).

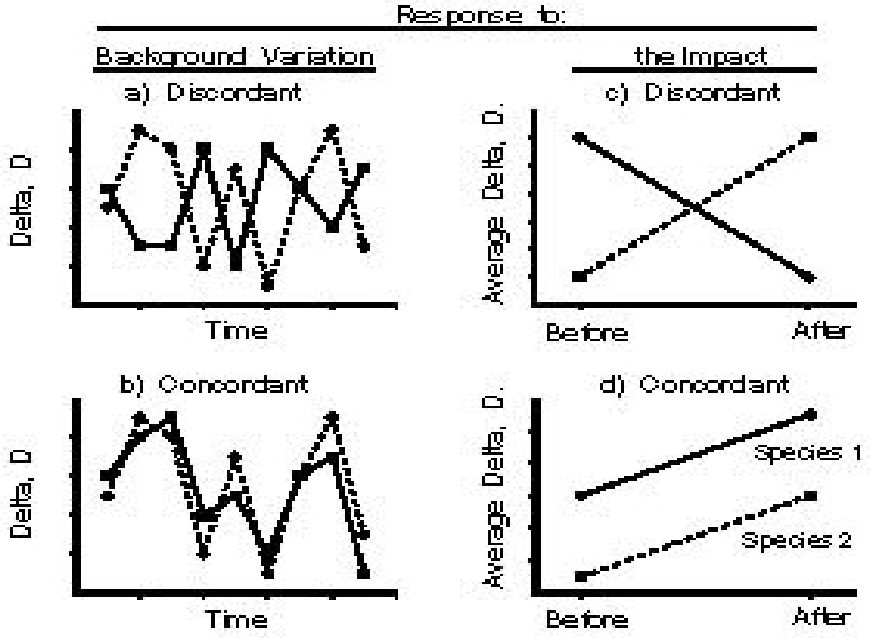


Thus, the two main sources of variation in a BACIPS design are quite different from those used in other designs (e.g., Table 1). First, the estimate of an effect is derived from the Period x Location term, which indicates how much the density at the Impact site (*relative* to the Control site) changes from the Before to After periods (i.e., $D_{B\bullet} - D_{A\bullet}$). Second, the error component measures how much the difference between the densities at the Control and Impact sites vary when there is no change in the intervention. Other designs focus on the within site variation in density (Control-Impact design) or temporal variation in density (Before-After design). By taking the differences in density, the BACIPS design accounts for the effects of many sources of spatial and temporal variation, and thus does not confound them with effects of the intervention (Stewart-Oaten et al. 1986, Stewart-Oaten 1996a,b). To highlight these distinctions, we have illustrated how variability of deltas (s^2_D) can be altered without any change in the temporal or spatial variability of a parameter (e.g., density), or in the amount of within-site sampling error (Figure 1). The critical feature in determining the variability of deltas is the extent to which estimates of parameters at the two sites track one another though time; Magnuson *et al*. (1990) refer to this as temporal coherence.

Expected Effects of Taxonomic Aggregation

In a BACIPS design, the efficacy of taxonomic aggregation will depend on the covariance (in space and time) of the deltas (differences in density) of the species that are pooled into higher units. It will also depend upon the relative abundances of the species because the pattern of a higher unit will be most influenced by the most abundant of the lower units. It has been argued that pooling could reduce error variance and thus increase power of a statistical test of an impact (e.g., Carney 1996). This could occur if species negatively covary in their responses to natural processes that drive spatial and temporal variation (i.e., compare Figures 2a and 2b). However, this assertion ignores the sensitivity of different species to the impact. If species within a pooled taxonomic group exhibit opposite responses to the impact (e.g., some increase in abundance while other decreased), then pooling would reduce the probability of detecting the impact by reducing the "strength of the signal" (Figure 2c vs. 2d). Thus, the effect of taxonomic aggregation on power will depend on how species (within a higher taxonomic level) respond to "natural" sources of variation (i.e., sources other than the activity being studied) vs. the impact itself: e.g., concordant responses to one source need not dictate concordant responses to the other. Because the processes driving these changes can be very different, there seem to be few reasons to expect, *a priori*, aggregation to either increase (e.g., through combination of 2a and 2d) or decrease (2b and 2c) power of a statistical test. The overall effect of taxonomic pooling (or resolution) can only be assessed by simultaneous consideration of different species' responses to "natural" variation and to the putative impact. This cannot be assessed by existing studies of taxonomic aggregation because they have not considered the appropriate sources of variation.

Figure 2. Schematic illustrating responses of two species to different sources of variation: background variation, which comprises the error term, and the impact, which comprises the signal. Concordant responses to the impact (d), and discordant responses to background variation (a) facilitate detection of impacts using aggregated taxonomic units (because the error term is reduced while the signal is enhanced). Similarly, discordant responses to the impact (c) and concordant responses to background variation (b) decrease power by reducing the signal:noise ratio.



Taxonomic Aggregation and the Portfolio Analogy

Doak et al. (1998) and Tilman et al. (1998) examined the effects of species aggregation on temporal variance. Tilman's approach emphasized the portfolio theory of investment diversification. Although both papers were most interested in the relationship between species diversity and stability, the approach has direct relevance to the effects of taxonomic aggregation in BACIPS designs. Thus, we briefly review this body of work, extend it, and discuss its relevance to BACIPS.

Both models, as well as our own, make the following assumptions. First, that the abundance of each species in a community is random and independent, with all covariances equal to zero. Further the models assume that all members of the community are equally abundant, on average (i.e., $m_1=m_2=\ldots=m_k$). In the Doak et al. model and the Tilman et al. model they further assume that the total community biomass is M. Thus, for a community of k species, $m_i=M/k$. At this point, Tilman et al. argue that a general relationship between the mean, m_i, and variance, $V(m_i)$, can be modeled using $V(m_i) = cm_i^z$, where z represents the scaling between the mean and variance of a species. Tilman et al.'s also showed that the effects of statistical averaging (as represented by the degree to which the coefficient of variation of the community, $CV_{(M)}$, depends on k) are dependent on the values of z. Importantly, Doak et al. considered only the case where z=2 and found no relationship between CV and the number of species that were combined, whereas Tilman et al. argued that $1 \leq z \leq 1.5$ might be more appropriate. Indeed, with z=1, k has no effect on variability.

And that, with what they argue are more realistic values of z, $CV_{(M)}$ is independent of k. While we agree that the magnitude of statistical averaging will depend on z, the models considered by Doak et al. and Tilman et al. both rely on yet another simplifying assumption which, as we will show, affects their results. Specifically, both models assume the total biomass of the community, M, is independent of biodiversity. Thus, a monoculture will have the same mean biomass as a community consisting of several species. This is certainly not true for our problem that deals with aggregation and it is probably also not true for communities studied in the context of biodiversity-stability relationships. Therefore, we have generalized their models to include the relationship between species numbers and community biomass, such that $M=\square k^a$ and therefore, $m_i = M/k = \square k^{a-1}$. In this generalized formulation, a represents the scaling of community biomass with species numbers. For taxonomic aggregation, we are most interested in the case where a=1.

Given this generalized formulation of the model, we can now evaluate the circumstances under which the $CV_{(M)}$ is dependent or independent of k, and to what degree. In the general case, $V(m_i) = cm_i^z = c\square k^{a-1}$. Thus,

$$M = \sum_{i=1}^{k} m_i = \mu k^a \text{ and } V(M) = \sum_{i=1}^{k} V(m_i) = c\sum m_i^z = c\mu^z k^{z(a-1)+1}.$$

The coefficient of variation of the community is therefore,

$$CV_{(M)} = \frac{V(M)^{\frac{1}{2}}}{M} = \frac{(ck^{z(a-1)+1}\mu^{z})^{\frac{1}{2}}}{uk^{a}} = c^{\frac{1}{2}}\mu^{\frac{z}{2}-1}k^{\frac{z}{2}(a-1)+\frac{1}{2}-a}.$$

This is a messy formulation, but in essence we can now define the conditions under which $CV_{(M)}$ is dependent on k and to what degree by evaluating the exponent of k, namely E=z(a-1)/2 + ½ - a. The effect of diversity on stability depends on the parameters a and z, and this more general formulation includes the special cases examined by Doak et al. and Tilman et al.

Doak et al. presented the specific case of $z = 2$. In this case, E = ½., and is independent of a. Thus, $CV_{(M)} \propto k^{-0.5}$, and variability of an aggregated assemblage declines as the number of species in the assemblage increases. Tilman et al. discussed the case of a=0 and $z = 1$, and later varied z, $0 \le z \le 1$. In the first instance, $E = 1$, and thus, $CV_{(M)}$ is independent of the number of species, k. However, if $z < 1$, then $E > 0$ and thus variability increases as k increases. For example, if $z = 0.5$, then $CV_{(M)} \propto k^{+0.5}$, and thus, the averaging phenomenon (caused by aggregation) will result in greater levels of variation in more species rich communities.

In the majority of (a,z) space, $E < 0$ or $E > 0$. Generally speaking, values of $E < -0.5$ can be expected within two of four quadrants of (a,z) space, when the quadrants are defined by the lines $a = 1$ and $z = 2$. Positive values of E are associated with the other two quadrants.

For our case, being interested in aggregation in a BACIPS context, diversity is not varied. Instead, we have a particular community and we are choosing to aggregate the data in different ways. This simplifies to the case where a=1 (and assuming all species are equally represented – an assumption needed for mathematical convenience, but which can be relaxed via simulation). In this case, $CV_{(M)} \propto k^{-0.5}$, indicating that the CV will decline with aggregation: aggregation will lead to a decline in this measure of temporal variance. What effect it will have on other measures of variability (spatial or spatiotemporal) is still unknown.

Species-level identification using existing samples

Produced water

Several previous studies funded through the MMS/UC SCEI provided samples of infaunal density (e.g., projects by Osenberg et al., Schmitt and Osenberg, Carr et al.) at sites that have been (or were expected to be) subjected to produced water discharge near Carpenteria and Gaviota, California. These studies have yielded important findings about the impacts of produced water and the design of assessment studies (Osenberg et al. 1992a,b, 1994, Stewart-Oaten et al. 1992, Krause et al. 1992, Raimondi and Schmitt 1992, Krause 1994, Schmitt and Osenberg 1996). However, the studies (due to financial constraints) were limited to identifying organisms to crude taxonomic levels (e.g., Family at best, and often Class, or Order and sometimes even Phylum). At Gaviota, California, sampling at three study sites yielded 6 years (1989-1994) of infaunal samples collected in the absence of produced water (these comprise a "Before" sampling period at a proposed produced water outfall). These samples are important because they provide sufficient

sampling intensity to quantify natural spatial and temporal patterns of variation in density (e.g., 6 years, 4-12 surveys per year, from 3 sites situated .25 - 2 km from one another -- a common spatial scale for Control-Impact studies). In conjunction with the sampling of infaunal density, emergence rates of demersal zooplankton were also quantified using re-entry traps and emergence traps placed on the sediments over a 24-hour period. Environmental characteristics (e.g., sexton flux, sediment organic matter, grain size, temperature) were also recorded. A subset of the Gaviota data also were previously used to conduct a power analysis using the BACIPS design and infaunal densities of crude taxonomic groups (e.g., typically to the level of Order or Family) (Osenberg et al. 1994). These analyses suggested that information on the behavior, size and performance of individuals might yield the more powerful tests of impacts than assessments based on density (see also Carney 1987).

At Carpenteria, California, sampling was conducted at 20 sites (distributed across a 2 km transect) over a 5-year period (1990-1994) that straddled a "discharge" period and a "shut-down" period; this facility, which had discharged produced water since before 1978, went out of operation in 1992. Thus, this study provides sufficient sampling intensity to quantify shifts in the spatial patterns between the "discharge" and "shut-down" periods using the Before-After/Control-Impact Paired Series Assessment (BACIPS) design (Stewart-Oaten et al. 1986, Schmitt and Osenberg 1996). The Carpenteria data allow us to estimate the magnitude of the effect of produced water, but provide relatively few data to assess patterns of spatial and temporal variance.

Thus, the Gaviota and Carpenteria studies complement one another quite nicely -- one provides a long time series in the absence of a perturbation (to quantify background spatial and temporal variation) and the other provides an estimate of the response of taxa to produced water discharge (albeit with a more limited time series). Before this study, however, the benthic samples had only been identified to broad taxonomic levels, upon which previous analyses (e.g., Osenberg et al. 1992, 1994, 1996) were based. During this project, organisms in these samples were identified to much lower taxonomic levels, making it possible to explore the effects of taxonomic aggregation.

Power plant

The Marine Review Committee (MRC) conducted an intensive investigation of the effects of the discharge of cooling water from the San Onofre Nuclear Generating Station, SONGS (Murdoch et al. 1989). The MRC used a BACIPS design for many of their assessments (including benthos), and their data are available. The data for infauna span a period of 7 years, (3 years before operations, ~1 year during an interim operating period, and 3 years during operation), yielding a total of 59 surveys from 12 different sites. All benthic infaunal samples were identified to the species level (with a few exceptions). To make these data comparable to the Carpenteria and Gaviota datasets, we required that the species coding from these samples be standardized with the coding generated as part of the species-level identification performed on the Carpenteria and Gaviota samples. This was one of the goals of our project.

Approach taken

Samples were selected from the archived Gaviota and Carpenteria studies (Table 2) to provide a representative spatial and temporal coverage. All samples that were further analyzed were collected between 1990 and 1995 and collectively contained over 250,000 individual organisms and 800 taxonomic groups.

Table 2. Summary of samples for which species level identification was obtained.

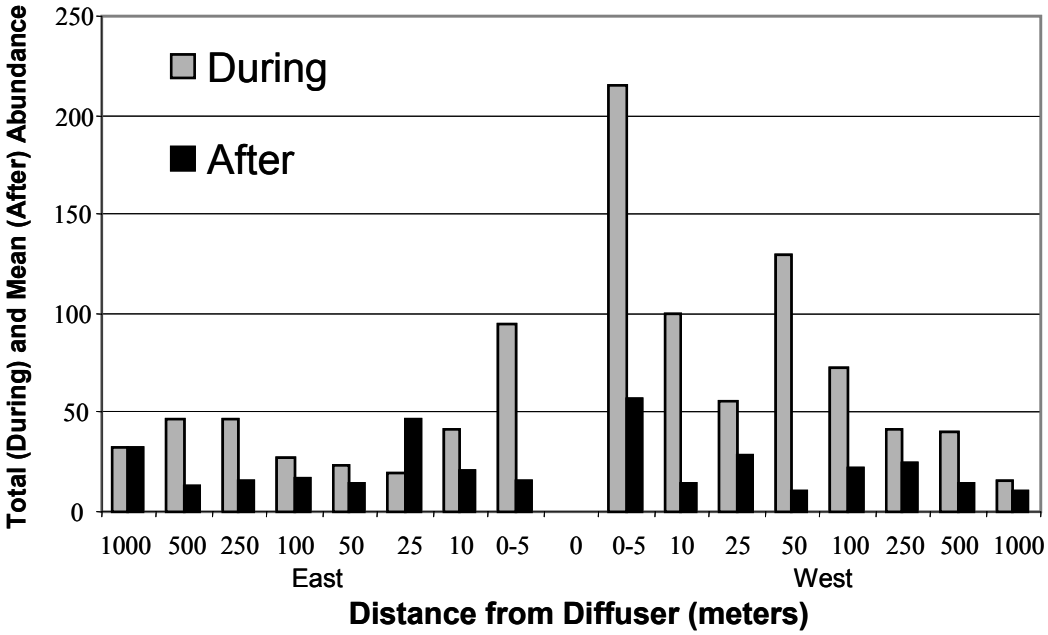
Site:	CARPENTERIA	GAVIOTA	GAVIOTA	GAVIOTA
Sample type:	Infaunal cores	Infaunal cores	Emergence traps	Re-entry traps
Earliest date	February 1990	January 1990	January 1990	January 1990
Latest date	June 1995	October 1994	October 1994	October 1994
Number of dates	9	19	19	19
Number of sites	20	3	3	3
Number of replicates per date and site	3	2 or 3	2	3
Total number of organisms	124,099	104,307	16,010	6,285

To obtain taxonomic identifications at the finest resolution possible (usually to species), we arranged a sub-contract between the University of California and Lovell Taxonomic Consultants. Gaviota and Carpenteria samples had been previously identified to crude taxonomic levels which facilitated transport of the different samples to taxonomists who specialized in different groups. Larry Lovell identified the polychaetes, Doug Deiner identified the crustaceans, and John Ljubenkov identified "other taxa" (an aggregate of a diverse set of taxa, such as sipunculids, chordates, and chaetognaths). These three taxonomists have extensive expertise with southern California marine invertebrates and were also involved in the species-level identification of the MRC samples. Two technicians at UCSB (Kristin Zabaronick and Bryn Evans) identified the molluscs following training by Paul Scott and Henry Chaney at the Santa Barbara Museum of Natural History. Paul Scott and Henry Chaney assembled a voucher collection of all mollusk species, and Lovell et al. completed one for Polychaetes, Crustaceans and Others. Problematic species identifications were double checked with other taxonomic experts that are also members of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT).

For Gaviota, species-level identification was obtained for 19 surveys (5 years, 3-4 surveys/year, 3 sites), consisting of infaunal samples, re-entry trap samples, and emergence trap samples (for all animals retained on a 0.5 mm sieve). The emergence and

re-entry traps (Alldredge and King 1980; Stretch 1983) provide estimates of migration rates of infauna. For the Carpenteria study, a total of 9 surveys were enumerated (3 surveys conducted during discharge and 6 surveys conducted after discharge was terminated; 20 sites/survey, which vary in their proximity to the diffusers [range: 3 - 1000 m upcoast and downcoast]).

Figure 3. Total and mean abundance of *Tellina carpenteri* across sample dates during discharge of produced water and after its cessation. Currents tend to flow from east to west, leading to a possible westward displacement of any impact (relative to the location of the diffuser: i.e., at "0").



Each organism was assigned a species code that indicated its identification (to the lowest possible taxonomic level). The same species codes that were established for the MRC studies were used for these samples. The codes were designed in the following manner. Each species code is an eight character alphanumeric designation. The first letter representing the group designation (P=Polychaetes, C=Crustaceans, M=Mollusc, O=Others). For the Polychaetes and Others, the next three letters represent the Family to which the species belongs. The four digit code that follows the family abbreviation that designates different groups (e.g., species) within that family. An example: *Acmira catherinae* is encoded as PPAR0001: the first 'P' is for Polychaete, 'PAR' is for the Family Paraonidae, and 0001 is an arbitrary numeric codes that indicates the genus and species (i.e., *Acmira catherinae*). For Crustaceans, the three-letter abbreviation reflects the Order, not the Family, to which the species belongs. For example: *Photis sp.* is encoded as 'CAMP0160', where 'C' indicates 'Crustacean', 'AMP' indicates the Order Amphipoda, and '0160' is the unique numeric code within Amphipoda for *Photis sp.* The Molluscs' letter codes indicate Class (MGAS= Gastropoda, MPEL= Pelecypoda (or Bivalva)). All codes ending in 0000, are for individuals in the appropropriate higher taxonomic level (e.g., Family for Crustacea or Class for Mollusca) that could not be identified beyond the Family level. For example: 'ONEM0000' indicates Nemerteans that could not be further identified. Species occurring at Gaviota and Carpenteria that were not originally present

in the MRC list were given temporary codes for the purpose of data entry and were then reassigned permanent codes by Dr. Lovell according to the system mentioned above.

77.1% of all individuals could be identified to species; only 12.1% could not be identified to at least the genus level. Species codes and counts for each sample were recorded on datasheets and transferred to UCSB where data were entered into electronic spreadsheets indicating the species code, the count within each sample (or subsample), the date, the site, and the person who identified the organisms.

The taxonomists also went through the MRC list of species and updated them based on taxonomic information available in 1997 (since some taxonomic revisions had occurred since the MRC studies of the mid-1970's). This "Taxon List" therefore contains all species codes used in the MRC and Carpenteria/Gaviota studies. The Taxon List was later expanded to include the Phylum, Class, Order, Family, Genus, Species, and when appropriate Subspecies.

The electronic databases and Taxon List were proofed and finalized by technicians at UF. The species-level identifications, data entry, and data proofing all took more time than originally budgeted. Data files are now complete and will be made available to the scientific community via the UCSB LTER web site (http://sbc.lternet.edu).

Figure 4. Example comparison of the size structure (size frequency distributions) of *Tellina carpenteri* at six distances to the west and east sides of the discharge (a) during produce water discharge, and b) after cessation of discharge at the Carpenteria study site. Sampling dates were 10 and 11 February 1990 during discharge and 13 and 14 January 1994 post-discharge. Discharge ceased in July 1992.

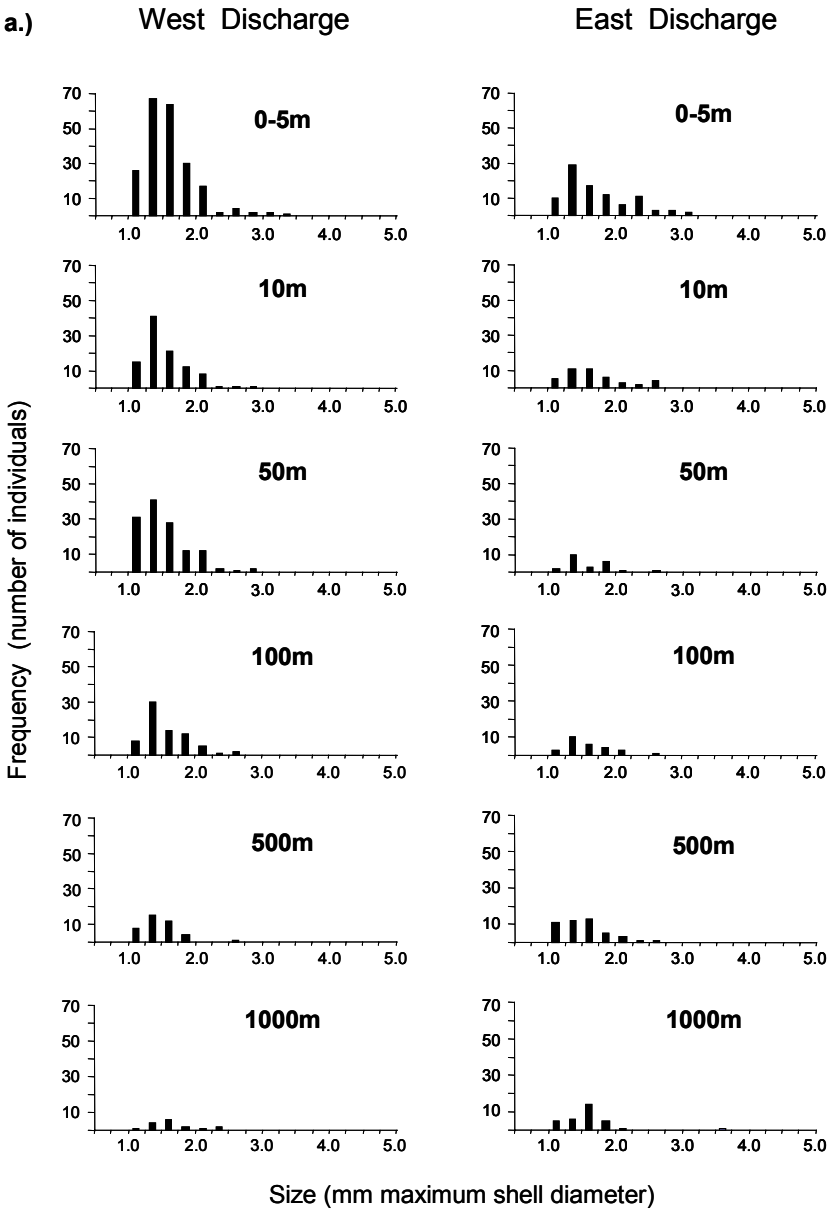
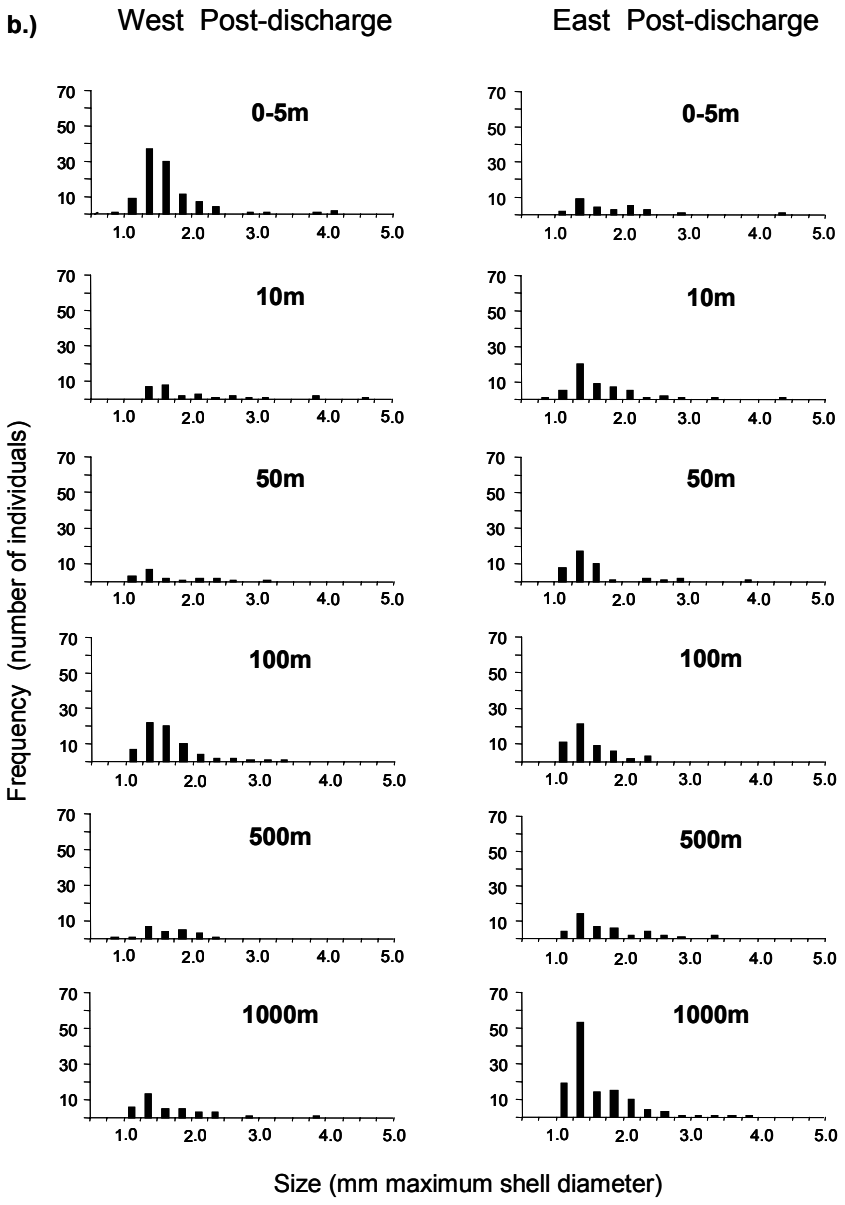


Figure 4. (continued: Panel b).



As each sample was opened and identified by the taxonomists, certain species were removed and packaged for possible analysis of body size by students working at UCSC or other interested investigators. The selected species from Gaviota consisted of *Amphideutopus oculatus, Campylaspis hartae, Levinsenia gracilis, Foxiphalus obtusidens, Nephtys cornuta, Parvilucina tenisculpta, Rochefortia tumida, Rudiderma rostratum, Spiophanes missionensis,* and Tellinidae (including a mix of species, but primarily *Tellina carpenteri*; other species included *T. bodogensis, T. modesta, T. nucloides, T. idea, Macoma carlottensis, M. yoldiformis*); the selected species from Carpenteria were *Apoprionospio pygmea, Diastylopsis tenuis, Levinsenia gracilis, Nephtys cornuta, Parasterope hulingsi, Spiophanes missionensis* and Tellinidae (see above).

Samples separate out for size-frequency analysis were then shipped to Carr's lab, where we used an image analysis system to obtain images and sizes of individuals. The system consisted of a Leica 'StereoZoom 6 Photo' dissecting scope with a Pulnix TM-&CN black and white video camera attached to a Macintosh PowerComputing computer with frame grabber and Scion Image (version 1.62) software. This system allowed video images to be captured and saved as JPG image files. Scion Image software allows image databases to be exported as Microsoft Excel files. For each image, one to several individual organisms (depending on size) were placed together with a ruler in a petri dish of 95% ethanol. Once the image was captured, the ruler was calibrated for each image and each bivalve was measured digitally along the longest axis of the valve. Length measurements are stored for each individual in the image. Because the entire process from setup to measurements was time consuming, we first captured images from many samples and subsequently recorded their lengths.

We focused the initial processing and analysis of size-structure on bivalve mollusks from biocore samples because of their abundance and ease of measuring individual size relative to more complex body forms. *Macoma yoldiformis, Parvilucina spp., Rictaxis spp., Rochefortia spp., Tellinaidae, Telliina spp.*, and *Tellina Carpenteri* were targeted for size-frequency estimation and analysis based upon their abundance and occurrence across most sample sites at Gaviota and Carpenteria. Images were collected for all of these taxa at both the Gaviota and Carpenteria study sites except for *Parvilucina* spp., *Rictaxis* spp., *Rochefortia* spp., for which images were collected for Gaviota only. Thousands of images have been recorded, and hundreds of measurements have been made. A summary file of the images and measurements available will be provided as databases (next section).

Initial comparisons of size structure were limited to *Tellina carpenteri*, because of its relatively higher abundance across sample sites and dates. During the period of produced water discharge, the abundance of *T. carpenteri* was greater near the diffuser array and tended to decline as distance from the array increased (Figure 3). Following the cessation of produced water discharge, the marked abundance pattern was greatly reduced and dissipated with time (Figure 3). Spatial and temporal changes in size-structure were less clear, but there was a tendency for larger individuals to be present at sites closer to the discharge (Figure 4a). Following the cessation of produced water discharge, this pattern was somewhat reduced if not reversed (Figure 4b).

The Databases

Four databases were generated from the species-level data on infaunal densities; one for the Carpenteria infaunal density cores, and three for the Gaviota studies (one each for the infaunal density cores, emergence traps, and re-entry traps). Information on each database is given in Appendices A-E.

Two databases were generated from the size-structure data. One database is a collection of digital images of bivalves that were recorded in the process of measuring individuals. The second database contains the size measurements recorded from the digital images.

As noted above, these databases will be available to the public via the UCSB LTER website and upon request. We especially encourage other scientists to make use of these

data in their analyses and future publications. Requests for density data should be sent to Dr. Craig Osenberg (osenberg@zoology.ufl.edu), and requests for size-frequency data should be sent to Dr. Mark Carr (carr@biology.ucsc.edu). We request that we be consulted after data acquisition and prior to publication so that we can ensure that the sampling and identification protocols are appropriately interpreted.

Samples are currently stored in the labs of Sally Holbrook (UCSB) and Mark Carr (UCSC), but we are attempting to house them more permanently at the LA County Museum.

Issues that can be addressed with the new databases

Carpenteria: BACIPS analysis
Using species-level identifications, the Carpenteria database can be used to conduct a BACIPS analysis of the environmental effects of produced water. The analysis could follow the general approach laid out in Osenberg et al. (1992a), who analyzed the data from the first "discharge" survey. Analyses could be based on log-transformed data (to better satisfy assumptions of additivity: Stewart-Oaten et al. 1986, Osenberg et al. 1994). Under this scenario, estimates of effect size would provide a common measure of proportionate change that should remove concerns about measurement scale as lower units are combined into larger groups.

Carpenteria: Effect of taxonomic aggregation on estimates of the strength of the impact
The effect of taxonomic resolution (e.g., identification to Species, Genus, Family, Order, or Class) can be evaluated by aggregating the species-level data into different taxonomic levels and repeating the BACIPS analysis.

Carpenteria and Gaviota: Effect of taxonomic aggregation on background variability
The Carpenteria and Gaviota data can be used to estimate background variability (Equation 2), which constitutes the error term in the BACIPS design. The Gaviota data set is valuable here because of its relatively long time frame (5 years of data at the species level) without an intervention. For a given sampling effort (number of surveys) these results would yield estimates of the power to detect a particular, proportionate change in density. These results can then be examined as the level of taxonomic aggregation is varied.

Individual-based metrics
Data for species-specific migration rates (the Gaviota study), and body size (the Gaviota and Carpenteria studies) can be used in analogous ways as the density estimates to look at the effects of taxonomic aggregation in BACIPS designs. The data can also be used to test the suggestion (Osenberg et al. 1994, and Carney 1987) that metrics more closely tied to individual behavior and performance might provide more powerful tests of environmental impacts.

Comparison with the MRC's study of SONGS
The MRC's study of infaunal density responses to cooling water discharge from SONGS provides one of the most complete BACIPS studies, consisting of 59 surveys of 12 sites (which vary from 0.7 to 9.4 km from the discharge) distributed over 7 years, (3 years

before operations, ~1 year during an interim operating period, and 3 years during operation). The data are available to the public and can be directly compared to the results obtained using the Carpenteria and Gaviota data.

Other forms of aggregation

Much of the interest in taxonomic aggregation lies in the belief that ecologically similar species will be affected similarly by a perturbation, and that ecologically similar species are more likely to be closely related. This expectation corresponds to that illustrated in Figure 2d. [However, similar species might also display concordant responses to other sources of variation (Figure 2a) and thus reduce power.] If the correlation between phylogeny and ecology is low, then a more powerful way to aggregate data would be at the level of functional groups rather than taxonomic units (although this would usually require identification to the species level and then pooling into higher functional units). It has also been argued that random aggregation retains much of the pattern revealed at the species level (Herman and Heip 1988). These issues can be explored by attempting different aggregation schemes, including that based on functional groups (although there is a relative dearth of detailed ecological information about many infaunal invertebrates) and random assignment. Such an approach can also be useful in isolating the causes for the observed effects of taxonomic aggregation. The pattern of covariance in density among species belonging to the same group (taxonomic or functional) can be quantified. The most critical source of this covariance is their response in relative abundance (i.e., *D*'s) through time in response to background variation and in response to the perturbation (Figure 2). Different results among different taxa (e.g., molluscs vs. crustaceans vs. polychaetes) might help isolate features that distinguish the effects of aggregation among these groups (e.g., if aggregation leads to reduced power for molluscs but increased power for polychaetes, is it because polychaetes show a more concordant response to the impact, or a more discordant response to other sources of variation).

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Appendix A: Carpenteria Infaunal Density Cores

File Contents: **Carpenteria Infaunal Density Cores** (11-Feb-90 to 20-Jun-95)
File Name: **Carbio_t.xls** (Excel 2000) or **Carbio_t.sas7bdat** (SAS v 8.02)

Variable Name	Description	Units	Options for data field
SPCODE	Species code	-	Numeric & Character (e.g., CAMP0034)
PHYLUM CLASS ORDER FAMILY GENUS SPECIES SUBSPECIES	Taxonomic classification	Character	Many…
STAGE ZOEA,	Life stage	Character	' ' (adult or not noted), LARVAE, JUVENILE, ARMS (used for *Astropecten* that were broken during collection)
DATE	Date	na	DD-MM-YY (e.g., 11-Feb-90)
TRANS	Transect direction	na	E (East) W (West)
DISTANCE	Distance	Meters	Distance W (2, 3, 5, 10, 25, 50, 100, 250, 500, 1000) Distance E (5, 7, 10, 15, 30, 55, 100, 250, 500, 1000)
REP	Replicate	-	1 or 2
SIEVE	Sieve Size	mm	2.0, 1.0, or 0.5
NUMBER	Number of species per sample	No./sample	Numeric (>0)
IDBY	Identified by	-	LL (Larry Lovell) DD (Doug Deiner) JL (John Ljubenkov) KZ (Kristin Zabaronick) BE (Bryn Evans)

Appendix B: Gaviota Infaunal Density Cores

File Contents: **Gaviota Infaunal Density Cores** (04-Jan-90 to 26-Oct-94)
File Name: **gavbio_t.xls** (Excel 2000) or **gavbio_t.sas7bdat (**SAS 8.02)

Variable Name	**Description**	**Units**	**Options for data field**
SPCODE	Species code	-	Numeric & Character (e.g., CAMP0034)
PHYLUM CLASS ORDER FAMILY GENUS SPECIES SUBSPECIES	Taxonomic classification	Character	Many…
STAGE ZOEA,	Life stage	Character	' ' (adult or not noted), LARVAE, JUVENILE, ARMS (used for *Astropecten* that were broken during collection)
DATE	Date	-	DD-MM-YY (e.g., 04-Jan-90)
SITE	Sample site	-	NI (Near Impact or Outfall) FI (Far Impact or Upcoast) C (Control Site)
REP	Replicate	-	1 or 2
SIEVE	Sieve Size	mm	2.0, 1.0, or 0.5
NUMBER	Number of species per sample	No./sample	Numeric (>0)
IDBY	Identified by	-	LL (Larry Lovell) DD (Doug Deiner) JL (John Ljubenkov) KZ (Kristin Zabaronick) BE (Bryn Evans)

Appendix C: Gaviota Emergence Traps

File Contents: **Gaviota Emergence Traps** (05-Jan-90 to 26-Oct-94)
File Name: **gavet_t.xls** (Excel 2000) or **gavet_t.sas7bdat (**SAS 8.02)

Variable Name	**Description**	**Units**	**Options for data field**
SPCODE	Species code	-	Numeric & Character (e.g., CAMP0034)
PHYLUM CLASS ORDER FAMILY GENUS SPECIES SUBSPECIES	Taxonomic classification	Character	Many…
STAGE ZOEA,	Life stage	Character	' ' (adult or not noted), LARVAE, JUVENILE, ARMS (used for *Astropecten* that were broken during collection)
DATE	Date	-	DD-MM-YY (e.g., 05-Jan-90)
SITE	Sample site	-	NI (Near Impact or Outfall) FI (Far Impact or Upcoast) C (Control Site)
REP	Replicate	-	1 or 2
SIEVE	Sieve Size	mm	2.0, 1.0, or 0.5
NUMBER	Number of species per sample	No./sample	Numeric (>0)
IDBY	Identified by	-	LL (Larry Lovell) DD (Doug Deiner) JL (John Ljubenkov) KZ (Kristin Zabaronick) BE (Bryn Evans)

Appendix D: Gaviota Re-Entry Traps

File Contents: **Gaviota Re-Entry Traps** (30-Apr-90 to 26-Oct-94)
File Name: **gavrt_t.xls** (Excel 2000) or **gavrt_t.sas7bdat (**SAS 8.02)

Variable Name	Description	Units	Options for data field
SPCODE	Species code	-	Numeric & Character (e.g., CAMP0034)
PHYLUM CLASS ORDER FAMILY GENUS SPECIES SUBSPECIES	Taxonomic classification	Character	Many…
STAGE ZOEA,	Life stage	Character	' ' (adult or not noted), LARVAE, JUVENILE, ARMS (used for *Astropecten* that were broken during collection)
DATE	Date	-	DD-MM-YY (e.g., 30-Apr-90)
MUDSITE	Collection site for sediments	-	NI (Near Impact or Outfall) FI (Far Impact or Upcoast) C (Control Site)
TRAPSITE	Site at which re-entry trap was deployed	-	NI (Near Impact or Outfall) FI (Far Impact or Upcoast) C (Control Site)
NUMBER	Number of species per sample	No./sample	Numeric (>0)
IDBY	Identified by	-	LL (Larry Lovell) DD (Doug Deiner) JL (John Ljubenkov) KZ (Kristin Zabaronick) BE (Bryn Evans)

Appendix E: Taxonomic List

File Contents: **List of Species Codes and Taxonomic Affinities**
File Name: **taxonlst.xls** (Excel 2000) or **taxonlst.sas7bdat (**SAS 8.02)

Variable Name	**Description**	**Units**	**Options for data field**
SPCODE	Species code	-	Numeric & Character (e.g., CAMP0034)
PHYLUM CLASS ORDER FAMILY GENUS SPECIES SUBSPECIES	Taxonomic classification	Character	Many…
STAGE ZOEA,	Life stage	Character	' ' (adult or not noted), LARVAE, JUVENILE, ARMS (used for *Astropecten* that were broken during collection)

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.