TECHNICAL REPORT
TO THE
CALIFORNIA COASTAL COMMISSION

E. Kelp Forest Invertebrates

MARINE REVIEW COMMITTEE, INC.

William W. Murdoch, Chairman
University of California

Byron J. Mechalas
Southern California Edison Company

Rimmon C. Fay
Pacific Bio-Marine Labs, Inc.

Prepared by:

James R. Bence
Stephen C. Schroeter
Analysts

and

Richard O. Smith
Staff Programmer

April 1989

TABLE OF CONTENTS

This page intentionally left blank.

SUMMARY

The study of large benthic invertebrates found in kelp forests began in the fall of 1980. Ten Before (preoperational) and eight After (operational) surveys were conducted at four stations. The two impact stations were approximately 500 m and 1.5 km from the diffusers, within the San Onofre kelp forest (SOK). Two stations were located far enough from the San Onofre Nuclear Generating Station (SONGS) so that impacts from the power plant were expected to be minimal. However, one of these potential control stations (Barn kelp forest = BK) was not used in our primary analyses because giant kelp declined to near zero abundance there at the beginning of the study. In addition, the substrate at our primary control (San Mateo Kelp forest = SMK) and at SOK consists of cobbles in a sand matrix, while consolidated reef predominates at BK.

Most of the species for which we were able to make a determination of SONGS' effects were gastropod mollusks, and there was a general decline in the density of these species in SOK (relative to their density in SMK) after the SONGS' Units 2 and 3 began operating. This decline was largest at the station closest to SONGS' diffusers, in the upcoast portion of San Onofre kelp forest. The most likely mechanisms underlying the observed changes are changes in habitat caused by loss of kelp and understory algae, and an increase in seston flux and sedimentation. One of the striking changes during the After period was the accumulation of relatively fine sediment with apparently cohesive properties *in situ* at the upcoast station at San Onofre. This sediment was first seen in the fall of 1985. Its spatial distribution and the timing of its appearance suggest that it may be related to the operation of SONGS Units 2 and 3 (Final Technical Report B).

This page intentionally left blank.

1. INTRODUCTION

Here we report on the effects of the operation of Units 2 and 3 of the San Onofre Nuclear Generating Station (SONGS) on populations of large benthic invertebrates in the San Onofre kelp forest (SOK). The field work was carried out by the Kelp Forest Invertebrate Project=KIP (University of Southern California). Over the course of the project, Drs. J. Kastendiek, J. Dixon and S. Schroeter acted as principal or co-principal investigators. Like most kelp forests in southern California, San Onofre contained a diverse group of plants and animals, including hundreds of species of benthic invertebrates. Among the latter were species of sport and commercial importance (e.g., abalones, lobsters, sea urchins, and sea cucumbers), and those of functional importance in structuring the kelp bed community (e.g., sea urchins and sea stars). The species composition of the large benthic invertebrates seen at SOK did not appear especially unusual in comparison with that seen in other southern California kelp beds (Dixon *et al.* 1988).

Thirty-six species of invertebrates were counted in non-trivial numbers (i.e. at least four animals ($0.1/m^2$) one time at one of the four stations). Species chosen to be counted 1) are characteristic of kelp forests in southern California, and/or 2) have been shown to influence the structure and dynamics of kelp bed communities, and 3) can be counted easily by divers in the field under conditions of relatively poor visibility. Small sessile invertebrates, which form a turf on many hard substrates (such as bryozoans, hydroids, and sponges), are difficult to reliably identify in the field and are not included as part of this study. Several larger species of sessile invertebrates were counted, however.

Of the 36 species that sometimes exceeded $0.1/m^2$, 16 were rare (as defined in section 3.12) on most surveys. In this report we evaluate the effects of SONGS on the remaining 20 species that were relatively common at the Impact stations during the Before period, along with five pooled groups of species constituting larger taxonomic groups, and thereby including the rarer species. The pooled groups analyzed were (1) all snails, (2) non-muricid snails, (3) muricid snails, (4) sea urchins, and (5) (large) sessile invertebrates. Muricids (family Muricidae) are small predatory and scavenging snails. We were able to evaluate the effects of SONGS statistically on all but one of these species groups; we could not do so for sessile invertebrates because of violations of the statistical assumptions of our procedures as discussed below in the Methods. The natural history of the kelp forest invertebrate species are reviewed in Dixon *et al.* (1988), and relevant background is included with the Results.

Of the species of sport and commercial interest [Abalones (*Haliotis* spp.), lobsters (*Panulirus interruptus*), crabs (*Cancer* spp.), and red sea urchins (*Strongylocentrotus franciscanus*)], all are harvested locally, and were therefore excluded from the analysis. With the exception of red sea urchins, all are also normally too rare to be effectively sampled on a continuing basis.

Of crucial importance to the study was the selection of the stations at which the species were monitored. Ideally, the Impact area and the Control areas to which it would be compared would differ only in the impact. Such a situation rarely exists in nature. In the vicinity of SONGS there were only three more or less persistent giant kelp forests (Final Technical Report K). Besides San Onofre, there were the San Mateo kelp forest (SMK) and the Barn kelp forest (BK) (Figure 1). Despite some differences in bottom composition and relief, we chose these latter areas as

Control stations. The use of two widely spaced Controls was intended to estimate natural variability on the scale of several kilometers. Unfortunately, the giant kelp population at BK declined to near zero during the first year of our study, and did not reestablish itself through the end of the study in 1986. The loss of this giant kelp forest may be related to a very local increase in sedimentation by sand during the 1978-1980 period (Final Technical Report K). Consequently we do not use data from this station in our primary analyses. However, qualitatively similar conclusions are reached when this station is included in our analyses (Appendix A). In addition, the substrate characteristics at our primary control more closely matched those at the impact station, consisting of cobbles in a sand matrix rather than consolidated reef as was the case at Barn kelp forest (Table 1, for further Discussion of these kelp forests see Final Technical Report K).

Two stations were established in the San Onofre kelp forest. The cooling waters from Units 2 and 3 are discharged from a series of ports upcoast from the kelp bed. The two stations were placed under the kelp canopy, one station as close to these diffuser ports as possible, and the second as far away as possible. This design was intended to provide a rough estimate of the distance over which the cooling water discharge had an effect.

The sampling design approximates the Before-After/Control-Impact-Pairs (BACIP) design discussed in Interim Technical Report 2 and by Stewart-Oaten *et al* (1986), but differs in that we had two Impact stations. Replicate samples were taken through time both Before and After Units 2 and 3 began operating. For each species or species group, the difference in density between the Control station and each of the two Impact stations was calculated for each survey. If the power plant had no effect, one would expect that the average difference between Impact and

Control stations would be the same after Units 2 and 3 began operating as before. In this report we use the test of this hypothesis to evaluate SONGS' impact on the abundance of kelp forest invertebrates.

2. FIELD METHODS

2.1 Station Locations and Configuration

The studies reported here were done in kelp forests in northern San Diego County, California (Fig. 1). Four monitoring stations were established in Fall 1980. The station nearest the Units 2 and 3 diffusers was chosen to be within the area predicted to be most affected by the operation of Units 2 and 3 (Murdoch *et al.* 1980, see Fig. 2, SOKU). A second "Impact" station was located further downcoast in the San Onofre kelp bed (SOKD). Distant Control stations were located in the San Mateo kelp forest (Figure 3, SMK), and in the Barn kelp forest (BK). As stated previously we do not use data from BK in our primary analyses.

The stations were placed in about the same depth of water (approximately 14 meters) in locations where giant kelp had been present prior to the beginning of the study. SMK was thought to be far enough away from SONGS in the upcoast direction so as not to be affected by the discharged cooling water. All stations were located on hard substrates at least 10 meters from the nearest sand plain.

Each station consisted of a surface buoy anchored by a metal plate which marked the origin of four 40-m transects (oriented at 35°, 125°, 215°, and 305°). The transects were marked with 1/4-inch steel reinforcing bar stakes. Ten permanent 1-m^2 quadrats were positioned every 4 meters along each transect.

2.2 Sampling Schedule

By May 1983, Units 2 and 3 were pumping water at rates near the levels they are expected to operate at over the long-term (but see Discussion). For the analyses presented here, the period from October 1980 through the end of April 1983 is considered to be the "Before" period. Eleven Before surveys were done during this period at two to four month intervals. Since the species that were monitored tend to be long-lived and to recruit sporadically, we thought there should be a time lag between the start of normal plant operation and the beginning of the "After" (operational) period. We therefore designated the period from the beginning of May 1983 to the beginning of October 1984 as the "Interim" period during which sampling frequency was reduced, and only two surveys were done. The period from the beginning of October 1984 to the end of December 1986 is considered the After period, during which eight quarterly surveys were done. SONGS' operating characteristics during each of these periods are presented in Table 2.

The first survey of the study was not used in our analyses because methods were still being developed and field technicians were still being trained. Data collected during the two surveys in the Interim period are also not used in the analyses presented here.

2.3 Sampling Protocol

In addition to the target species whose individuals were counted throughout the study, individuals of twelve new species of snails were counted beginning on the next to last survey during the Before period. This was possible because of the increased experience of the field crew by that time.

In order to avoid disturbing the sessile species, the quadrats were sampled non-destructively; i.e., only those animals on the surface of the substrate were counted. Animals which could escape out of the quadrat were counted first; those which crawled into the quadrat after the census began were not counted. Although it is possible (even likely) that the proportion of the invertebrates that was exposed varied seasonally, or through time for other reasons, we have no reason to expect that this proportion would change differently from the Before to After periods at the different stations. Thus, such temporal changes in behavior might decrease our power of detecting effects, but would be unlikely to produce biases.

Training dives were made before all but one survey. Training was done in SMK, which was considered the most difficult station due to the high diversity and abundance of invertebrates. Several quadrats were randomly chosen from the sampling array, and were sampled by each diver. The results were used immediately to standardize methods used by each diver during each survey. After the training dive, counts were compared to those of the field leader, sampling techniques discussed, and another set of quadrats was sampled. This was repeated two or three times, in order to ensure that all divers were sampling in the same manner.

In October 1985, patches of fine anomalous sediments were first seen. Thereafter their presence was periodically mapped in the field, and samples were collected for laboratory analysis (Final Technical Report B). The presence/absence of this new substrate type was recorded for each kelp forest invertebrate sample quadrat beginning in October 1985, the first survey on which it was noted. These sediments were distinguished from other sediments through a set of field tests described in Final Technical Report B. These field tests identified this sediment by its apparently cohesive nature (for example it could hold a divers hand print while other sediments within the kelp forest could not). The sediments identified as anomalous in the field differ from other sediments in the area. The organic content of these deposits is higher than surrounding sediments, and they are generally finer than the sands at the same depth in and around SOK (Table 3, see Final Technical

Report B). In grain size and organic content they were similar to the sediments found in 30 m depths, about 1 km offshore of the kelp forests (Table 3). The timing of their appearance (after SONGS began operating) and the location of these deposits (found primarily at the station closest to the diffusers), it seems possible that these fine deposits are related to the operations of SONGS Units 2 and 3 (Final Technical Report B).

3. ANALYSES

All programs used to do analyses, and to prepare tables and figures, are listed in flow charts in Appendix B. The programs implemented before January 1, 1988 were saved on the "report" disk of the Kelp Forest Invertebrate Project following procedures outlined in the MRC's Data Standards Document (Titan 1988). New programs implemented for this revised version of the report have been saved on a read only disk space on the University of California at Santa Barbara's mainframe computer system, and copies of all these programs will be saved on tape.

We test for an impact of SONGS' Units 2 and 3, and estimate the size of its effects, using a modification of the BACIP procedure outlined by Stewart-Oaten (1986). Basically, our approach is the same here as in the other MRC studies (Interim Technical Report 2). We calculate the "delta" (the mean difference between the density (usually log transformed) at Impact and Control stations) during periods both Before and After Units 2 and 3 became operational. We test whether, on average, the size of the deltas was different between the After period and Before periods, and we use the size of the Before to After change to estimate the percentage increase or decrease in abundance that could be attributed to the operations of SONGS Units 2 and 3.

Our implementation of the BACIP design needs to take into account some special attributes of the Kelp Forest Invertebrate Studies design. First, we have two potential Control stations, located in Barn and San Mateo kelp forests. During the design phase of this study both kelp forests were persistent, but nearly all kelp was lost from Barn kelp forest prior to the first sample date in November 1980. We therefore excluded the station in Barn kelp forest from our primary analyses, and used only the San Mateo kelp forest station as a Control. Analyses in Appendix A show that our general conclusions do not depend upon the exclusion of the Barn kelp forest data. In addition, the substrate at San Mateo kelp forest, like the substrate at San Onofre kelp forest consists of cobbles in a sand matrix, while the substrate at Barn kelp forest consists of much more consolidated reef (Table 1, see Final Technical Report K).

Just prior to the next to last survey during the After period a large moving aggregation (termed a front) of red sea urchins (*Strongylocentrotus franciscanus*) invaded a portion of SMK. Fronts of sea urchins are known to have tremendous effects on invertebrate communities (Ebert 1978), and the front in SMK probably affected the abundance of some invertebrates. We therefore exclude those impacted quadrats from our calculation of the mean density at each station during the final two surveys. Quadrats that were impinged by the sea urchin front were determined from field notes and maps made by the Kelp Forest Invertebrate Project.

In addition to multiple control stations, our design also differed from the standard BACIP by having two, rather than one, impact stations. These impact stations were approximately 500 and 1500 meters from the diffusers, and thus relatively stationary invertebrates would not necessarily experience the same magnitude of impact at the two stations. This enables us to examine not only whether the density of kelp forest invertebrates was affected by SONGS Units 2 and 3, but also whether these effects were larger at the near than at the far Impact station. One way of approaching this analysis would be to do three sets of BACIP tests. We could first compare the near Impact with the Control, then the far Impact with the Control, and finally we could use the far Impact as a Control for the near Impact. The first two comparisons would test for SONGS' impacts at each station individually. A significant result in the third comparison would indicate a difference in the size of the effect at the two impact stations. Instead of this set of three separate tests, we test for SONGS effects using a unified model. We calculate the "deltas" for each of the Impact stations using SMK as the Control. This delta vector (of length two) was then subjected to "repeated measures ANOVA" (e.g. Winer 1971) with station being a repeated (or within subject) main effect, and period (Before or After) being the other main effect. Our "subjects" here are the surveys. A main effect of period indicates that on average (across the two Impact stations) there has been a net effect of SONGS. A significant interaction between period and station indicates that the two Impact stations were affected to a different extent or in different directions. We do not report the results of tests for station effects. A main effect of station is of less interest in the context of this report, since it merely indicates that there are differences in average density at the two impact stations over the entire period of the study (and not that these differences changed after the power plant began operating).

In addition to repeated measures BACI analyses we used the BACIP t-test to compare two Control Stations (SMK and Barn) in ancillary analyses reported in Appendix A.

3.1 Details and Model Specification

3.1.1 Repeated Measures Model

Our repeated measures model can be expressed as: $\delta_{ijk} = P_i + S_j + T_k + PS(ij) + e_{ijk}$ where P is the period effect, S is the station effect, T is the time effect associated with a particular survey, PS(i,j) is the effect associated with the particular combination of period i and station j (i.e. an interaction), and e is the error term. There is some disagreement in the literature on whether it is better to analyze such "repeated measures" data using univariate or multivariate tests, however with a vector of deltas of only length two (i.e. with two Impact stations) the two methods are identical (LaTour and Miniard 1983). Thus our analysis is equivalent to a standard univariate split-plot analysis of variance, where Periods are the whole plots and surveys are the split plots (e.g. Milliken and Johnson 1984).

3.1.2 Choosing a Transformation

The validity of our repeated measures analyses (and our ancillary BACIP analyses) depends upon several assumptions, and we test for violations of the most crucial of these. Our primary assumption tests are for additivity, lack of serial correlations in the deltas, and lack of temporal trends in the deltas in the absence of an impact of SONGS. The details of these assumption tests are described in Interim Technical Report 2. Because we use data from two Impact stations in a single analysis we need a single transformation for three stations simultaneously. To implement the repeated measures test we required additivity of, and no trends in the deltas. These assumption tests were done for one Control-Impact pair of stations at a time, as described in Interim Technical Report 2. The station pairs for which we ran our assumption tests were: near Impact-Control, far Impact-Control and near Impact-Far Impact.

We started with an *a priori* expectation of a multiplicative model, and attempted to induce additivity (perhaps the most basic assumption of the analysis) by using log transformations. Because we sometimes encountered zero values and the log of zero is undefined, we needed to add a constant. We chose a constant that results in an additive model. Our first choice of a constant was 0.025, the smallest possible nonzero station mean. If this constant failed the assumption tests, we then considered sequentially larger constants, scaled by percentiles of "unimpacted abundances" (pooling Control and Impact in the Before period with the After data at Control). We considered the 1, 5, 10, 25, 50, 75, 95, and 99th percentiles, as well as the mean of the unimpacted abundances as possible constants. Because more than one constant might induce additivity and we select among these by the *a priori*, but somewhat arbitrary rule of picking the smallest satisfactory constant (i.e. one for which none of the assumption tests produced significant ($p<0.05$) results). In some cases there was no constant that passed all three assumption tests. In these cases we used the smallest constant that satisfied the additivity and no trends assumptions, even if it failed on the serial correlation test. In cases where no constant satisfied both the additivity and/or trends assumptions, we used a constant of 0.025. In this case, we present results graphically and calculate percentage changes, but do not report the results of the repeated measures test. All these assumption tests are done only on the Before data because effects of the power plant can masquerade as violations of assumptions during the After period. We note with our results cases where there was serial correlation. In cases where data are available from only two surveys in the Before period no assumption tests were done (these would have involved regressions through two data points), and the data were log $(x+0.25)$ transformed.

We present analyses for species that were chosen as follows. First, we selected those species which were present and counted at least once at one of the two Impact and at one of the two potential Control stations during at least two Before (preoperational) surveys. We also required that the species have a mean abundance, at one of the stations in the San Onofre kelp forest, of at least $0.1/m^2$ on at least one survey during the study. This is equivalent to a total of four animals at a station. The species meeting these abundance criteria are listed in Table 4.

Species were excluded from the repeated measures analysis which were absent during the entire After period at both stations of any of three possible station pairs in the primary analysis (i.e. SOKU-SMK, SOKD-SMK, SOKU-SOKD). In these cases it was still sometimes possible to estimate percent change in abundance at SOKU and/or SOKD if abundances were sometimes not zero at both SMK and the appropriate SOK station. Species for which we were able to estimate percent change for at least one impact station are indicated in Table 4. Any of the species satisfying the criteria for calculation of percent change in abundance at one or more of the SOK stations were then subjected to tests of the assumptions underlying the BACIP analysis.

In the above discussion, and in the Results we use "species" to indicate the lowest taxonomic level at which individuals were identified. In some cases several members of the same genus are included in such a category, when they were not consistently distinguished in the field.

3.1.3 Perturbations Unrelated to SONGS

During the course of our study two events occurred which were unrelated to the operation of SONGS but which could cause period by station interactions in the abundance of some echinoderm species. In 1981, and especially in 1983 and 1984, a series of epizootics similar to the episode observed in Baja California (Dungan *et al* 1982), virtually eliminated shallow water sea star populations in the southern California Bight (Tegner and Dayton 1987). Since densities of sea stars were initially more than two fold higher in SOKU than in SMK, the decline to low densities at all stations (Table 5) would lead to an estimated relative reduction at the SOKU station. A second perturbation unrelated to SONGS was the commercial harvesting of red sea urchins. Red urchins were initially more abundant at the

Control station in the San Mateo kelp forest than in the San Onofre kelp forest (Table 6). Harvesting was heaviest during the Interim period. By late 1984, fishermen could no longer find sufficiently dense populations in SOK to make harvesting economically feasible (See discussion in Final Technical Report K). However, dense populations were still found at SMK, where harvesting continued. We have not included sea stars or red urchins in our analysis because of these severe perturbations. All other species were analyzed using the repeated measures approach if they met the abundance and statistical criteria described above.

3.1.4 Statistical Power

Statistical power is the probability of detecting a significant effect when the null hypothesis of no effect is false, and a particular (specified) alternative is true. Power depends upon variability among the samples, the number of samples taken, and the particular alternative hypothesis that is specified. Power is of particular concern for the kelp forest invertebrates because many species were only sampled a few times during the Before period. We chose to evaluate the power for detecting a 50% decline in density. at the near Impact station, as detected by the Period x Station interaction in the repeated measures analysis. This is equivalent to the power of detecting a 50% reduction in density at the near Impact station relative to the far Impact station using the BACIP procedure.

3.1.5 Evidence of an Effect of the Power Plant

Our repeated measures test evaluates whether the differences between the abundance of organisms at the Control and the average of the two Impact stations changed after Units 2 and 3 began operating (the period effect), and whether the Impact - Control changes differed in size between the two Impact stations (the period x station effect). We take a statistically significant result for either of these effects as evidence that SONGS has affected the density of the organism in question. Our inference of a SONGS effect is greatly strengthened in cases where there are plausible mechanisms by which SONGS could produce the observed changes, and weakened by the existence of probable causes unrelated to SONGS.

3.2 Potential effects of anomalous sediments

During the After period there was a marked increase in anomalous sediments (see Section 2.3) at the near Impact station and surrounding areas (Table 7, see Final Technical Report B). Because changes in substrate could reasonably be expected to affect the abundance of benthic animals, the origin of the sediment and the cause of its deposition in the kelp forest immediately became topics of inquiry. It seems possible that this substrate is related to the operation of SONGS Units 2 and 3, and this a topic still under investigation as this report is being prepared (Final Technical Report B).

In the context of the kelp forest invertebrate studies there is no way to completely isolate the effects of sediments from possible effects of SONGS which are not directly related to sediments. However we were able to explore the effects of the sediments at the near Impact station by comparing "impacted" and "unimpacted" quadrats Before and After the sedimentation event using the BACIP procedure. This test should control for most potential SONGS effects unrelated to the sediments, because the quadrats are close to one another (all within an 80 m x 80 m area), and thus should experience roughly the same exposure to SONGS' effluents. We defined "impacted" quadrats as those which had any anomalous sediments on any survey. From October 1985 until the end of the study, anomalous sediments increased dramatically at the near Impact station (SOKU), covering more than 40% of the sample area by the last survey (Table 7), and being present to some extent on 90% of sample quadrats. In order to leave a reasonably large unaffected sample area, we excluded data from this last survey in our analyses. Even so, the data are sparse because we have taken them from a single station and partitioned them into two categories, and because there were at most four surveys in the After period used in this analysis (i.e. after October 1, 1985). For these reasons we present analyses for major groups (e.g. muricid snails) only, and not for individual species. We test for effects on total sea star abundance as well as the other pooled groups used in our repeated measures test. Because impacted and unimpacted quadrats are in the same area and had similar average densities prior to October 1985 (Unimpacted: mean = $0.86/m^2$, S.E. = 0.19; Impacted: mean=$0.80/m^2$, S.E.=0.17), the disease event does not constitute a potential confounding effect in our test on sea stars here, as it did in the overall analysis.

4. RESULTS

Twenty species were sufficiently abundant to warrant statistical testing to determine whether relative declines in abundance occurred at the Impact stations after SONGS Units 2 and 3 began operations (Table 4; see Section 3). In nine cases, because of violations of statistical assumptions, or because of rarity at the test stations, we only report estimated changes in relative abundance, and present the results graphically. In addition to tests on individual species, tests are also done on a number of major groups such as "total snails". For each test species and group we have evaluated temporal patterns in the differences between stations (Impact - Control, or deltas) both graphically and by linear regression against time. We also tested for the effects of anomalous sediments on the major groups at the near Impact station (see Section 3.2).

4.1 Gastropod Mollusks (Snails)

There was a general decline in the abundance of gastropod mollusks at the Impact stations in the San Onofre kelp forest relative to the Control station in San Mateo kelp forest (SMK). As a group, snails declined markedly (in excess of 70%) at both Impact stations in the San Onofre kelp forest relative to SMK after SONGS began operations (Fig. 4a, Table 8). The relative decline in snail density averaged over the two Impact stations (i.e. the "Period" effect) was statistically significant (Table 8), but the somewhat greater decrease at the near Impact station (SOKU) than at the far Impact station (SOKD) was not statistically significant (i.e. the period x station interaction was not significant). The failure to detect a significant interaction may result from the very low power of the test (Table 8). The average relative decline results from a decline in mean snail density at both Impact stations, together with an increase in mean snail density at the Control station (Fig. 4a). There was a tendency for the density of snails to decline through time during the After period at the Impact stations relative to the Control station, with a particularly sharp drop at the end of the After period (Fig. 4a), and the linear trends are nearly significant (Table 9). Because the combined snail group was evaluated during only two surveys during the Before period, trends in that time period cannot be evaluated.

BACI repeated measures tests on both the non-muricid and muricid snail subgroups showed much the same patterns as were seen for total snails (Table 8, Figs. 4b & c). There was a significant or nearly significant decline in density of both groups at the Impact stations (Table 8). The percentage decline was greater at the near Impact station than the far Impact station in both cases, but the period by station interaction terms were not statistically significant in either case, although the interaction was nearly significant in the case of non-muricid snails. Again the interaction tests had low power (Table 8).

Temporal trends in the After period differed between non-muricid and muricid snails. For both Impact stations, the Impact-Control differences decreased significantly through time during the After period for non-muricids (Table 9, Fig. 4b). In contrast, muricids were generally scarcer at the Impact stations relative to the Control during the After period but showed a sharp increase at the Impact stations relative to the Control station during the second to and next to last surveys in 1986 (Fig. 4c), and the overall trends during the After period are positive and not statistically significant (Table 9).

The large declines at the Impact stations, and the larger declines at SOKU relative to SOKD seen for all snails as well as the muricid and non-muricid subgroups, are seen in most of the individual species for which we are able to make a determination. We estimated relative percent change in density during the After period for 13 species at SOKU. All 13 showed declines, 11 of which exceeded 50% (Table 8). For 11 of the 13 species we were able to estimate percent change at SOKD. For 10 of the 11 there was also a decline at SOKD (Table 8). The percentage decline at SOKU was greater than at SOKD for nine of ten species showing declines at both Stations, and one "species" (*Calliostoma* spp.) declined at SOKU but increased at SOKD. These patterns are supported by statistical analyses. For eight species we were able to conduct a repeated measures analyses: in all eight cases either the main effect of period, or the interaction of period x station was significant ($p<0.05$) or near significance ($p<0.15$, Table 8).

The results for individual snail species are given in greater detail below.

<u>Astraea undosa</u>

The abundance of this snail trended (negatively) during the Before period at SOK relative to SMK, and the deltas were serially correlated (Table 8, Fig. 4d). Therefore no statistical test was done. However, there were large declines in relative density at the Impact stations, with the larger decline at the near Impact station (Table 8). Although this pattern suggests a SONGS effect, the temporal trends in the Before period deltas raise the possibility that these declines simply reflect a trend that began Before SONGS started operations.

Calliostoma spp.

These trochid gastropods are omnivores that are often found on giant kelp and other algae in kelp forests. The animals included in this category are mostly *Calliostoma supragranosum*, but also some *C. gloriosum* and an occasional *C. annulatum*. Initially, *Calliostoma* was most abundant at SOKU, the near Impact station. They declined at SOKU after the onset of SONGS operations, whereas populations at the SOKD (far Impact) and the SMK (Control) stations increased somewhat (Fig. 4e). The changes in density resulted in a significant period x station interaction in the repeated measures BACI analysis (Table 8). Although density appears to be declining at SOK relative to SMK through the After period (Fig. 4e), the temporal trend is nonlinear (showing a sharp drop near the end of the After period) and is not statistically significant (Table 9).

Conus californicus

Conus californicus is a predatory snail common in kelp forests that is often associated with kelp holdfasts, perhaps because that is the home of their prey (SCS, *personal observation*) These snails were most abundant at the stations in the San Onofre kelp forest during the Before period, and within SOK they were most abundant at SOKU (Fig. 4f). During the After period, populations in SOK declined sharply relative to those in SMK, with the decrease being more pronounced at the SOKU station (Fig. 4f). These temporal patterns show up as a highly significant effect of period and a nearly significant period x station interaction in the repeated measures BACI analysis (Table 8).

There was a slight (nonsignificant) tendency for the deltas from both Impact stations to decline linearly with time during the After period (Fig. 4f, Table 9).

There was also a negative but statistically nonsignificant trend during the Before period. In view of the low power of the test for trends in the Before period (with only five surveys) we cannot reject the possibility that the BACI result may reflect the continuation of a temporal trend from the Before period.

Crassispira semiinflata

Crassispira semiinflata occurred at relatively low densities at all the stations, although it was most abundant in SOK. During the course of our observations the population densities have varied widely and asynchronously. Density at the stations in SOK fell from the Before to the After period. The declines were greatest at SOKU, while densities increased at SMK (Fig. 4g). These changes resulted in substantial percentage declines in density at the Impact stations relative to the Control (Table 9). There was a significant negative trend in the deltas at SOKU during the Before period which weakens the case for a SONGS effect, and prevented use of the repeated measures analysis.

Cypraea spadicea

We were not able to do the repeated measures analysis for this species due to violation of statistical assumptions (trends and serial correlations). The percent decline at both far and near Impact stations was greater than 50%, with the greater decline occurring at the nearer SOKU station (Table 8). These results stem from an increase at SMK following the onset of the After period, and smaller decreases at SOKU and SOKD (Fig. 4h). As with *Conus*, the presence of negative trends in the deltas during the Before period raises the possibility that the losses are not due to SONGS.

Kelletia kelletii

Kelletia kelletii is a large predator and scavenger that is a conspicuous member of the fauna in most kelp forests. These snails were abundant at all the monitoring stations during the Before period, but were slightly more numerous at San Onofre than in SMK (Fig. 4i). Substantial declines in relative density occurred at both the Impact stations (SOKU and SOKD), and this is reflected in a significant main effect of period (Table 8). In addition, the decline was again more marked at the nearer SOKU Impact station, and the period x station interaction is nearly significant (Table 8).. There is a general tendency for *Kelletia* to decline through time at SOK relative to SMK, especially during the last four After surveys (Fig. 4i), although the linear trend is not significant for any given station or period (Table 9). The marked decline in the deltas seen at the end of the After period argues for a SONGS' effects.

Mitra idae

Mitra idae is a relatively abundant snail that was generally more numerous in SOK than in SMK. Within SOK its density was highest in the upcoast portion of the bed (Fig. 4j). During the After period, the mean density of *Mitra* increased at both SOKD and SMK, but remained nearly constant in upcoast SOK (Fig. 4j). These temporal changes in density resulted in a large relative decline at SOKU and a smaller decline at SOKD. The interaction of period x station was nearly significant, but the main effect of period was not significant (Table 8). Density at SOK trended negatively (significantly or nearly significantly) relative to SMK during the After period (Table 9), largely because of a sharp drop at the end of the study (Fig. 4j).

Nassarius spp.

Because of its scarcity at the far Impact station (a delta could be estimated on only one survey), it was not possible to test for effects on this genus, or to estimate a percent reduction at the far Impact station. We estimated a 36 percent reduction of density at SOKU during the After period relative to SMK. Temporal patterns at SOKU and SMK are given in Fig. 4k.

Ophiodermella inermis

Ophiodermella inermis were only counted twice during the Before period and were uncommon. We estimated reductions of 32 and 69 percent at SOKU and SOKD, respectively, during the After period relative to SMK (Table 8). The effect of period was significant and the period by station interaction was nearly so (Table 8). During the After period densities at the Impact stations relative to SMK appear to be declining (Fig. 4l; Table 9). For this species densities were similar at SOKU and SOKD and were higher than those at SMK during the Before Period. The density changed little at SOKU from Before to After, but declined at SOKD and increased somewhat at SMK, so that SMK and SOKD had similar densities during the After period.

Tegula aureotincta

Tegula aureotincta were absent at SOKD in the Before period, and the initial density was high at SOKU, and very low at SMK (Fig. 4m). As a consequence of the low densities at SMK and SOKD, it was not possible to conduct a repeated measures BACI test for this species. However, we were able to estimate the percent reduction at SOKU, which exceeded 90% (Table 8).

Maxwellia gemma

In the Before period, *Maxwellia gemma* were counted on only two surveys. At that time they were present at low densities at the Control stations and at SOKD, but were quite abundant at SOKU (Fig. 4n). They declined at the Impact stations from Before to After, whereas the average abundance at the SMK Control station increased (Fig. 4n). These shifts in density resulted in lower average deltas during the After period, (Fig. 4n), relative reductions in density at the Impact stations exceeding 60%, a nearly significant main effect of period, and a significant period x station interaction in the repeated-measures analysis (Table 8). There were no strong temporal trends in the deltas during the After period (Table 9).

Murexiella santarosana

The densities at the Impact stations declined from the Before to the After period, whereas the abundances of these snails increased slightly at the SMK Control station (Fig 4o). As a result, the estimated percentage reductions in density was quite large (Table 8), and even with relatively low power the main effect of period was nearly significant (Table 8). There was some indication that densities in SOK relative to SMK were increasing near the end of the After period (Fig. 4o), although the linear temporal trends during the After period were not significant (Table 9).

Pteropurpura festiva

Pteropurpura festiva were counted twice during the Before period. During that time they occurred at relatively low numbers at SMK, but were quite abundant in the San Onofre kelp forest (Fig. 4p). Abundances declined at both Impact stations from the Before to the After period, while the average density at SMK increased (Fig. 4p). As a result, the deltas were lower during the After period (Fig 4p), and declines in relative density in excess of 70% from the Before to After periods were estimated at both SOK stations (Table 8). Statistical power was low, and the repeated measures analysis revealed no significant effects (Table 8). There were no clear linear temporal trends in the deltas during the After period (Table 9).

4.2 Sea Urchins

Sea urchins were generally more abundant in SOK than in SMK during the Before period. After the Interim period, densities were generally higher at all stations, but had increased proportionately most at SMK and proportionately least at SOKU (Fig. 4q). As a result we estimate a substantial reduction in density (in excess of 50%) at SOKU relative to SMK. There was a more modest and positive change (approximately 25%) at SOKD (Table 8). These changes lead to a significant interaction of period x station in the repeated measures BACI analysis (Table 8).

There were significant positive temporal trends in the deltas for both Impact stations during the Before period, and significant negative trends in the deltas during the After Period (Table 9). Because the temporal trends in the Before period are in the opposite direction of the apparent (negative) SONGS effect, we included the results of the repeated measures analysis for this group.

Results for the two main species comprising this category (excluding red sea urchins, see Methods) follow.

Lytechinus anamesus

During the Before period white sea urchins were more common in the San Onofre kelp forest than at SMK (Fig. 4r). Since 1983 there has been an increase in the density of white sea urchins at many stations in the Southern California Bight (Tegner and Dayton 1987). In some places, as at the San Onofre and San Mateo kelp forests, this resulted in higher densities of these urchins inside kelp beds. In the past they have been most common outside the kelp beds and in deeper water. The change may be related to the decline of predatory sea stars due to disease (Schroeter *et al.* 1983). At our study stations the proportional increases have been greater at San Mateo, and within SOK at SOKD (Fig. 4r). As a result we estimate fairly substantial relative reductions in density (greater than 40%) at the SOK stations. The main effect of period and the interactive effect of period x station were statistically significant (Table 8). There was a significant negative trend in the deltas during the After period (Table 9). Our confidence in these patterns arising because of the operation of SONGS is somewhat weakened both by the existence of significant serial correlation, and a significant BACIP effect when the BK and SMK (the two potential Control stations) were compared (Appendix A). In this comparison we saw a significant increase at SMK relative to BK, arising because densities declined at BK while they increased at SMK.

Strongylocentrotus purpuratus

Purple sea urchins are generally more abundant at San Mateo than in SOK (Fig. 4s). This may be related to habitat availability. Purple sea urchins are generally found in the cryptic habitats that are in greater supply at SMK than at the other stations (see Final Technical Report K). There was a small positive increase in abundance at SOKU relative to SMK, and an increase of approximately 50%

relative to SMK at SOKD (Table 8). As a result, there was a significant period by station interaction in the repeated measures analysis (Table 8), but no significant period effect. Within SOK, purple urchins were more abundant upcoast than downcoast, but this difference became smaller during the After period because densities declined in SOKU. Deltas declined significantly through time at both Impact stations during the After period (Table 9).

4.3 The holothurian *Parastichopus parvimensis*

The sea cucumber, *Parastichopus*, is common on both sand and mixed sand and cobble bottoms. This deposit feeding species was initially much more abundant in SMK than in SOK. Its mean After density was about half the Before density in SMK, while densities increased only slightly from their very low levels in SOK (Fig. 4t). These temporal changes in density resulted in a significant period effect (Table 8). This species, which may benefit from increased organic content in the sediments, showed a positive relative change in density at SOK. However, because of the extremely low densities of this species in SOK in both periods (zero abundance on many surveys) we feel that the evidence for an effect of SONGS is weak.

4.4 Large Sessile Invertebrates

As a group and individually, large sessile invertebrates were statistically intractable. There were problems with additivity, serial correlations and trends during the Before period. In addition to violations of statistical assumptions, the changes in density of these invertebrates did not fit a single pattern suggestive of an effect of SONGS, as was the case for snails. Such a pattern might indicate the existence of effects even in the absence of strong statistical evidence for individual species.

In total, sessile invertebrates were most abundant in SMK and least abundant in upcoast SOK during the Before period (Fig. 4u). Abundance increased in the After period at all stations, but did so proportionately most at SOKD and proportionately least at SMK (Fig. 4u). As a result we estimate a relative increase of 37 and 92 percent at SOKU and SOKD, respectively (Table 8). It seems possible that the differences in proportionate increases among stations may be due, at least partially, to density dependent responses. Support for this speculation comes from the observation that proportional increases in density from Before to After were inversely proportional to initial density (Fig. 4u), but with only three data points the pattern is certainly not compelling.

Below we consider each taxon separately.

<u>Muricea californica</u>

During the Before period, *M. californica* was rare in the San Onofre kelp forest and abundant at SMK. There was substantial recruitment at all the stations, but less at the near Impact station than at the far Impact station (Fig. 4v). On the other hand, the proportional increase was greater at both Impact stations than at SMK (Fig. 4v). Again the relative changes were increases, with the increase at SOKD, the far Impact station, being the greatest (Table 8). Because of the larger increase at the more distant Impact station, the lack of additivity, and because the difference between Before and After appears to be the result of a single recruitment event (note the steady decline in the deltas in the After period (Fig. 4v)), we do not think the observed density changes should be interpreted as effects of SONGS.

Muricea fruticosa

Like its congener, *Muricea fruticosa* was rare in the San Onofre kelp forest during the Before period. There was some recruitment in 1984, but less than for *M. californica* (Fig. 4w). We estimated percent changes in density of 59 and 371 percent at SOKU and SOKD, respectively. We place little confidence in these estimates because of the failure of the additivity assumption, and the larger increase at the far Impact station.

Styela montereyensis

This solitary tunicate was very abundant in the downcoast portion of SOK during the Before period, and was common elsewhere (Fig. 4x). It declined to near zero at all stations before the beginning of the After period. We do not think these results should be interpreted as a SONGS effect, because of the violation of statistical assumptions, because the larger decline was at SOKD, the far Impact station, and because the decline started in 1981 (Fig. 4x), before Units 2 and 3 were pumping much water (Table 8).

Tethya aurantia

Tethya is a solitary sponge, quite common in many giant kelp forests. The density of *Tethya* was always low at our study stations, particularly in the downcoast portion of SOK and at San Mateo. Densities at the upcoast station in the San Onofre kelp forest and at SMK declined from the Before to the After periods, while the density at SOKD remained relatively constant (Fig. 4y). As a result, we estimated a relative increase of 85 % at SOKD, and a smaller increase at SOKU

(Table 8). We do not think that these patterns are due to SONGS because the greater relative increase occurred at the more distant Impact station (Table 8).

4.5 Effect of Anomalous Sediments

The plume generated by SONGS Units 2 and 3 is generally turbid (Final Technical Report L), and because of the increased seston concentration in the water, irradiance is reduced within SOK (Final Technical Reports L and K). In addition, there is clear evidence that seston flux has increased on the bottom (by about 46%, Table 10, see also Final Technical Report K) in the upcoast portion of SOK, relative to downcoast SOK since the new Units began pumping water (Final Technical Report K). Perhaps associated with these physical changes, there was an influx of anomalous sediments at the near Impact station (SOKU) first seen in October 1985 during the After period. We refer to these sediments as anomalous because prior to their appearance in SOK during 1985 we had never seen similar fine sediments in and about the kelp forest. In the field they have an apparently cohesive nature such that a lump could be formed in the field by light hand pressure. Upon first appearance the sediments had a consistency of pudding suggesting high water content and rapid deposition. Sediments identified by divers as being anomalous were finer grained and had higher organic content than other soft sediments at the same depth (Table 3).

It seems obvious that accumulations of such fine sediments will be deleterious to animals that prefer hard substrates, as do most of the species we monitored. Periodic influxes of sand are normal events in kelp beds and create open space for recruitment of plants and animals. However, a persistent increase in the percent cover of fine sands and silts would undoubtedly change community composition. Such an increase in cover has occurred in upcoast SOK (Final Technical Report B), and particularly at the SOKU station used to sample invertebrates, with the percent cover increasing through the end of the invertebrate study (Table 7).

We designated quadrats in SOKU where anomalous sediments occurred at any time (excluding the final survey) as Impact stations and used the others as Controls. Data from the final survey, done in December 1986, were not used in the analysis because anomalous sediments were present on >90% of the quadrats at that time (and covered more than 40% of the area), and as a result we would have had too few control quadrats. We then did the same BACIP analysis used to evaluate an impact when there is one Control and one Impact station (Interim Technical Report 2), but now the After period begins in October 1985, when the anomalous sediments began to appear. Because of the general sparseness of the data (from only one station, categorized into two groups), we did these analyses only on major groups and not individual taxa.

Table 11 shows that all groups declined in density in quadrats that were impacted by anomalous sediments, relative to Controls. These declines were significant for sessile invertebrates, sea urchins, and sea stars. Snails declined, but the declines were not especially large and were not statistically significant.

5. DISCUSSION AND CONCLUSIONS

The results of this study demonstrate that there was a general decline in the abundance of many species of snails in the San Onofre kelp forest (relative to the densities in the San Mateo forest) after Units 2 and 3 of the San Onofre Nuclear Generating Station began operating. Unfortunately, for most of these species we have few data on which to base tests of our statistical assumptions. It is thus possible, for example, that many of the declines we saw were simply continuations of trends that began before Units 2 and 3 began operating. Clearly a study such as this one would be greatly strengthened if data could have been collected for several more years in the Before period.

On balance, however, we believe that the evidence strongly indicates that the operation of the new generating units led to declines in snail abundances. Our conclusion is based upon several lines of evidence: (1) reductions in abundance were generally larger at the near than at the far Impact station; (2) when our Control station (SMK) was compared with another station distant from SONGS (Barn Kelp) no such pattern of "period x station" interactions were seen (Appendix A); (3) when the average of the two distant stations (SMK and BK) was used as a control the same pattern seen in the primary analyses was obtained (Appendix A); (4) we have identified a plausible mechanism for the decline in abundance; (5) many species showed sharp declines near the end of the After period (Fig. 4), when the anomalous sediments were becoming increasingly abundant (and when the amount of water pumped was higher than in earlier years, and (6) for several other species the negative effects are clearly not simply continuations of Before trends (e.g. *Mitra idae*, *Astraea undosa*, *Strongylocentrotus purpuratus*).

In addition to the snails, the white sea urchin, *Lytechinus anamesus*, seems to have been adversely affected by SONGS. This species declined relatively most at the station nearest SONGS, and its density appears to have been negatively impacted by the influx of anomalous sediments. A potential confounding effect is that sea stars can negatively influence the abundance of sea urchins (Schroeter *et al.* 1983). However, sea stars were most abundant in upcoast SOK and least abundant in SMK in the Before period. One would therefore expect that this confounding effect, resulting from the die-off of sea stars in the After period, would lead to a relative *increase* at SOK.

Although there are several species (sessile invertebrates, and the holothurian, *Parastichopus parvimensis*) whose relative abundance increased at one or more Impact stations in the After period, none of the data provide compelling evidence in support of a positive effect of SONGS. In the case of the two species of *Muricea* statistical assumptions were violated and the increases were greater at the far Impact station than at the near Impact station. The inference for a positive effect of SONGS on *Parastichopus* is weakened by the fact that densities were extremely low in SOK during both the Before and After periods.

The increase in fine anomalous sediments in the San Onofre kelp forest is a mechanism consistent with the effects we attribute to SONGS. If the trend of increasing deposition of these sediments continues we expect the effects to increase in size and number. Analyses of the effect of the anomalous sediments in SOKU (the near Impact station) suggest that some groups of organisms for which we could not identify an impact based on changes in density over an entire Impact station may indeed have been affected. These groups (such as sessile invertebrates) may be resistant to an increased flux of seston (or some other environmental changes caused by SONGS), but not to burial of substrate by the anomalous sediments, and thus only the contrast between abundances seen in quadrats "impacted" and "unimpacted" by these sediments at SOKU show a negative effect. For example, *Muricea* can survive when almost completely buried, so we wouldn't expect this group to show effects unless the substrate were persistently covered with anomalous sediments.

In contrast, snails, which showed the largest relative declines over all quadrats, provided the weakest evidence for effects of anomalous sediments. It seems likely that the large declines in this group came about due to processes impinging on both quadrats "impacted" by anomalous sediments, and "unimpacted" quadrats (perhaps by an increased flux of seston.) Thus, our failure to detect effects of anomalous sediments for snails might result precisely because this group may be highly sensitive to smaller amounts of increased sedimentation.

A frequent dusting of fine sediments on hard substrates in the San Onofre kelp forest could interfere with larval settlement and might decrease the chances of the successful attachment and development of eggs. All the gastropods we have discussed attach gelatinous egg masses or egg capsules to hard substrates or algae. After several days or weeks, the veliger larvae are released. The length of time before settlement is not known for these species. However, in general, free veliger stage lasts from a few hours or days to two to four weeks (Hyman 1967). If the larval life is less than a day or so, a negative effect on egg laying or development could result in a decrease in local adult population densities.

The available evidence also indicates that the operations of SONGS Units 2 and 3 have caused a reduction in the areal extent and density of giant kelp within the San Onofre kelp forest. The areal extent of SOK has been reduced by about 60%, and the average density of giant kelp on hard substrate has been reduced (relative to SMK) by approximately 50% in vicinity of the invertebrate sampling locations within SOK (Final Technical Report K). The loss of giant kelp within SOK is a potential mechanism by which SONGS could be impacting the macroinvertebrates within the kelp forest. To our knowledge, there are no studies that explicitly examine the effects of kelp density on the density of associated large benthic invertebrates. Nevertheless, such a linkage seems reasonable. For example, we might expect the abundance of *Conus* to be positively related to kelp density since many of its prey live in kelp holdfasts (SJS, *personal observation*). Other invertebrates feed upon drift kelp fronds, and a large proportion of the production of a kelp forest enters this pathway and is eventually eaten by invertebrates such as sea urchins within the kelp forest (Dean 1980, Gerard 1976). Indeed, sea urchins and other invertebrates such as abalone may compete for drift kelp fronds within some kelp forests (Tegner and Levin 1982).

We have, however, little direct evidence that loss of giant kelp has led to a loss of benthic macroinvertebrates. For example, although giant kelp went extinct at Barn kelp forest at the beginning of the Before period, we did not see pervasive temporal trends (relative to SMK) during the Before period (Appendix A, Table A-3). In two cases (*Lytechinus* and *Astraea*) we saw large declines at Barn Kelp (relative to SMK) from the Before to After periods. If these declines were due to the loss of giant kelp at BK, they were expressed with a three or more year delay, since the Before deltas did not have strong temporal trends. Nevertheless, it is possible that the loss of giant kelp contributed to the relative reductions of these two (and perhaps other) species in SMK.

On a broad spatial scale we might ask if the populations of invertebrates living on any two rocky reefs might fluctuate so differently through time, as to produce the "SONGS" effects we have seen, even absent an environmental insult. Ideally, we would like to compare the dynamics of invertebrates from many different kelp beds to answer this question. Unfortunately this can not be done. However, we did collect estimates of densities at Barn kelp forest. Although we rejected this bed from use as a control because kelp was lost from this bed at the beginning of the study, similar temporal patterns at Barn and SMK would be encouraging support for our approach. As it turns out, we can identify only a few significant "period by station" interactions between these two stations (Appendix A). In addition, if we replace SMK by the average of SMK and Barn kelp forest in our analyses we obtain similar results to those reported in Table 8 (Appendix A). Thus, it appears that populations of the benthic invertebrates we sampled in the two rocky reefs far from SONGS roughly tracked one another during both the Before and After periods. In contrast, the populations near SONGS changed in abundance relative to these more distant reefs after the plant was operating at a consistently high level.

It is still possible that the relative decline in macroinvertebrate densities was due to a natural event that had effects at SOK and no, smaller, or opposite effects at SMK and BK. There is however, good evidence that the variations in the natural oceanographic conditions (e.g. temperature, nutrients, wave climate) are similar at sites within the region encompassed by the three kelp forests (Final Technical Report L). Another possibility would be an interaction between difference in the topography at SOK versus other sites and changes in the physical environment from the Before to After periods. For example, Patton (1986) observed declines in the abundance of a number of the same macroinvertebrates we report on in SOK relative to SMK or BK, After Units 2 and 3 began operating, and attributed this to an interaction between the lower relief and greater prevalence of sand (see also Table 1) at SOK and the storms associated with the El Nino event. This potential interaction does not explain our results. If an interactive effect of the storms were responsible for the relative declines at SOK we would expect to see a marked drop from immediately before to after them (the great storms of the El Nino event occured in March 1983). However the changes at SOK relative to SMK from before to after the storms were negative in only 8 of 33 cases for which we reported declines from the Before to After operational periods in Table 8. (In evaluating the effects of the storms we use the two surveys immediately before the March 1983 storms as the "Before" period and the two surveys immediately after the storms as the "After period".) Clearly there is an unending list of other possible natural interactions that might explain our results. However, we have no evidence that such an event is responsible for the observed relative declines in macroinvertebrate densities in SOK.

Finally, it seems possible that we have somewhat underestimated the effects of Units 2 and 3. Although we have grouped surveys into a Before and an After period, the rate water has been pumped by the new units has increased through time beginning in the Before period. For example, during the last year or so of the Before period (1982), significant amounts of water were pumped by the new Units, on the order of 40% of the average during the After period (Table 2). Moreover, the rate water was pumped in the last year of the After period (1986) exceeded the rate during the previous two After years by about 16%. Pumping rates have remained near this higher level since the end of the After sampling period exceeding the levels during 1984 and 1985 by about 10% (Table 2).

This page intentionally left blank.

6. LITERATURE CITED

Dean, T.A. 1980. The effects of the San Onofre Nuclear Generating Station on the giant kelp, *Macrocystis pyrifera*, Annual report of the Kelp Ecology Project: January 1979 through January 1980. Report to the MRC. 280 pp.

Dixon, J.D., S.C. Schroeter, R.O. Smith. 1988. *Studies of benthic organisms in kelp forests near the San Onofre Nuclear Generating Station - 1980-1986.* Final Report submitted to the MRC, March 1988.

Dungan, M.L., T.E. Miller, and D.A. Thomson. 1982. Catastrophic decline of a top carnivore in the Gulf of California rocky intertidal zone. *Science* 216: 989-991.

Ebert, T. 1977. An experimental analysis of sea urchin dynamics and community interactions on a rock jetty. *J. Envir. Mar. Bio. Ecol.* 27: 1-22.

Gerard, V.A. 1976. *Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California.* Ph.D. dissertation. University of California, Santa Cruz. 173 pp.

Hyman, C.H. 1967. *The Invertebrates. Volume VI. Mollusca I.* McGraw-Hill, New York. 792 pp.

LaTour, S.A. and P.W. Miniard. 1983. The misuse of repeated measures analysis in marketing research. *J. Marketing Res.* XX(February): 45-57.

Milliken, G.A. and D.E. Johnson. 1984. *Analysis of messy data. Volume I.: Designed experiments.* Lifetime Learning Publications. Belmont, CA. 433 pp.

MRC. 1988. Interim technical report to the California Coastal Commission, 2. Sampling design and Analytical procedures (BACIP).

Murdoch, W.W., B.J. Mechalas and R.C. Fay. 1980. Predictions of the effects of San Onofre Nuclear Generating Station and recommendations, Part I: recommendations, predictions, and rationale. Report of the Marine Review Committee to the California Coastal Commission. MRC Document 80-04(I).

Patton, M.L. 1986. Changes in the abundance of subtidal epibiota during an episode of warm water and severe storm disturbance in the Southern California Bight. In: *Report on 1985 data, Marine environmental analysis and interpretation, San Onofre Nuclear Generating Station.* Southern California Edison Report No. 86-RD-26. Chapter 8, pp. 8-1 - 8-40.

Schroeter, S.C., J. Dixon, and J. Kastendiek. 1983. Effects of the starfish *Patiria miniata* on the distribution of the sea urchin *Lytechinus anamesus* in a southern California kelp forest. *Oecologia* 56: 141-147.

Stewart-Oaten, A. 1986. The before-after/control-impact-pairs design for environmental impact assessment. Prepared for the MRC, June 1986.

Stewart-Oaten, A., W.W. Murdoch, and K. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? *Ecology* 67: 929-940.

Tegner, M.J. and P.K. Dayton. 1987. El Nino effects on southern California kelp forest communities. *Adv. Ecol. Res.* 17: 243-279.

Tegner, M.J. and L.A. Levin. 1982. Do abalones and sea urchins compete in California kelp forest communities? In: International Echinoderms Conference Tampa Bay. J.M. Lawrence, ed. A.A. Balkeme, Rotterdam. pp. 265-271.

TITAN Systems, Inc. 1988. Marine Review Committee data standards document, Volume I, Standards and guidelines, Release 3. Report submitted to the MRC March 1988.

Winer, B.J. 1971. *Statistical principles in experimental designs* (2nd ed.). McGraw-Hill, New York.

This page intentionally left blank.

7. TABLES

Table 1

Average cover (%) of various substrates in kelp forests in San Diego county in November/December 1984. Estimates were made at a single site in each area. 40 1-m^2 quadrats were examined at SMK, SOKU, SOKD, and BK. 20 quadrats were used in the other kelp forests. SMK = San Mateo; SOKU = Upcoast San Onofre; SOKD = Downcoast San Onofre; BK = Barn kelp; CSB = Cardiff State Beach; LEU = Leucadia; SWA = Swami's; CAR = Carlsbad; LJ = La Jolla. Substrate categories defined by Wentworth scale (Inman 1963). Reproduced from Table 1, Technical Report K, based on Table 1, Dixon <u>et al.</u> 1988.

	Kelp Forest								
Substrate	SMK	SOKU	SOKD	BK	CSB	LEU	SWA	CAR	LJ
Reef	0.0	0.0	0.0	54	65	70	60	97	93
Boulder	24	21	12	2.7	0.0	1.1	0.0	0.7	1.4
Cobble	53	32	47	24	0.0	1.7	2.2	1.8	1.5
Gravel	11	7.7	14	2.7	0.0	0.4	3.4	0.0	0.4
Sand	12	40	27	17	35	27	34	0.0	4.3

Table 2

SONGS Units 2 and 3 operations.

A. By Year

YEAR		FLOW VOLUME ($M^3 \times 10^6$)	POWER (% OF CAPACITY)
1980		0.7	0
1981		0.9	0
1982		2.7	0.8
1983		5.7	31.5
1984		6.5	54.8
1985		6.9	48.9
1986		7.8	70.1
1987		7.3	71.5
1988	(through July 20)	7.5	70.0

B. By Period

PERIOD	FLOW VOLUME ($M^3 \times 10^6$)	POWER (% OF CAPACITY)
Before (October 1, 1980-April 30, 1983)	1.9	0.7
Interim (May 1, 1983-September 30, 1984)	7.1	53.3
After (October 1, 1984-December 31, 1986)	7.1	57.1
Post-sampling (January 1, 1987-July 20, 1988)	7.4	71.0

Table 3

Comparisons of the characteristics of the anomalous sediments with other sands and silts in the vicinity of San Onofre. The station designated "2000 m Upcoast" was 2000 meters upcoast of the midline of the Unit 2 and 3 diffusers. Cohesive sediments were collected in Oct. 1985, May 1986, Oct. 1986, Nov. 1986, and Oct. 1987. Details on methods are in Technical Report B.

LOCATION	N	MEDIAN PHI [$-\log_2$(MM)]	% SILT-CLAY (PHI >4)	TOC
Same Depth as Invertebrate Monitoring Stations (~15m)				
Anomalous sediments in vicinity of SOKU	9	4.21	55.0	0.44
SOK (other sediments)	7	3.94	45.0	0.20
SMK	2	3.68	16.5	0.07
2000 m upcoast	1	3.81	27.9	0.08
Deeper Water (30m)				
Off SOK	2	4.07	51.4	0.43
2000 m upcoast	1	4.36	64.1	0.46

Table 4
page 1 of 2

Species sampled in non-trivial numbers (see text). Species abundant enough at the SOK and SMK stations to warrant the calculation of percent change at at least one of these stations are marked by *, other species were not analyzed.

SPECIES
Porifera
*Tethya aurantia**
Cnidaria
Lophogorgia chilensis
*Muricea californica**
*Muricea fruticosa**
Pachycerianthus fimbriatus
Annelida
Diopatra ornata
Mollusca
*Astraea undosa**
Calliostoma spp.*
*Conus californicus**
*Crassispira semiinflata**
*Cyrpaea spadicea**
Fusinus spp.
Haliotis spp.
Hespererato vitellina
*Kelletia kelletii**
Latiaxis oldroydi
*Maxwellia gemma**
*Mitra idae**
*Murexiella santarosana**
Nassarius spp.*
*Ophiodermella inermis**
*Pteropurpura festiva**
Pteropurpura vokesae
*Tegula aureotincta**
Tegula eiseni
Trivia spp.
Echinodermata
*Lytechinus anamesus**
*Parastichopus parvimensis**
*Stronglocentrotus purpuratus**
Ascidiacea
*Styela montereynesis**

Table 4
page 2 of 2

SPECIES
The following sea stars and sea urchins were not tested because of episodes of disease or fishing (see text).
Echinodermata
Astrometis sertulifera
Centrostephanus coronatus
Henricia leviuscula
Linckia columbiae
Patiria miniata
Pisaster giganteus
Strongylocentrotus franciscanus

Table 5

Mean densities of sea stars at test stations for each period.

Period	SOKU Mean	SOKU S.E.	SOKU N	SOKD Mean	SOKD S.E.	SOKD N	SMK Mean	SMK S.E.	SMK N
Before	1.18	0.15	10	0.53	0.11	10	0.43	0.03	10
After	0.09	0.02	8	0.28	0.05	8	0.17	0.05	8

Table 6

Mean densities of red sea urchins (Strongylocentrotus franciscanus) at test stations for each period.

PERIOD	SOKU			SOKD			SMK		
	MEAN	S.E.	N	MEAN	S.E.	N	MEAN	S.E.	N
Before	0.04	0.01	10	0.19	0.04	10	1.05	0.15	10
After	0.05	0.02	8	0.003	0.003	8	0.49	0.06	8

Table 7

Percent cover of anomalous sediments at benthic invertebrate sampling stations after its first appearance at the SOKU station in October 1985.

DATE	ANOMALOUS SEDIMENT (% COVER) SMK	SOKU	SOKD
Oct. 10, 1985	0	14.7	0
Mar. 5, 1986	0	29.5	6.8
June 5, 1986	0	30.6	6.8
Sept. 8, 1986	0	35.0	3.9
Dec. 3, 1986	0	44.2	0.2

Table 8

Results of repeated-measures BACI analysis.

Estimated percent changes at the SOKU (near impact) and SOKD (far impact) stations relative to the values at the control site, SMK, and the results of repeated measures analyses. A, SC, and T refer to failure of the additivity, serial correlation, or trends assumptions tests. U indicates that the assumptions tests could not be done. No result (NR) indicates all densities were zero at the test stations. * indicates repeated measures analysis not done due to either additivity or trends in the SOKU-SOKD deltas. -- indicates test could not be done.

	Species/ Group	% Change SOKU	% Change SOKD	Period F(DF)	Period P	Period x Station F(DF)	Period x Station P	Power (% Period x Station
	Snails	-84.0^{U}	-73.2^{U}	8.15(1,8)	0.02	2.99(1,8)	0.12	7.6
	Non-muricid snails	-80.9^{U}	-68.3^{U}	5.31(1,8)	0.05	4.17(1,8)	0.076	9.7
30901	*Astraea undosa*	-85.5^{SC,T}	-68.2^{SC,T}	--	--	--	--	--
30500	*Calliostoma* spp.	-58.9^{U}	19.9^{U}	1.09(1,8)	0.33	8.29(1,8)	0.02	5.1
33501	*Conus californicus*	-90.8	-81.0	46.46(1,12)	0.0001	4.26(1,12)	0.06	50.1
33801	*Crassispira semiinflata*	-82.0^{T}	-60.1	--	--	--	--	--
31901	*Cypraea spadicea*	-85.5	-55.9^{SC,T}	--	--	--	--	--
32701	*Kelletia kelletii*	-63.5	-51.8	12.33(1,16)	0.003	3.12(1,16)	0.096	98.0
33401	*Mitra idae*	-70.5	-35.0	1.55(1,12)	0.24	3.47(1,12)	0.087	28.9
33100	*Nassarius* spp.	-36.3^{U}	(NR)	--	--	--	--	--
33701	*Ophiodermella inermis*	-32.3^{U}	-68.6^{U}	10.94(1,8)	0.01	3.59(1,8)	0.095	42.5
30701	*Tegula aureotincta*	-93.2^{U}	(NR)	--	--	--	--	--
	Muricid snails	-86.2^{U}	-74.9^{U}	7.58(1,8)	0.025	2.00(1,8)	0.195	6.0
32101	*Maxwellia gemma*	-88.9^{U}	-61.1^{U}	4.00(1,8)	0.08	6.00(1,8)	0.04	20.6
32201	*Murexiella santarosana*	-86.3^{U}	-62.8^{U}	3.42(1,8)	0.10	1.00(1,8)	0.35	9.1
32303	*Pteropurpura festiva*	-84.2^{U}	-73.6^{U}	2.87(1,8)	0.13	1.11(1,8)	0.32	5.2
	Sea Urchins	-51.2^{SC,T}	25.9^{SC,T}	0.65(1,16)	0.43	12.59(1,16)	0.003	73.6
61301	*Lytechinus anamesus*	-75.8^{SC}	-40.4^{SC}	17.31(1,16)	0.0007	14.77(1,16)	0.001	68.7
61402	*Strongylocentrotus purpuratus*	0.7	47.6	0.35(1,16)	0.56	4.43(1,16)	0.05	49.7
	Holothurians (includes only *Parastichopus*)							
	Parastichopus parvimensis	83.3	134.4	12.70(1,16)	0.003	1.08(1,16)	0.315	6.1
	Sessile invertebrates	36.9^{A,SC}	92.3^{SC,T}	--	--	--	--	--
	Muricea californica	318.0	590.6^{A}	--	--	--	--	--
	Muricea fruticosa	58.8^{A}	370.8^{A}	--	--	--	--	--
	Styela montereyensis	-42.9^{A,SC,T}	-95.2^{A,SC,T}	--	--	--	--	--
	*Tethya aurantia**	16.9	85.1	--	--	--	--	--

Table 9

Temporal trends in deltas (Impact - Control) using SMK as the control for those species analyzed in the repeated measures BACI test. "+" direction indicates deltas are increasing through time. N.A. indicates not applicable.

Species/ Group	Before						After					
	SOKU			SOKD			SOKU			SOKD		
	Direction	P	N	Direction	P	N	Direction	P	N	Direction	P	N
All Snails		N.A.			N.A.		-	0.08	7	-	0.08	7
Non-muricid snails		N.A.			N.A.		-	0.016	7	-	0.03	7
Calliostoma spp.		N.A.			N.A.		-	0.14	7	-	0.11	7
Conus californicus	-	0.10	5	-	0.30	5	-	0.36	7	-	0.20	7
Kelletia kelletii	-	0.07	9	-	0.36	9	-	0.08	7	-	0.25	7
Mitra idae	+	0.43	5	+	0.61	5	-	0.07	7	-	0.004	7
Ophiodermella inermis		N.A.			N.A.		-	0.03	7	-	0.14	7
Muricid Snails		N.A.			N.A.		+	0.66	7	+	0.34	7
Maxwellia gemma		N.A.			N.A.		+	0.26	7	+	0.25	7
Murexiella santarosana		N.A.			N.A.		+	0.74	7	+	0.09	7
Pteropurpura festiva		N.A.			N.A.		+	0.93	7	+	0.94	7
Sea Urchins	+	0.0009	9	+	0.01	9	-	0.003	7	-	0.02	7
Lytechinus anamesus	+	0.57	9	+	0.08	9	-	0.004	7	-	0.02	7
Strongylocentrotus purpuratus	+	0.11	9	+	0.49	9	-	0.0002	7	-	0.005	7
Holothurians	(includes only *Parastichopus*)											
Parastichopus parvimensis	-	0.80	9	+	0.11	9	+	0.48	7	-	0.75	7

	Spcode	Soku	Sokd
Calliostoma	30500	✓	✓
Crassispira	33801	—	✓
Nassarius	32100	✓	—
Ophiodermella	33701	✓	✓
Tegula aureotincta	30701	✓	—
Maxwellia	32101	✓	✓
Murexiella	32201	✓	✓
Pteropurpura festiva	32300	✓	✓

SOKD-SMK

SOKD + SMK / 2

Soku-Smk

Soku + SMK / 2

Table 10

BACIP test on seston flux (bottom data collected during gametophyte outplants) using an AR(1) time series model to correct for serial correlations (Preliminary analysis with an AR(3) model produced similar results and indicated that higher order correlations were not present). The SOKU (Impact) station is compared with the SOKD (Control) station. Too few data were available to use this time series method with comparisons with SMK. Daily seston flux was log (x + 0.53) transformed to induce additivity. Power to detect a 50% change at the impact stations was estimated assuming uncorrelated errors and this is somewhat inflated. Based on Technical Report K, Table A-2.

Mean Values				P	Power (%)	% Change
Before		After				
Control (SOKD)	Impact (SOKU)	Control (SOKD)	Impact (SOKU)			
7.62	7.65	7.47	11.16	0.001	~100%	45.8
(n = 31)		(n = 21)				

Table 11

Summary of BACIP tests on effects of cohesive sediments. Test compares densities Before and After influx of cohesive sediments on impacted quadrats relative to unimpacted quadrats in SOKU (the near Impact site).

GROUP	% CHANGE	P
Snails	-12.7	0.32
Non-muricid snails	-6.4	0.67
Muricid snails	-20.7	0.19
Sea urchins	-36.0	0.001
Sea stars	-56.4	0.02
Sessile invertebrates	-41.6	0.002

This page intentionally left blank.

8. FIGURES

Figure 1: Study areas in the vicinity of the San Onofre Nuclear Generating Station. The rectangles are the boundaries of the detailed maps of the San Onofre kelp forest (SOK, Figure 2), San Mateo kelp forest (SMK, Figure 3), and the Barn kelp forest (BARN). The Units 1, 2, and 3 intakes (circles), the Unit 1 outfall (triangle), and the Units 2 and 3 diffusers (labeled lines) are shown.

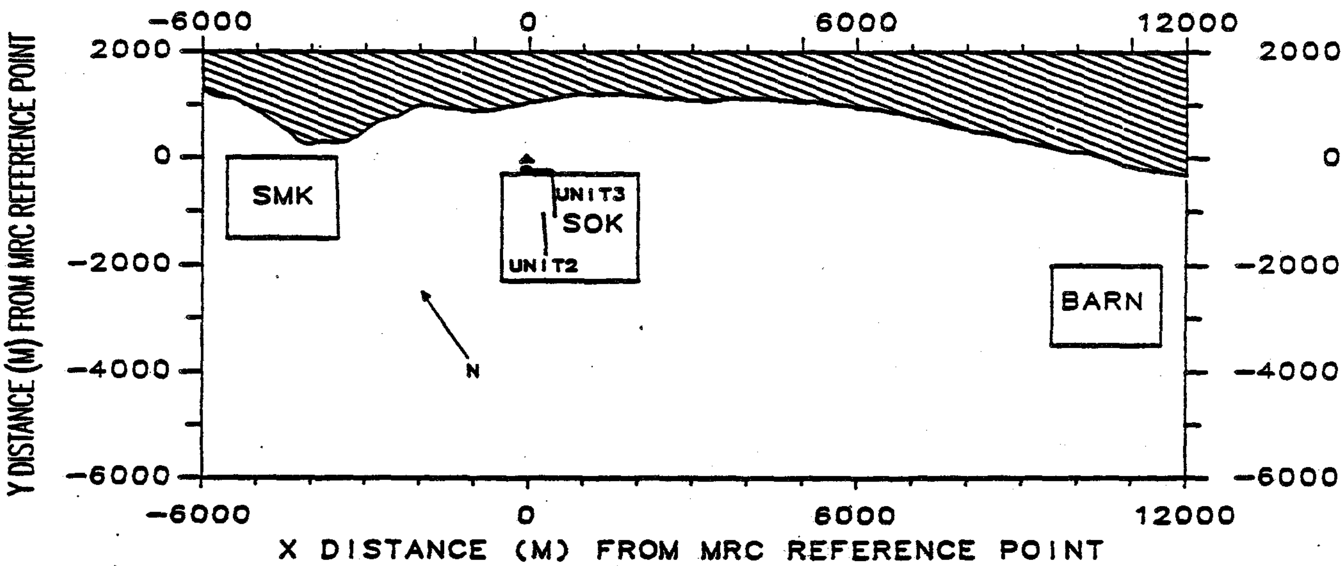
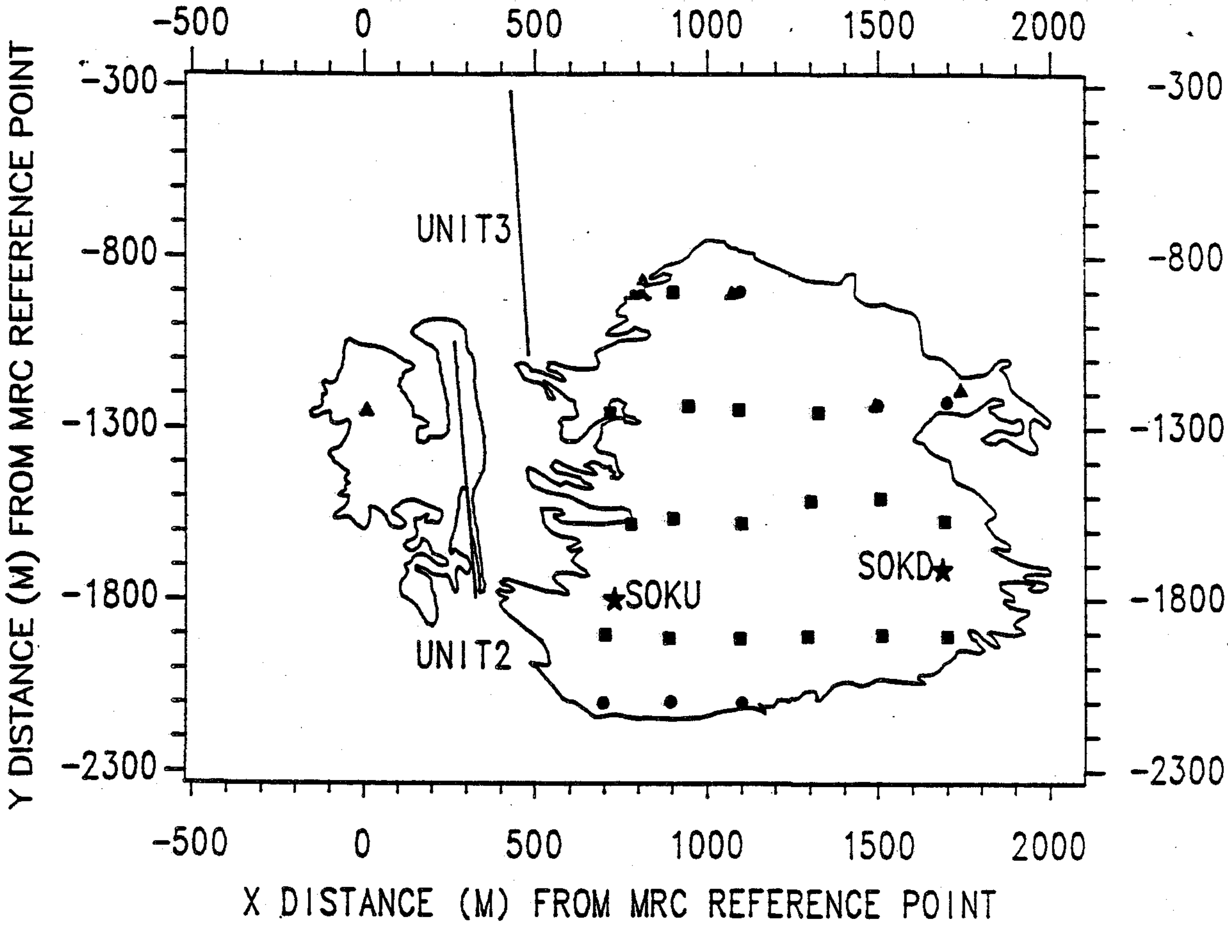

-6000
0
6000
12000
2000
0
-2000
-4000
-6000
Y DISTANCE (M) FROM MRC REFERENCE POINT
SMK
UNIT3
SOK
UNIT2
BARN
N
X DISTANCE (M) FROM MRC REFERENCE POINT

Figure 2: San Onofre kelp forest. The area of hard substrate is outlined in the upper figure, and the depth contours (m) are shown in the lower figure. The benthic survey stations are marked with stars. Extra stations sampled one time in 1981 only (circles), those sampled one time in 1986 only (triangles), and those sampled in both years (squares) are also plotted. These extra surveys were done to confirm that SOKU and SOKD were representative sites, and are discussed in Dixon _et_ _al_. (1988).


-500
0
500
1000
1500
2000
-300
-800
-1300
-1800
-2300
UNIT3
UNIT2
SOKU
SOKD
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

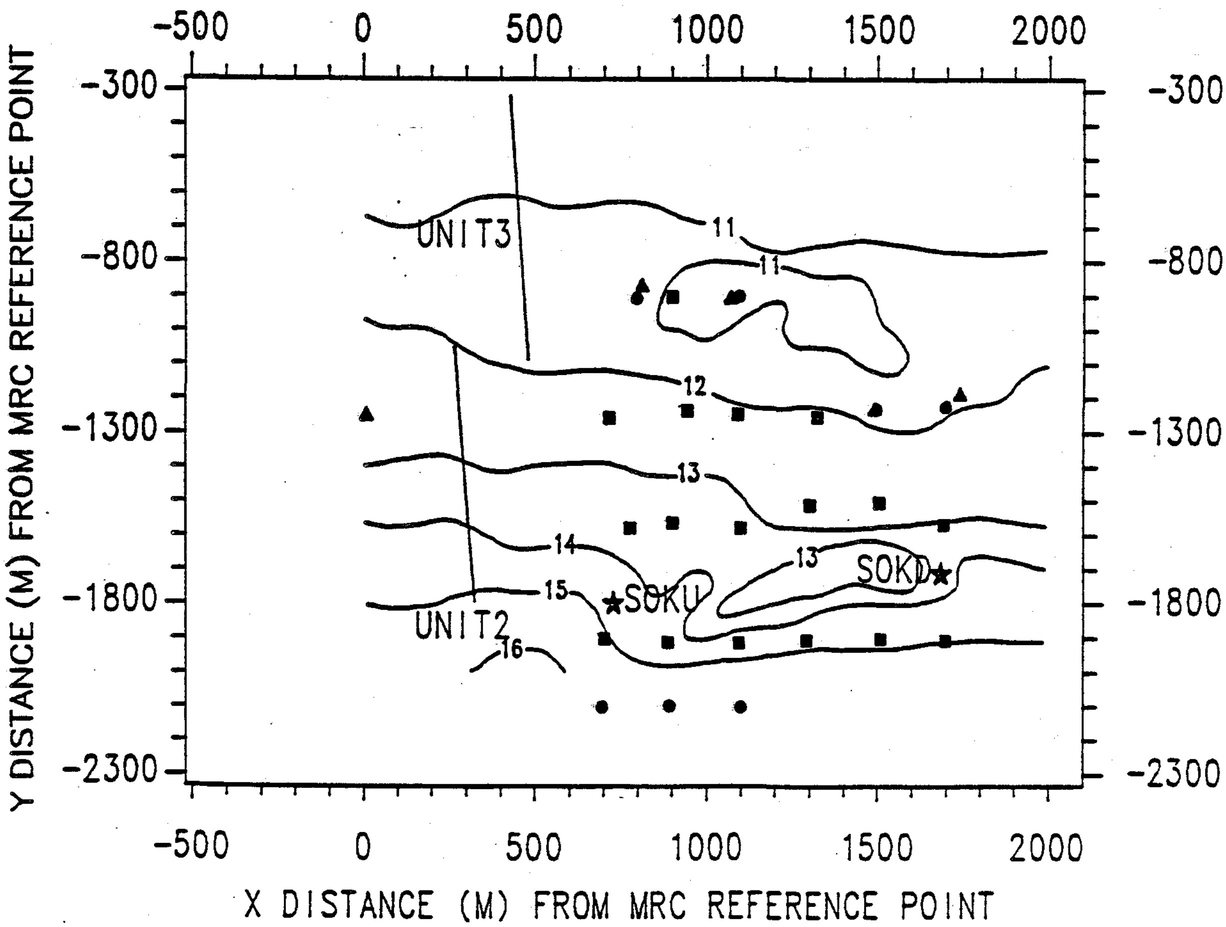
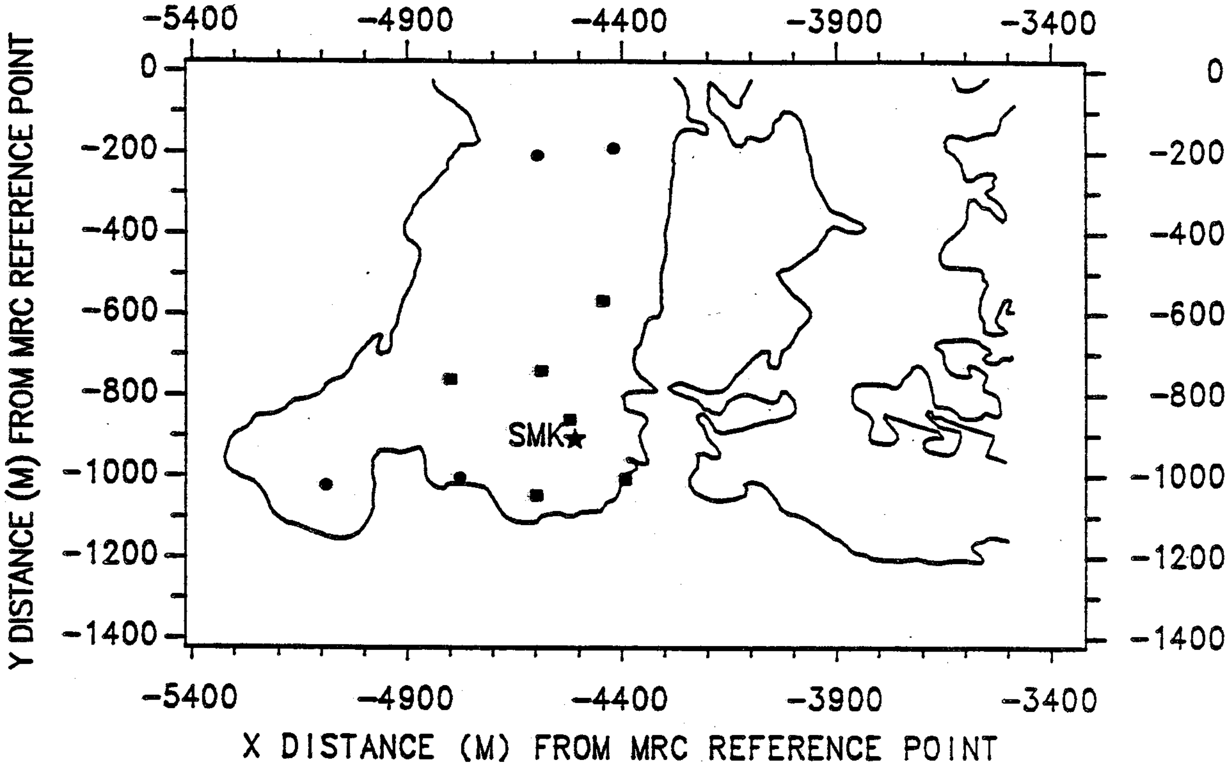

-500
0
500
1000
1500
2000
-300
-800
-1300
-1800
-2300
UNIT3
UNIT2
SOKU
SOKD
11
12
13
14
15
16
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

Figure 3: San Mateo kelp forest. The area of hard substrate is outlined in the upper figure, and the depth contours (m) are shown in the lower figure. The benthic survey station (star), the extra stations sampled in 1981 only (circles), and those sampled in both 1981 and 1986 (squares) are plotted. These extra surveys were done to confirm that SOKU and SOKD were representative sites, and are discussed in Dixon et al. (1988).


-5400
-4900
-4400
-3900
-3400
0
-200
-400
-600
-800
-1000
-1200
-1400
SMK
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

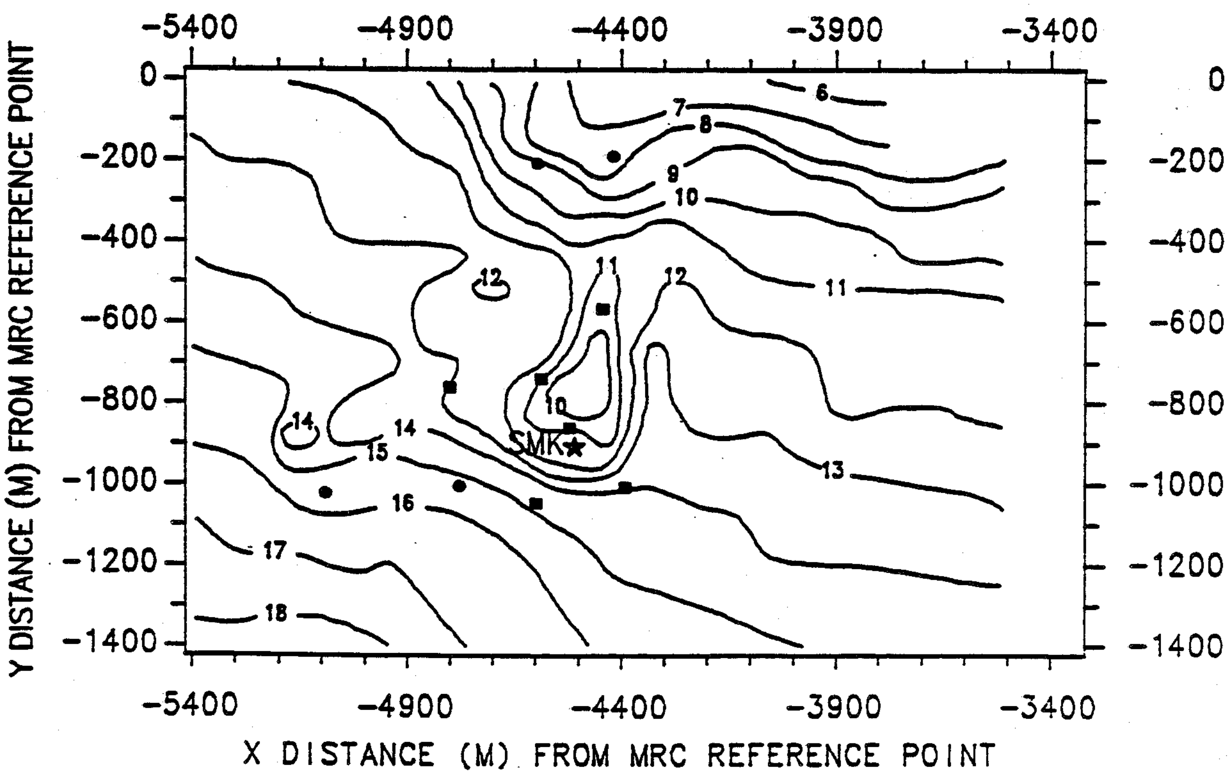
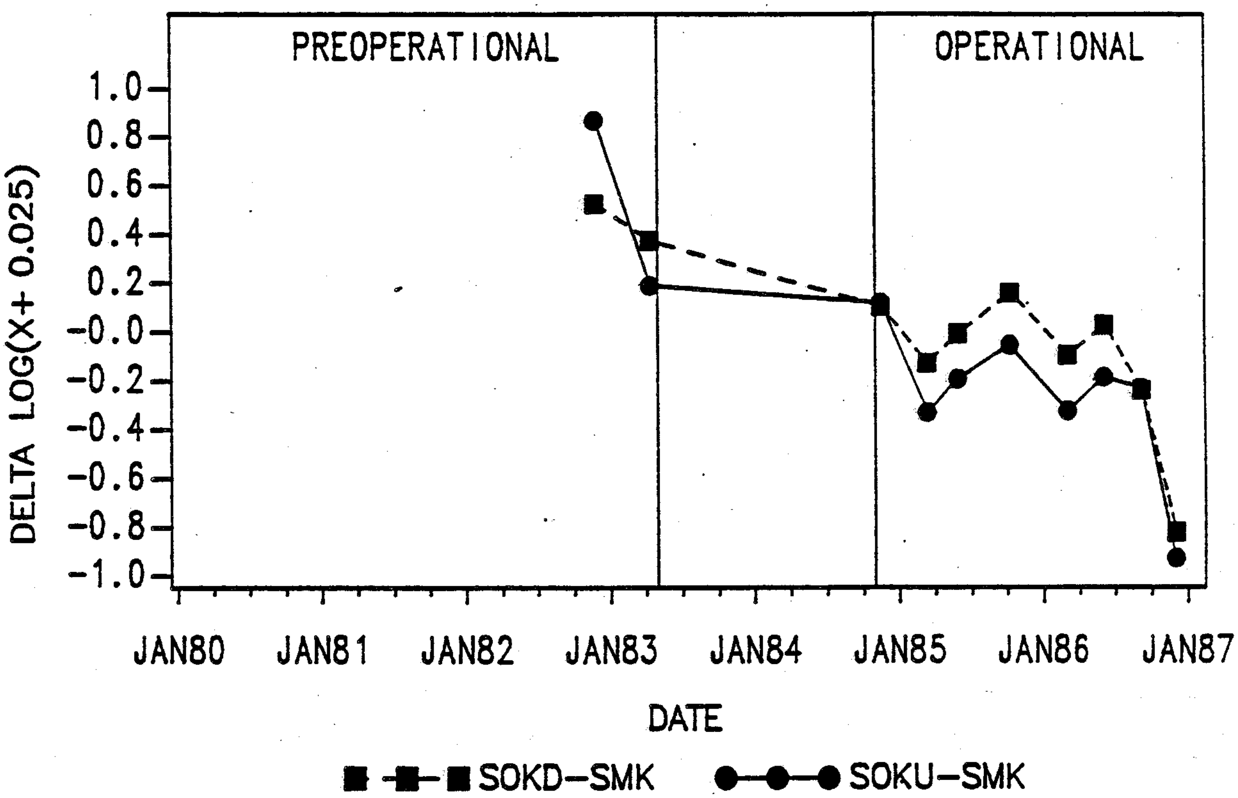
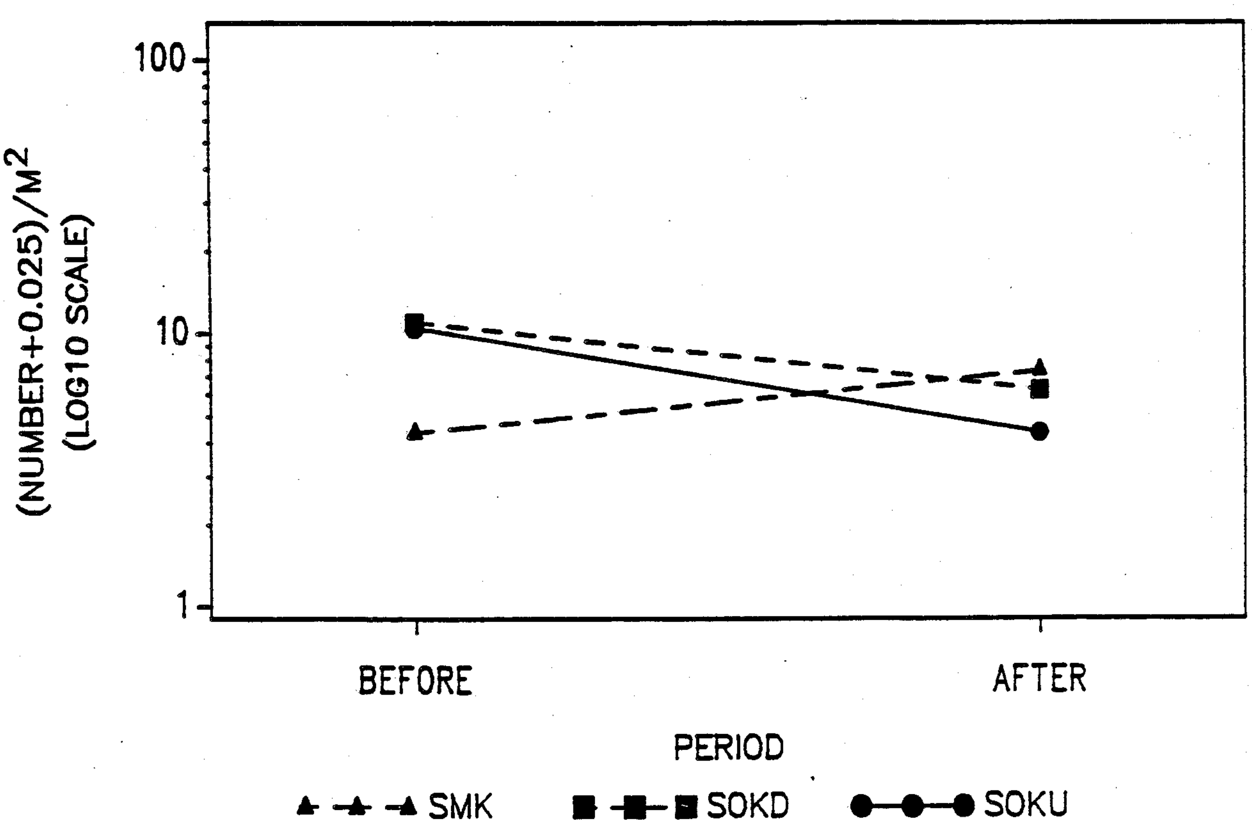

-5400
-4900
-4400
-3900
-3400
0
-200
-400
-600
-800
-1000
-1200
-1400
6
7
8
9
10
11
12
13
14
15
16
17
18
SMK
Y DISTANCE (M) FROM MRC REFERENCE POINT
X DISTANCE (M) FROM MRC REFERENCE POINT

Figure 4 a-y: Each page contains results for a taxon or group of taxa. On the top of each page is a plot of deltas (impact value - control value) against time for the near impact (SOKU) and the far impact (SOKD). The bottom of each page is the "interaction plot" containing the mean (back-transformed) density at each site (SOKU, SOKD, and the control at SMK) for the Before and After periods.

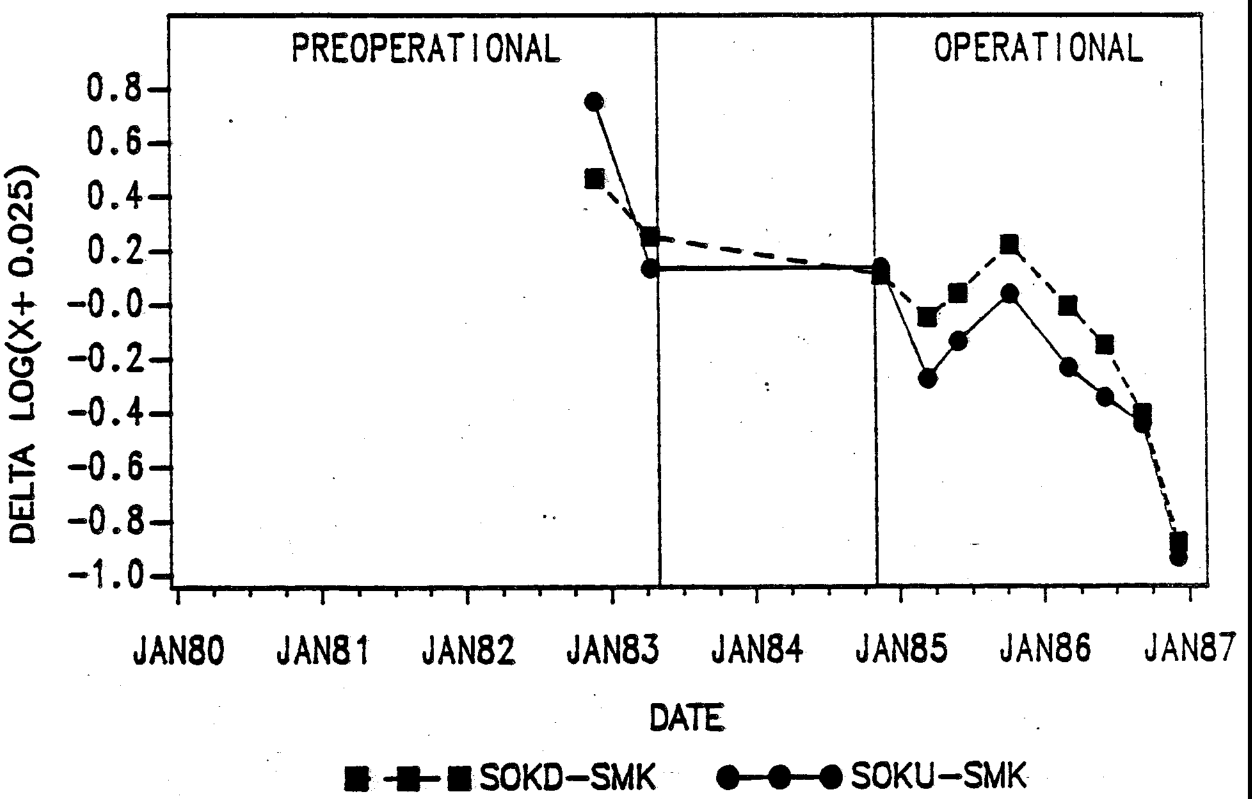
a

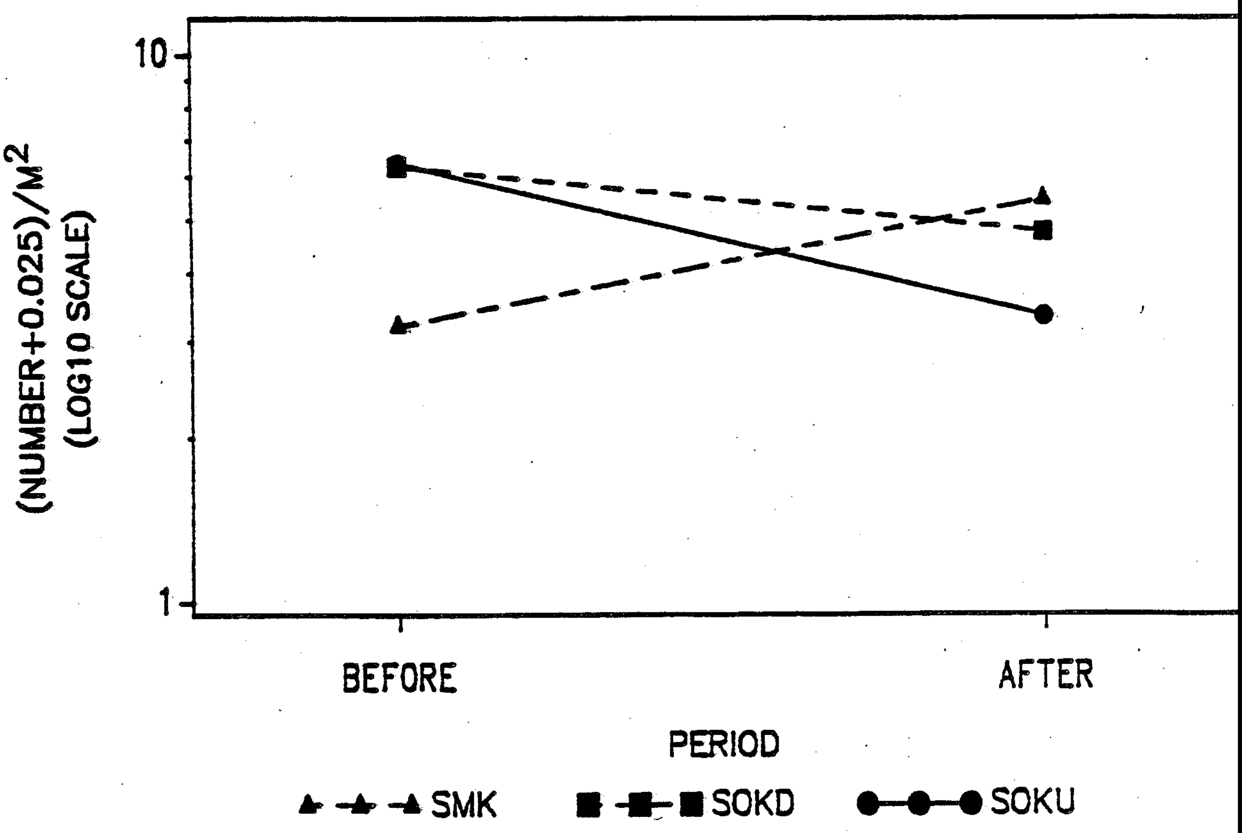
ALL SNAILS


PREOPERATIONAL
OPERATIONAL
DELTA LOG(X+ 0.025)
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK

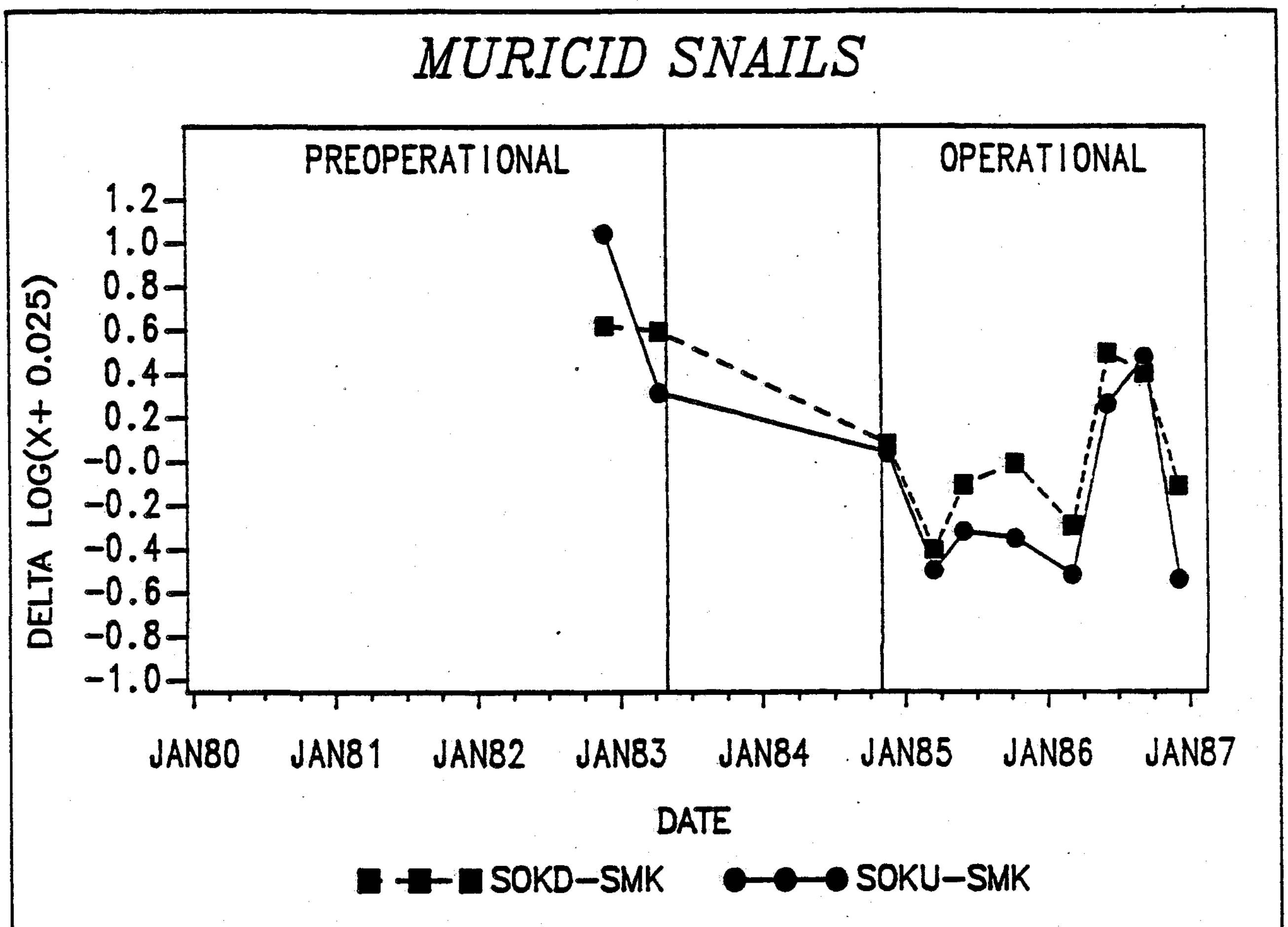

(NUMBER+0.025)/M2
(LOG10 SCALE)
100
10
1
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

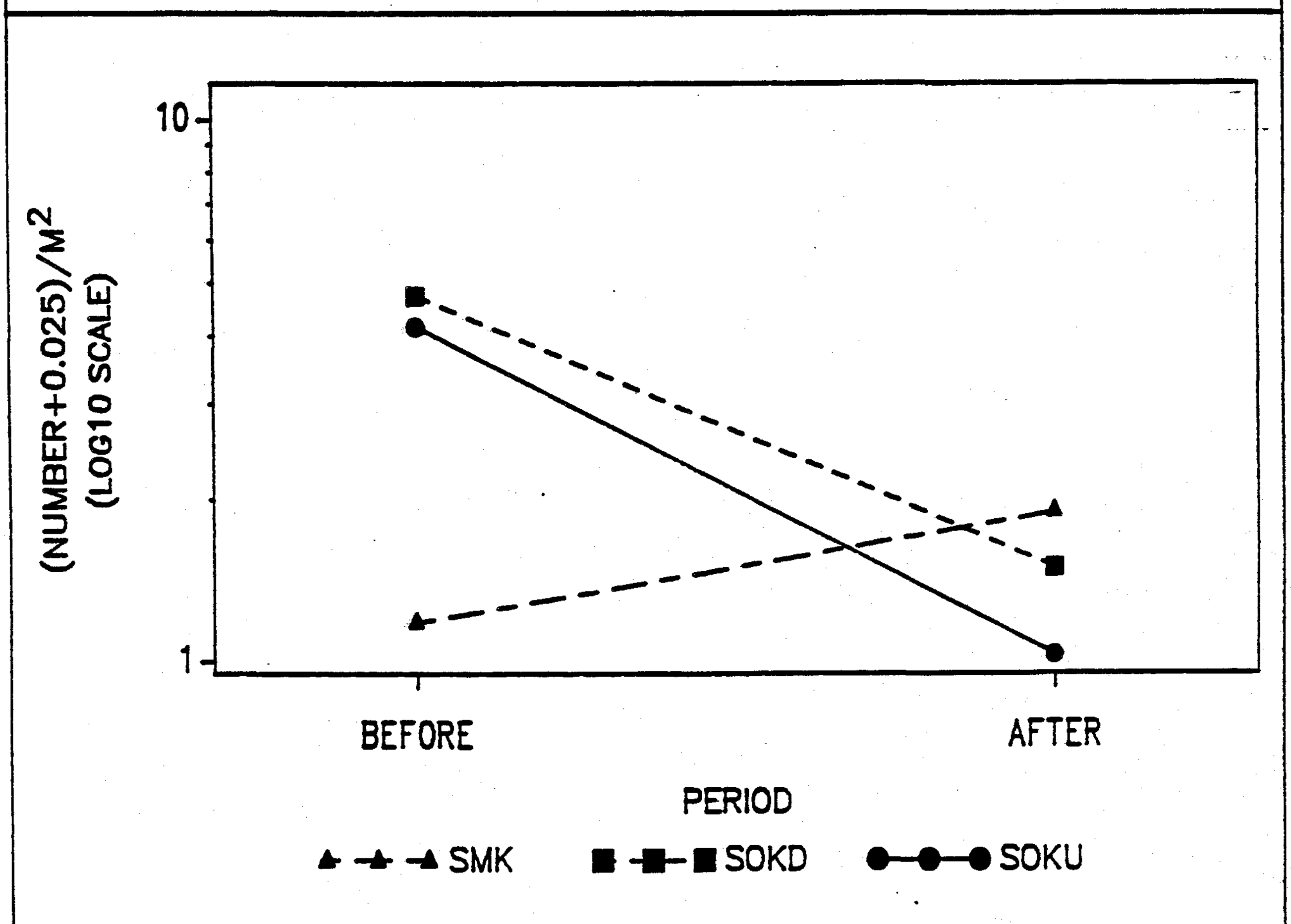
NON-MURICID SNAILS





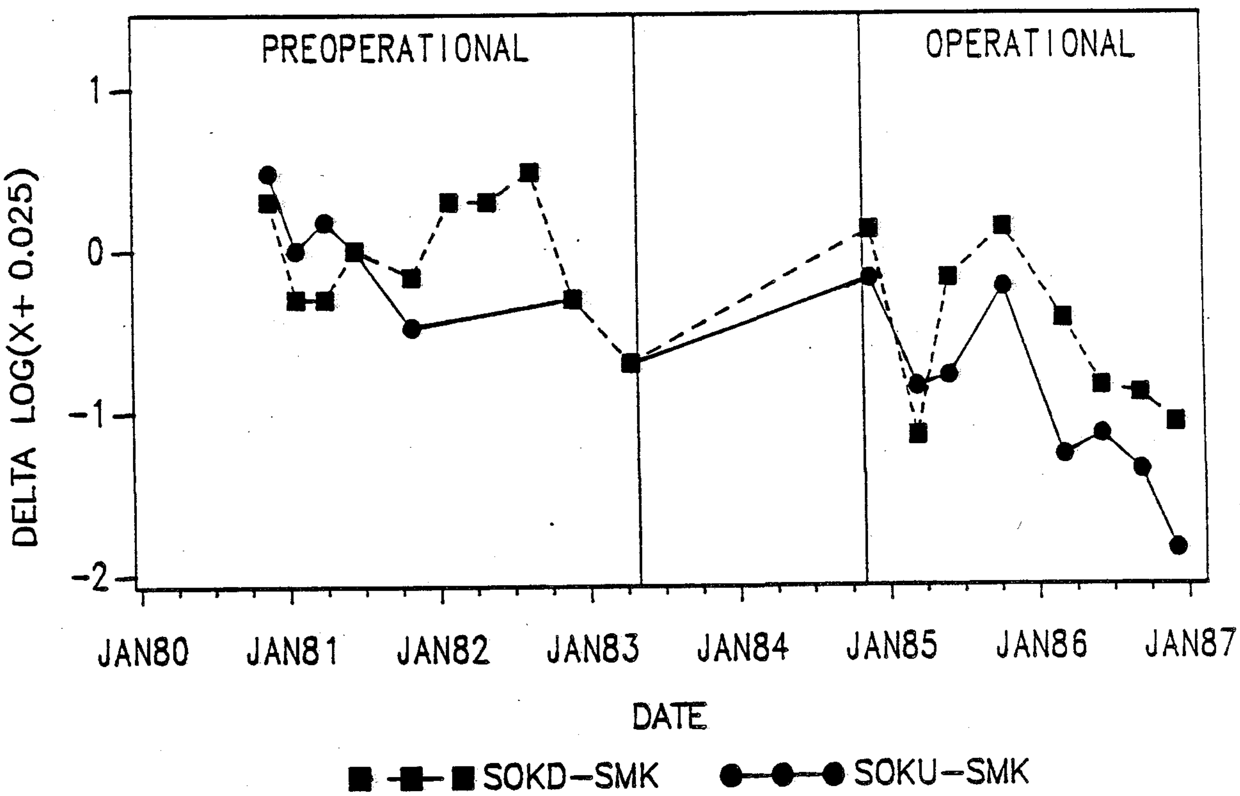
c

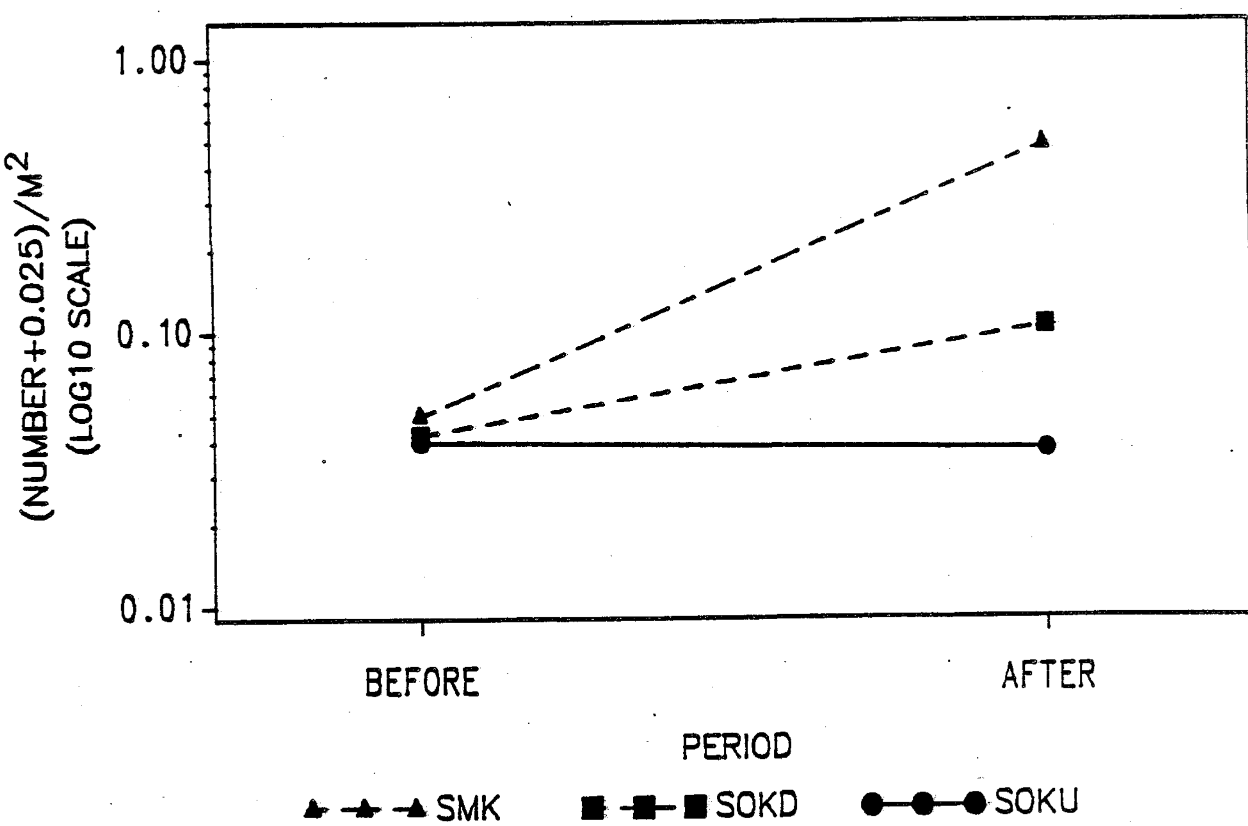

MURICID SNAILS
PREOPERATIONAL
OPERATIONAL
DELTA LOG(X+ 0.025)
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK


(NUMBER+0.025)/M^2
(LOG10 SCALE)
10
1
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

26-27
32938 179-197

Astraea undosa

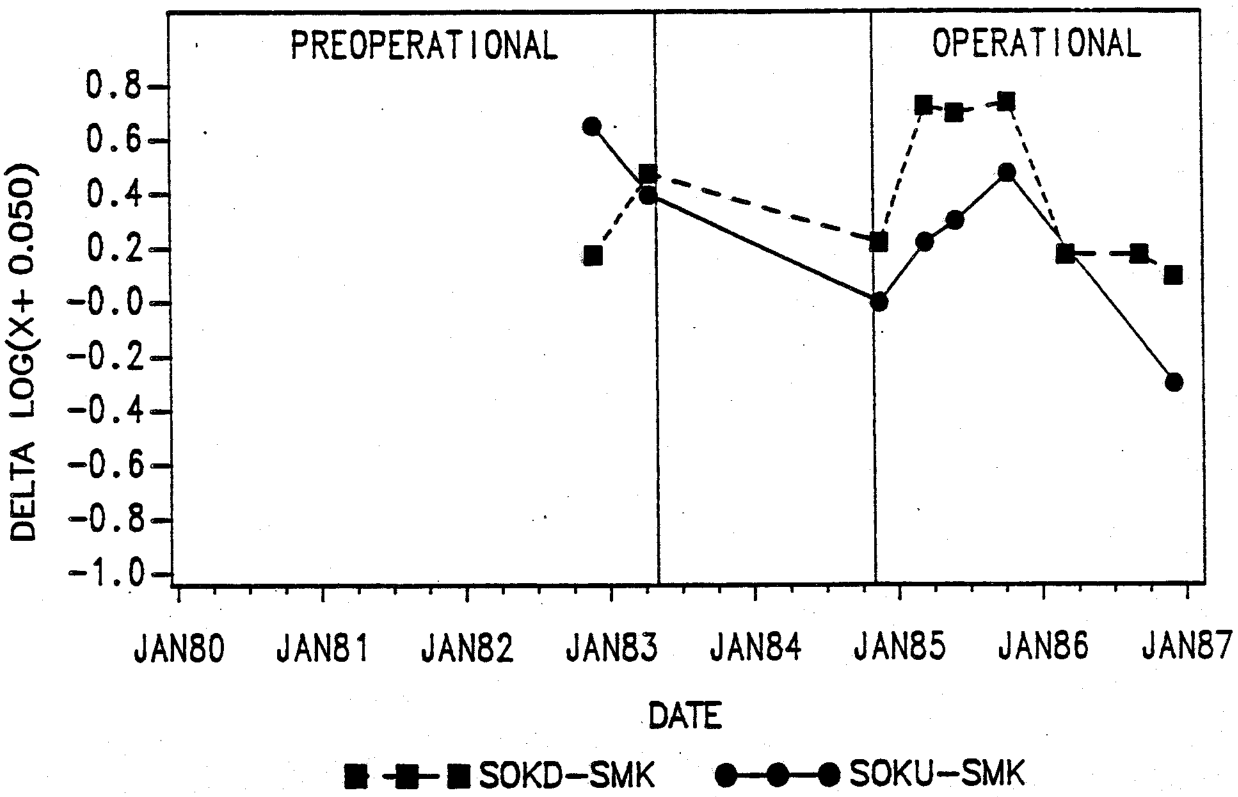


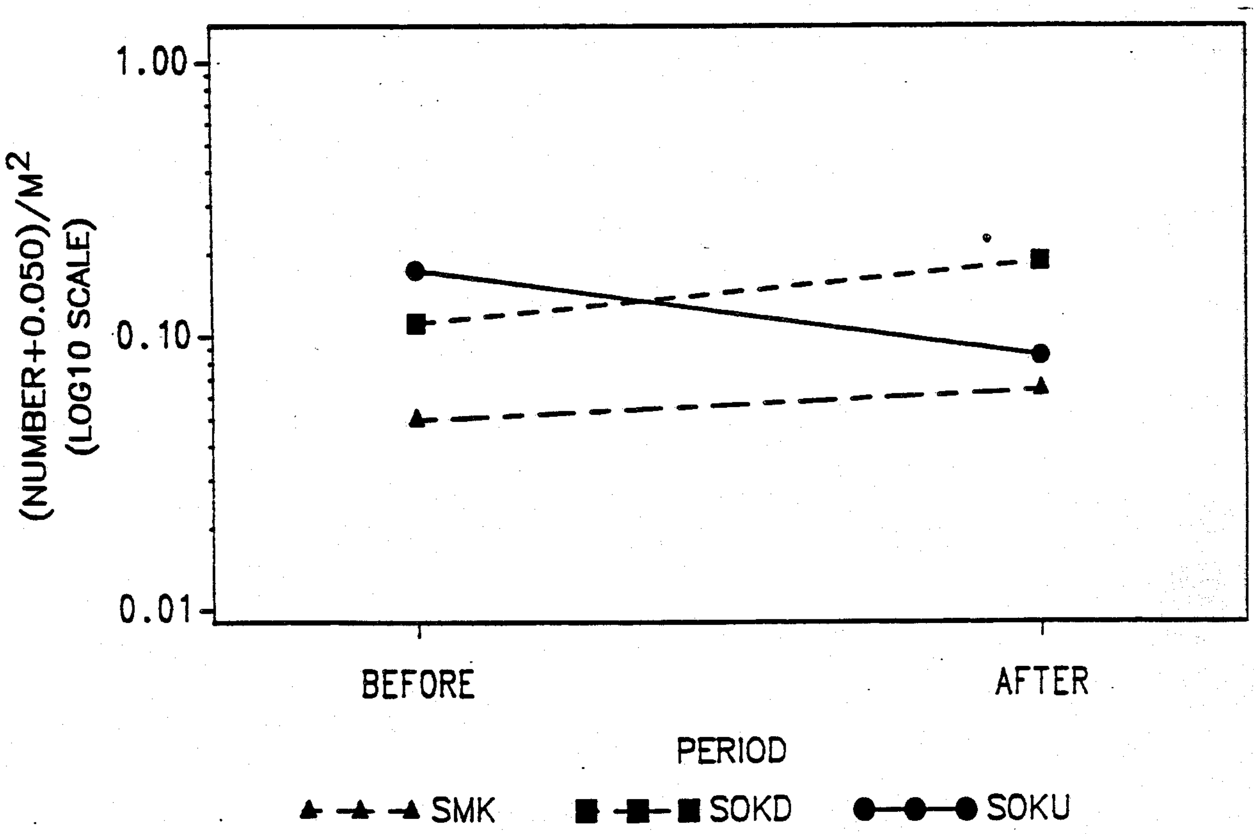


30500 12-7-137 18-19

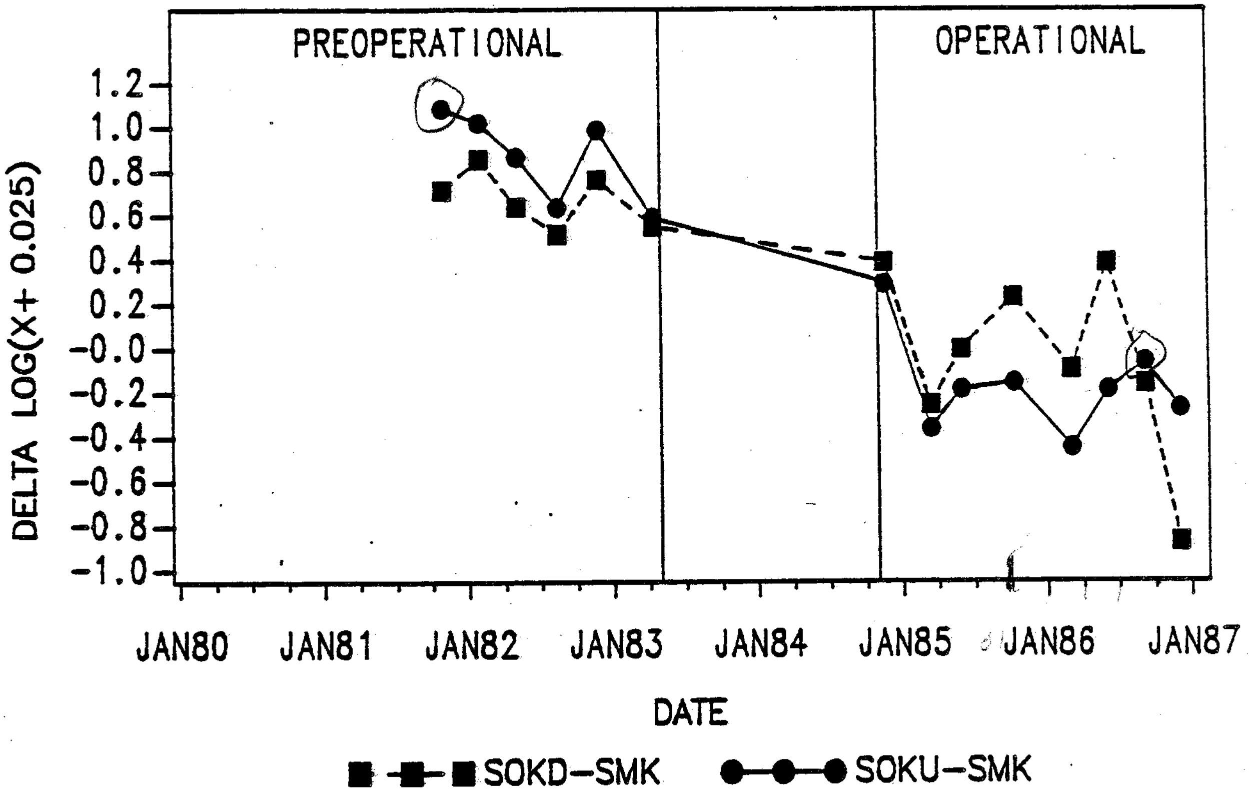
e

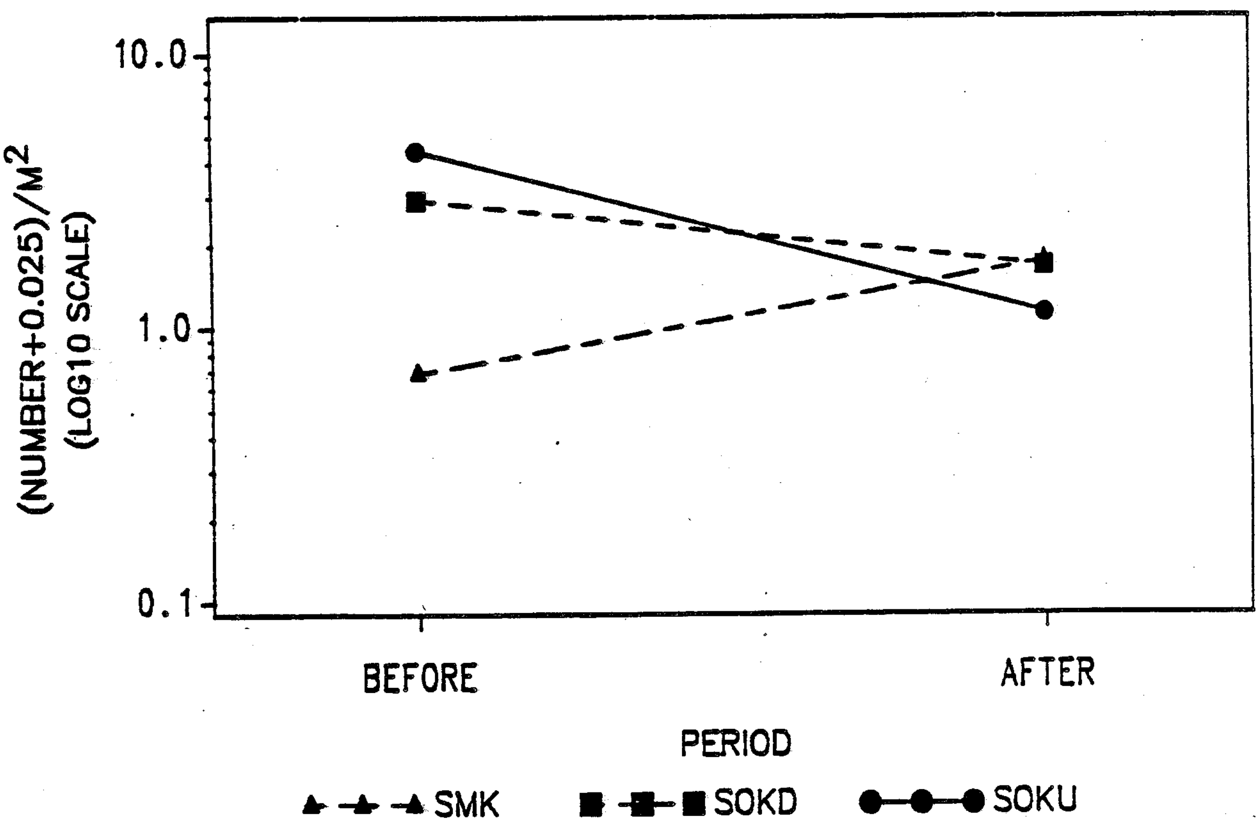
Calliostoma spp.





Conus californicus

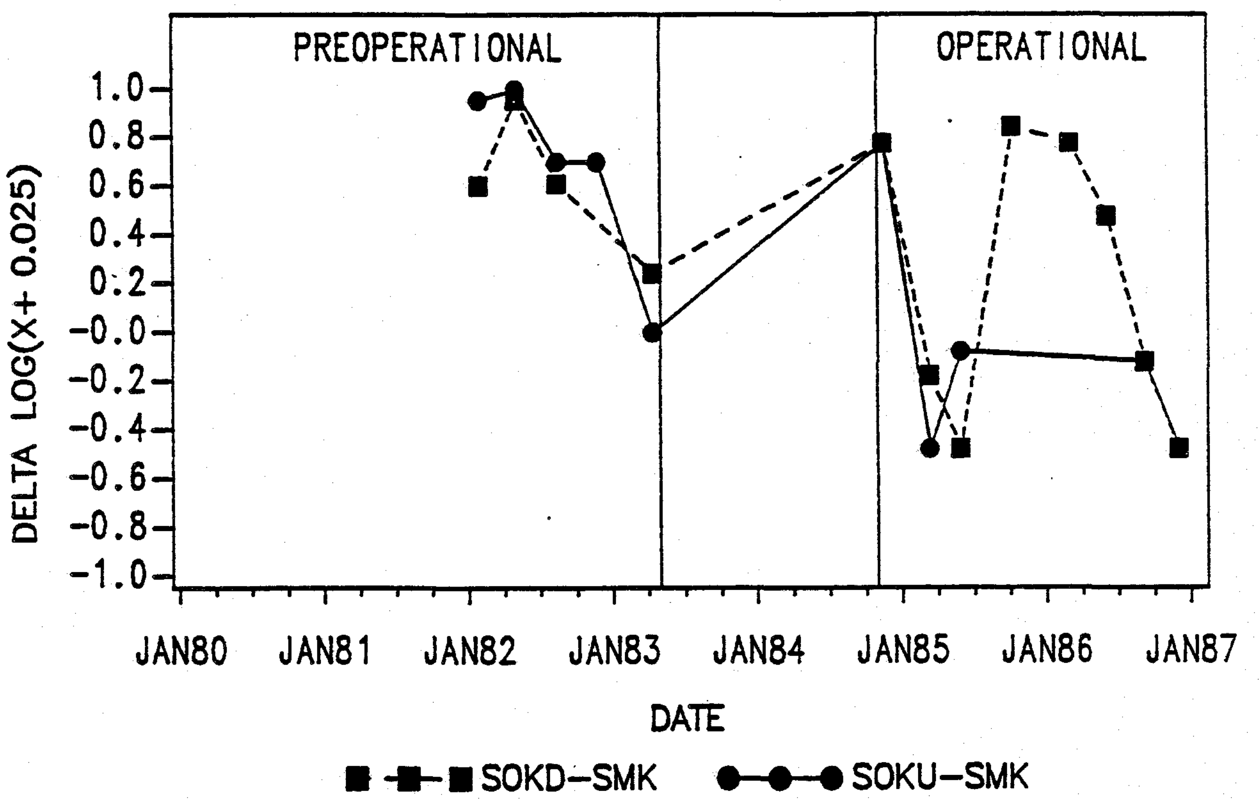


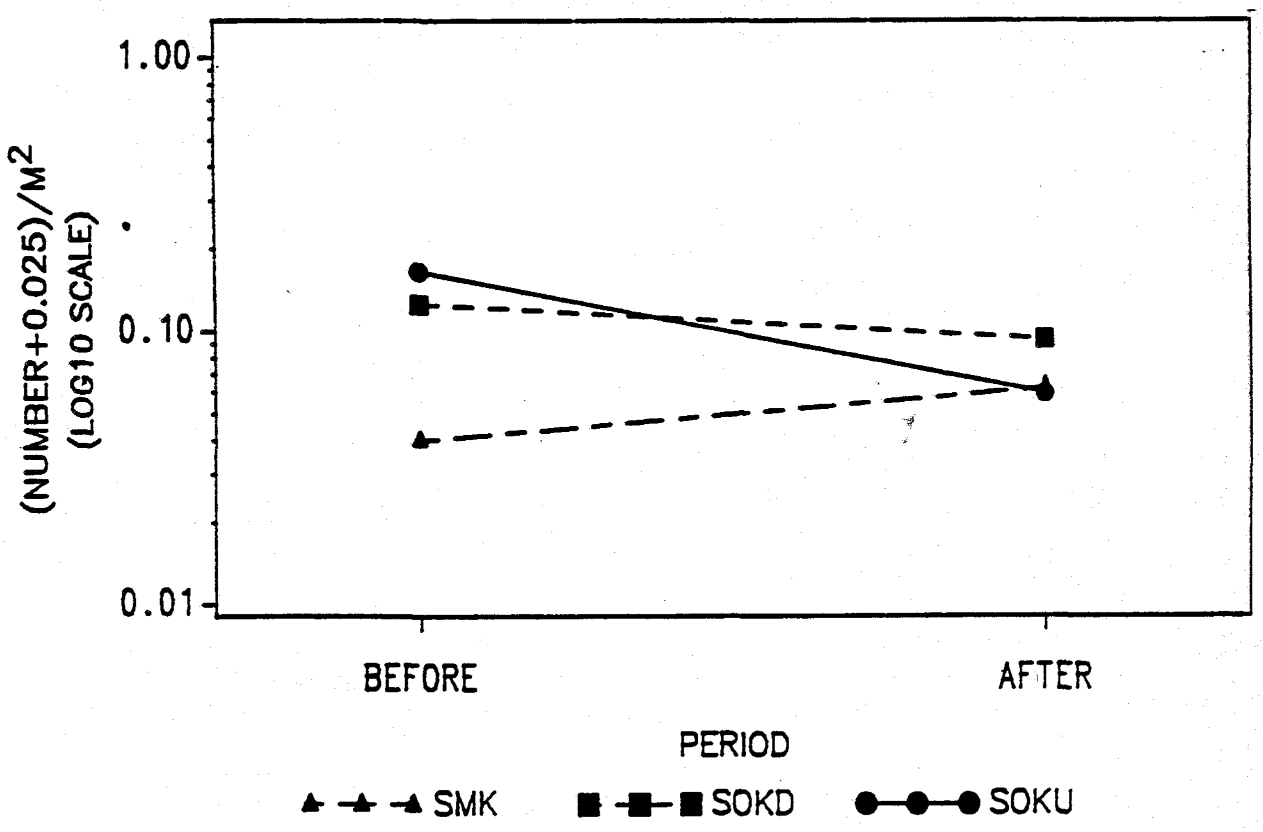


33801 412-425 61-62

g

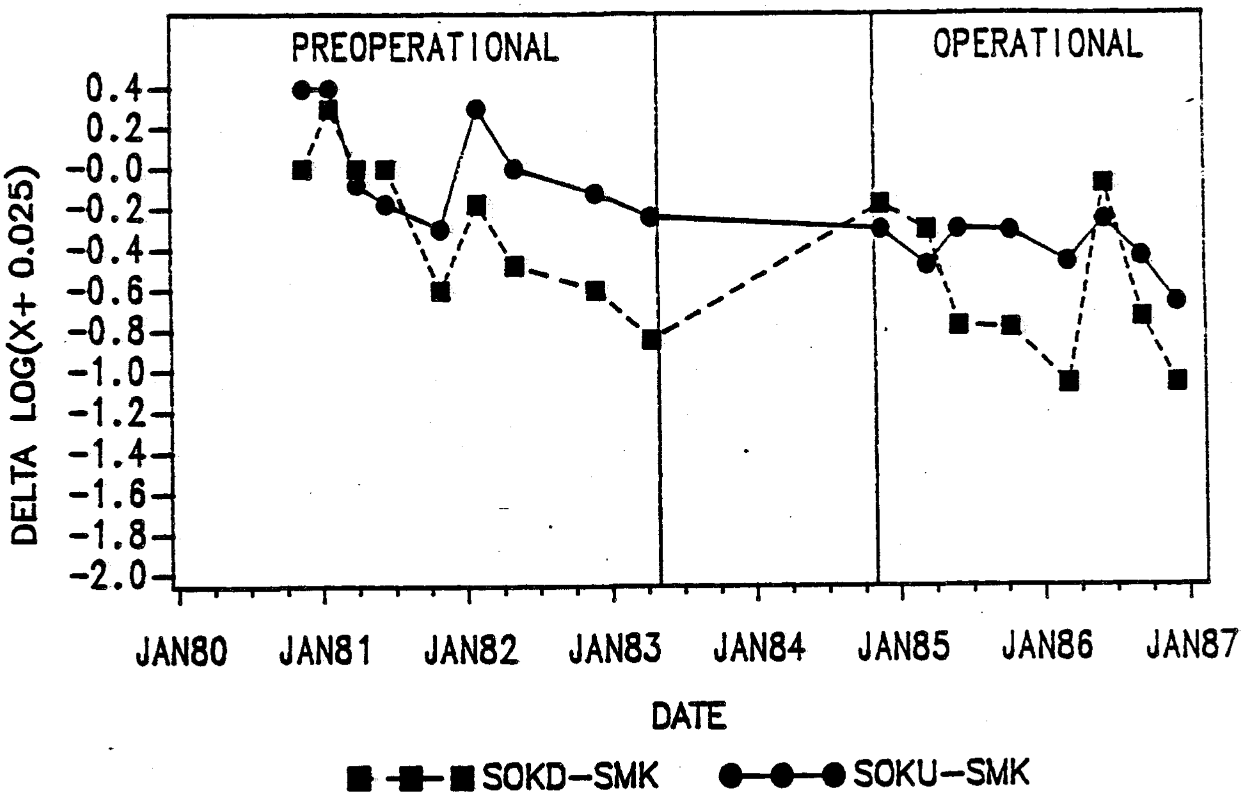
Crassispira semiinflata

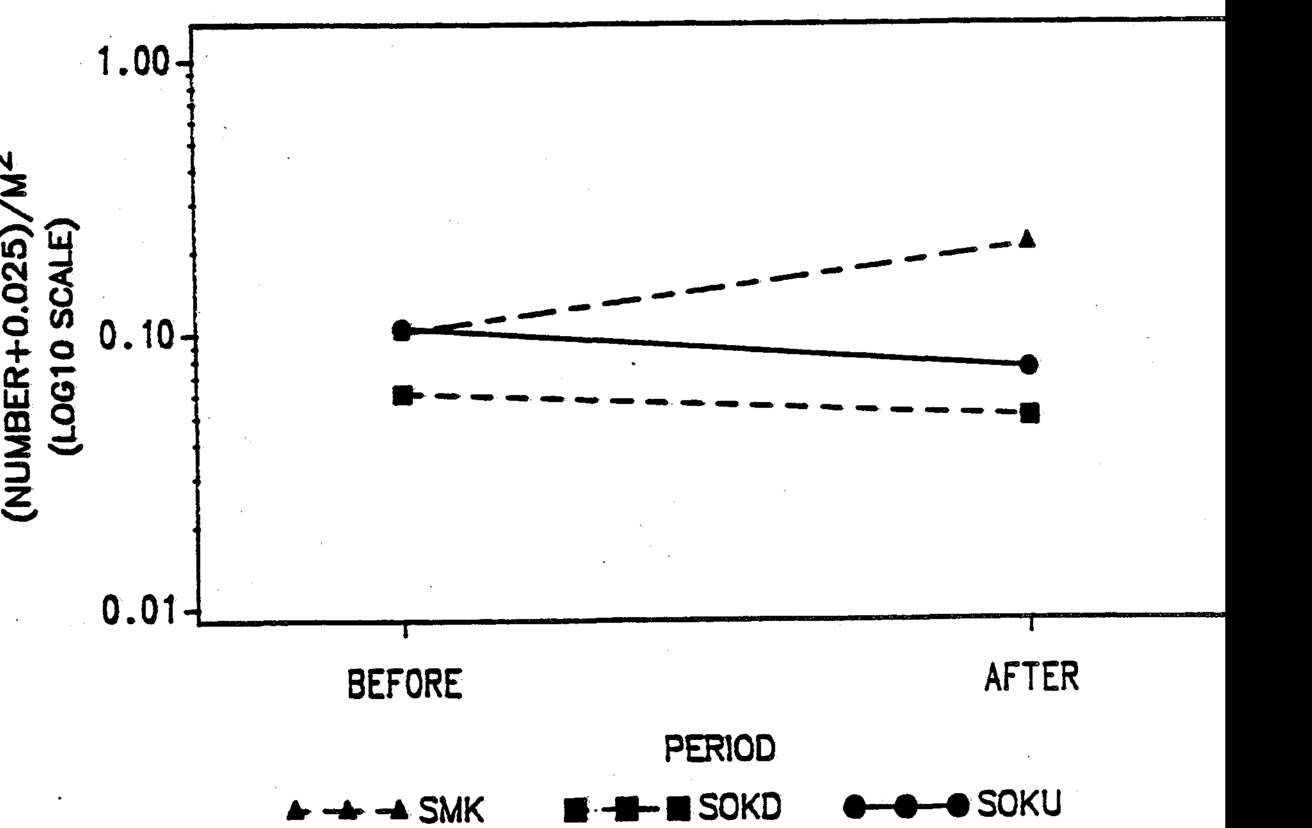




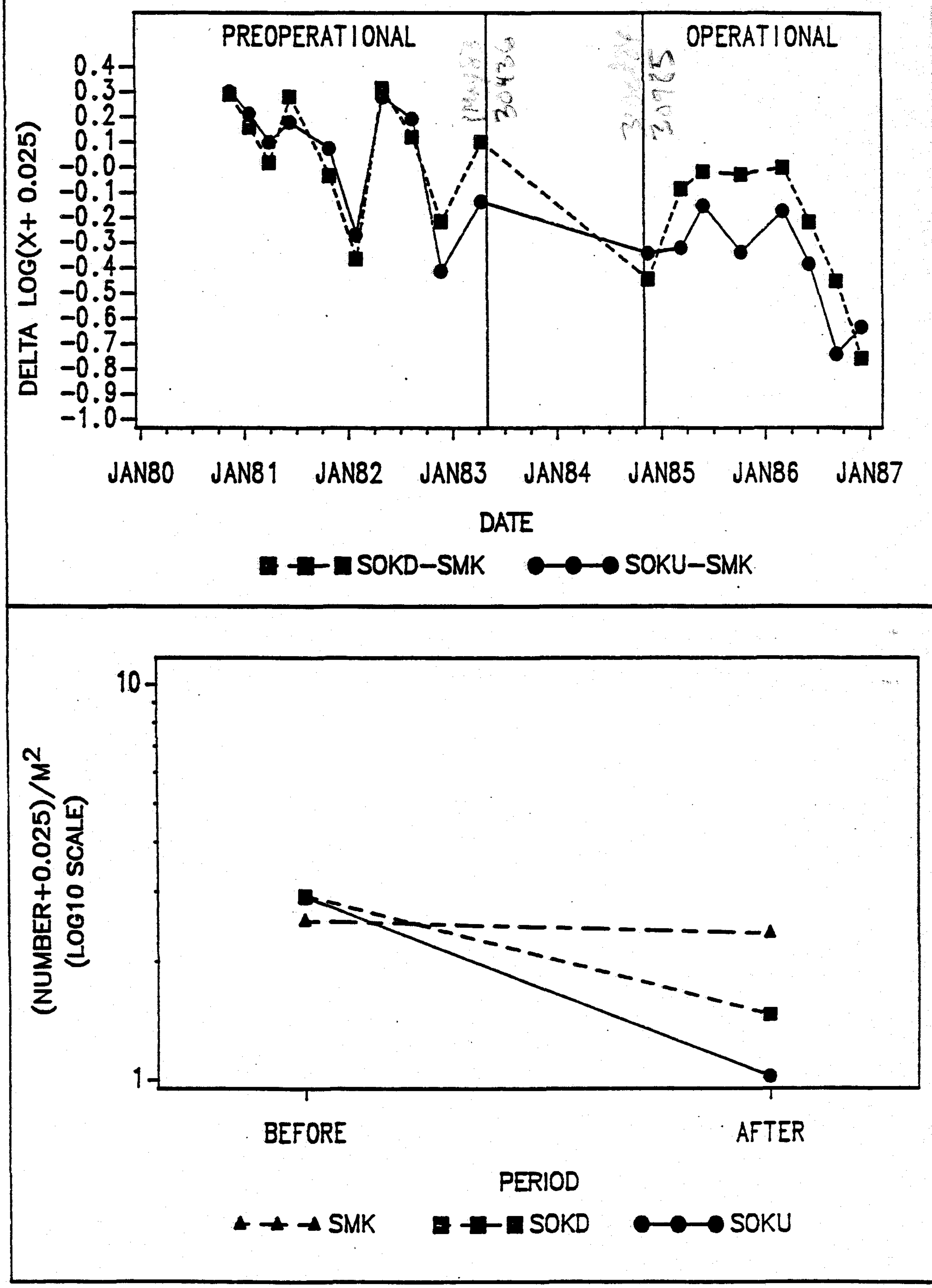
33-34 234-252

Cypraea spadicea



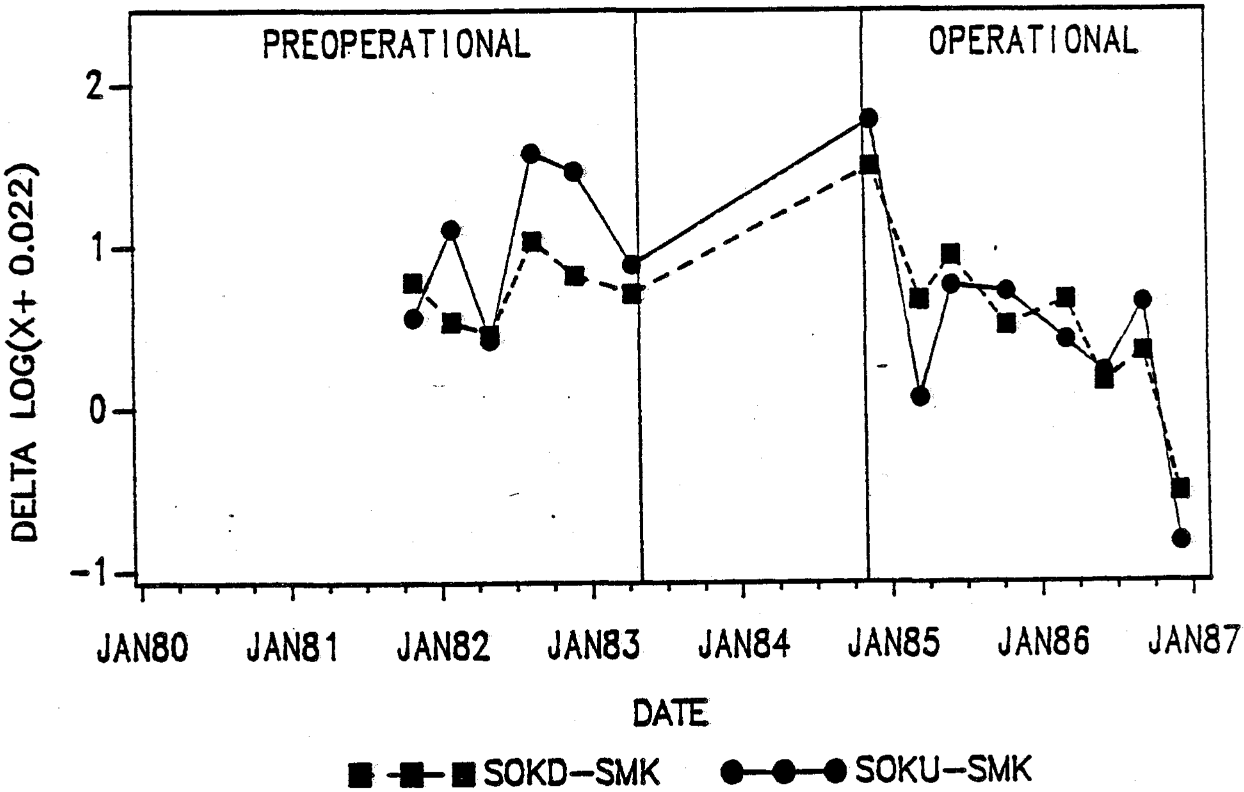


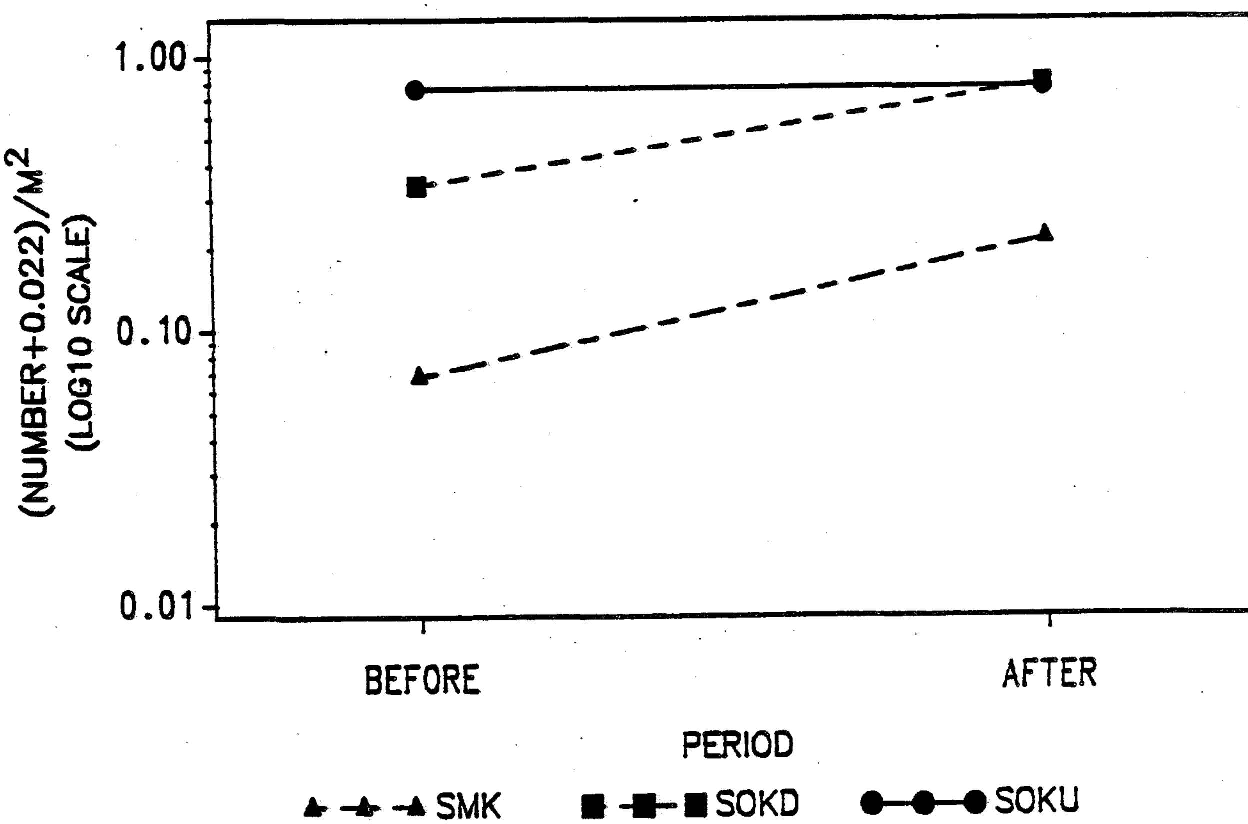
Kelletia kelletii

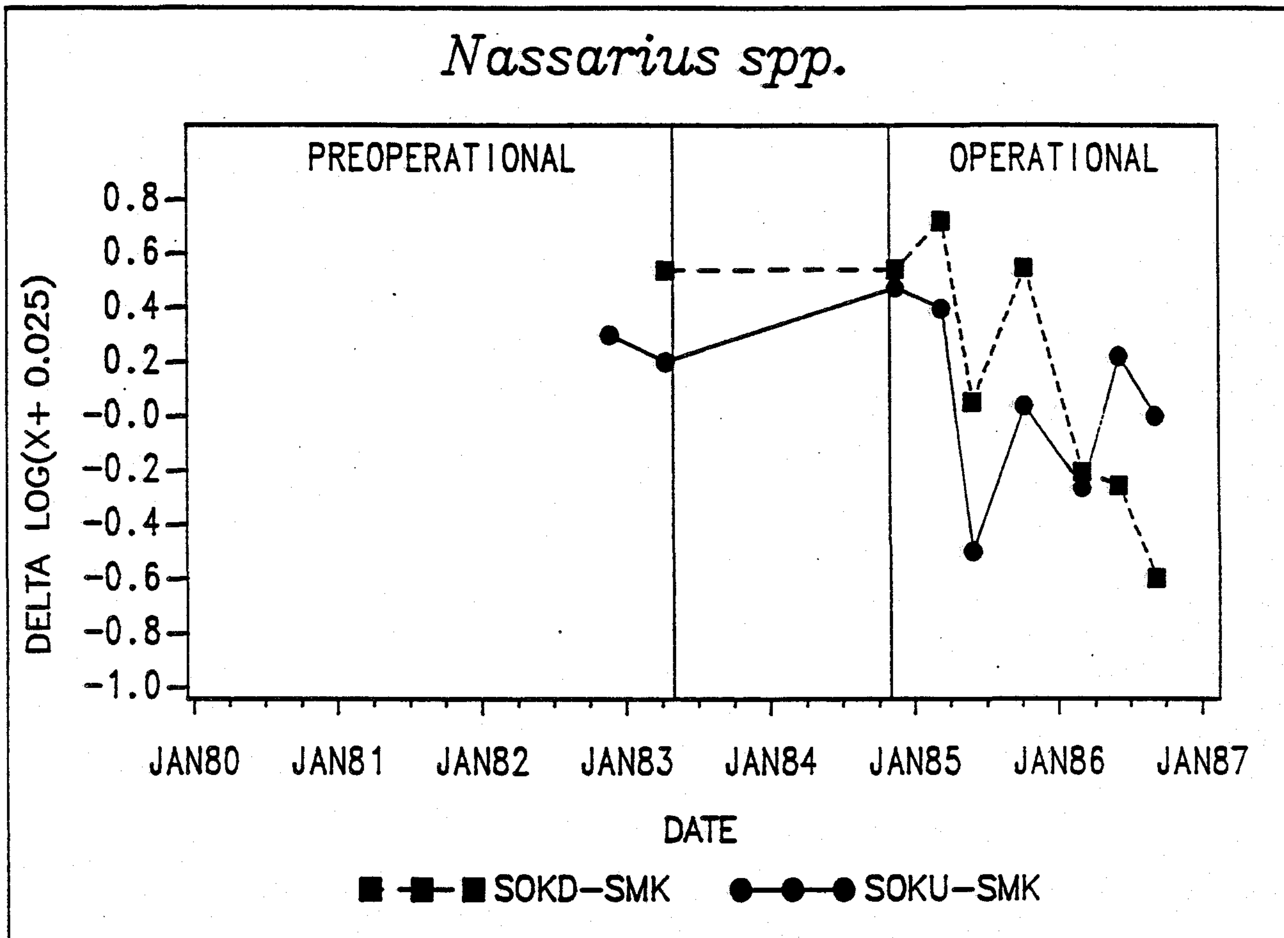


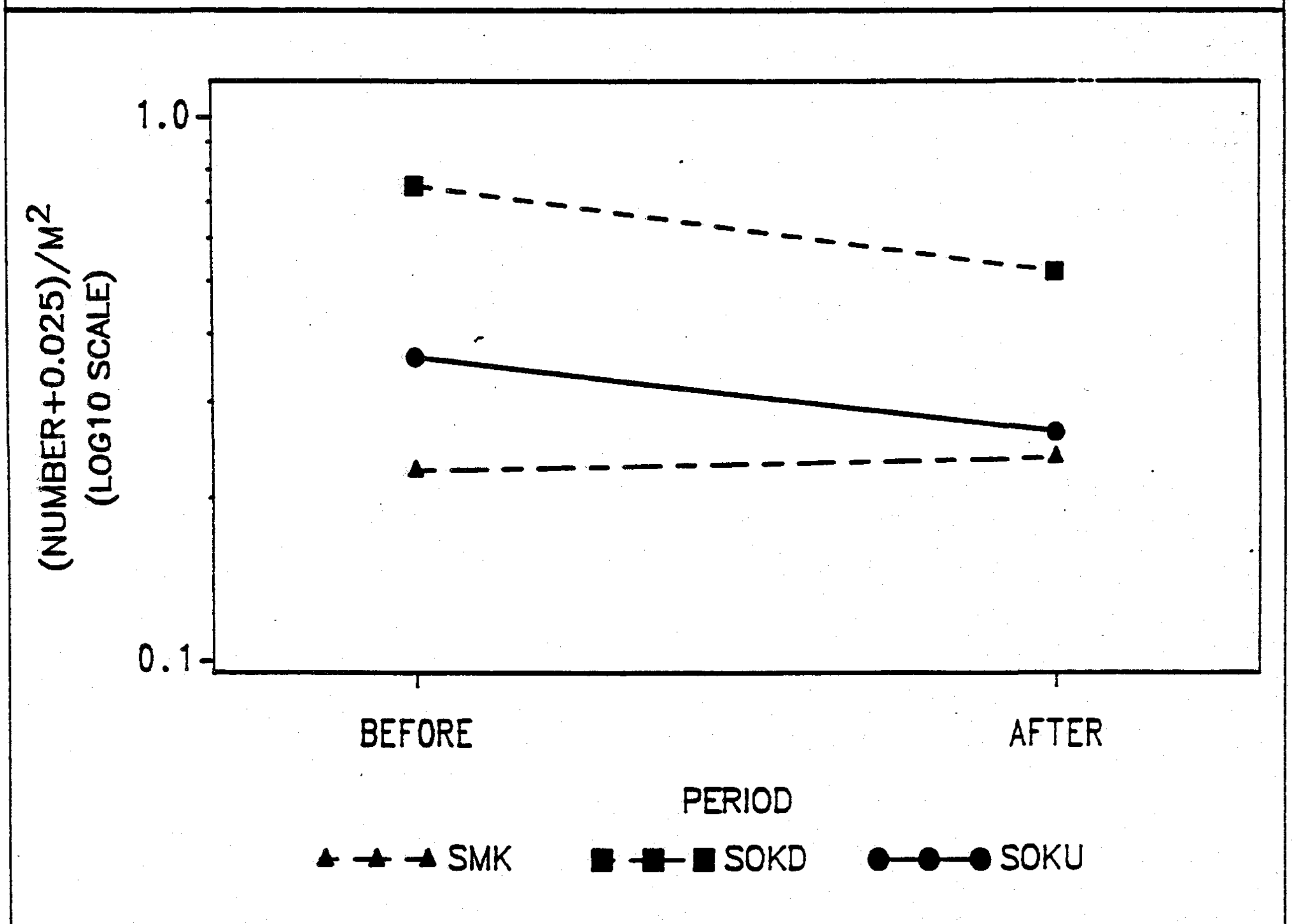
371-385 55-56

Mitra idae

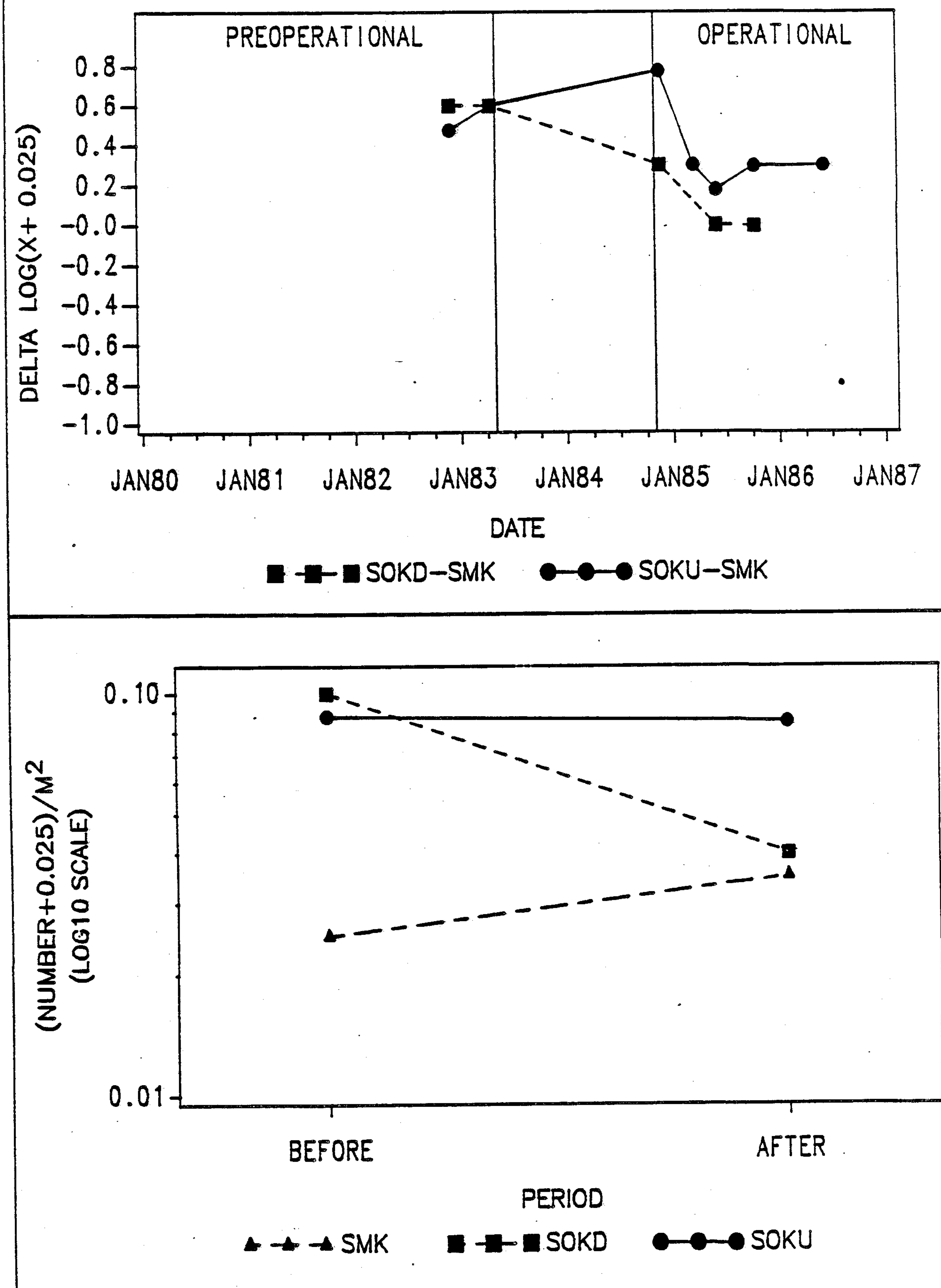




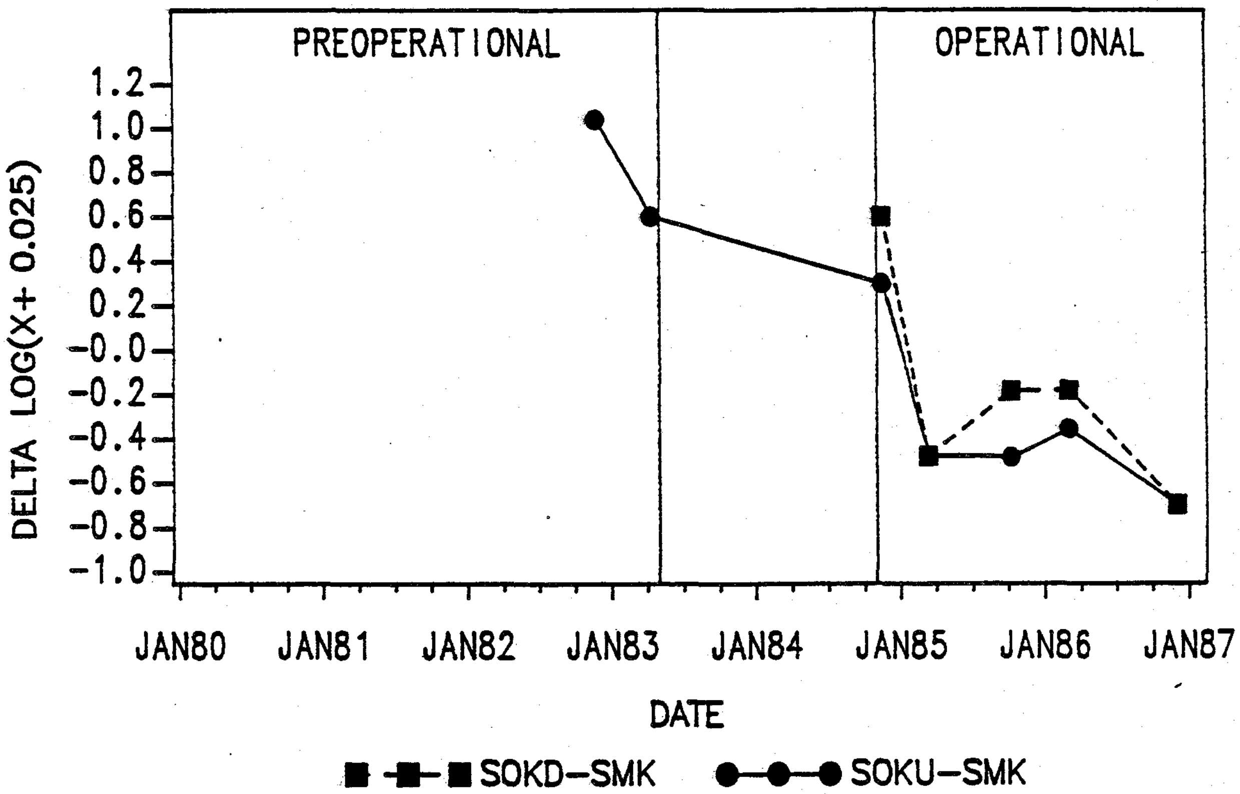

Nassarius spp.
PREOPERATIONAL
OPERATIONAL
DELTA LOG(X+ 0.025)
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK

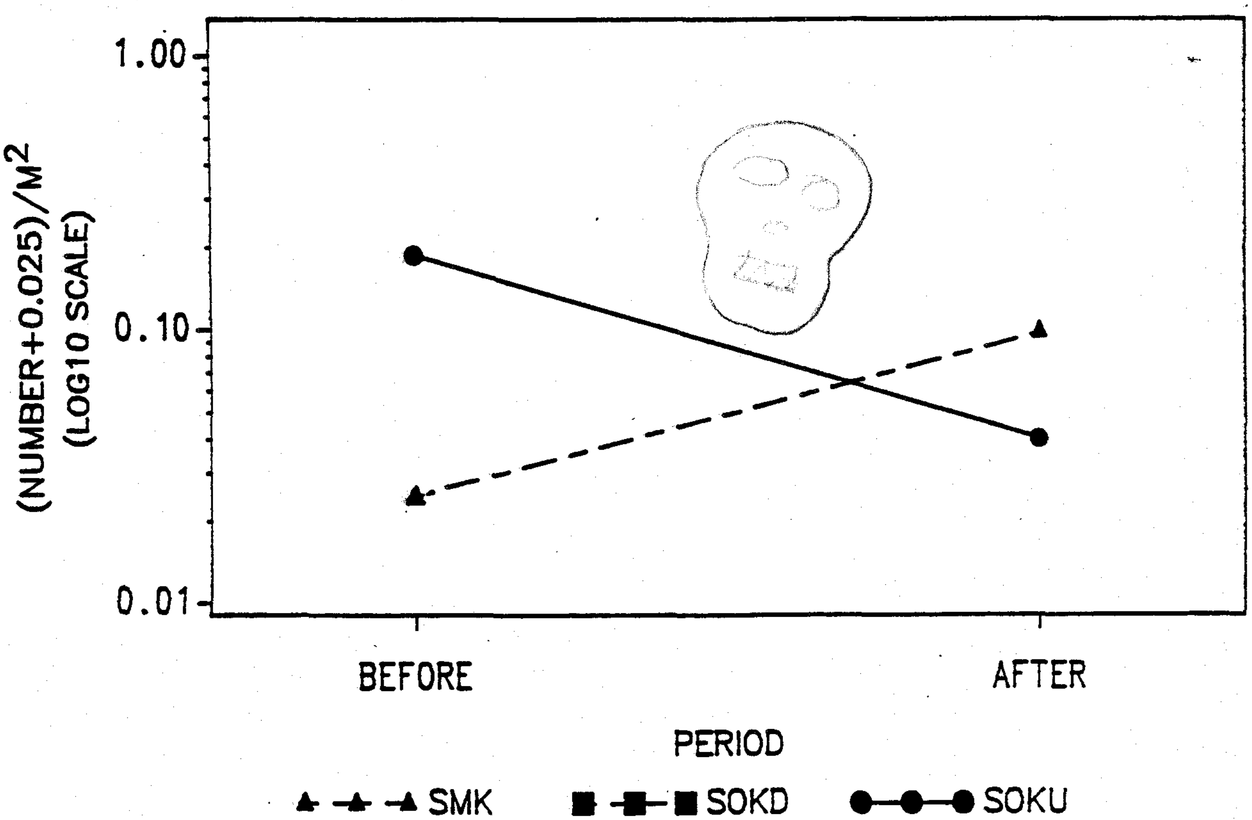

(NUMBER+0.025)/M2
(LOG10 SCALE)
1.0
0.1
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

Ophiodermella inermis

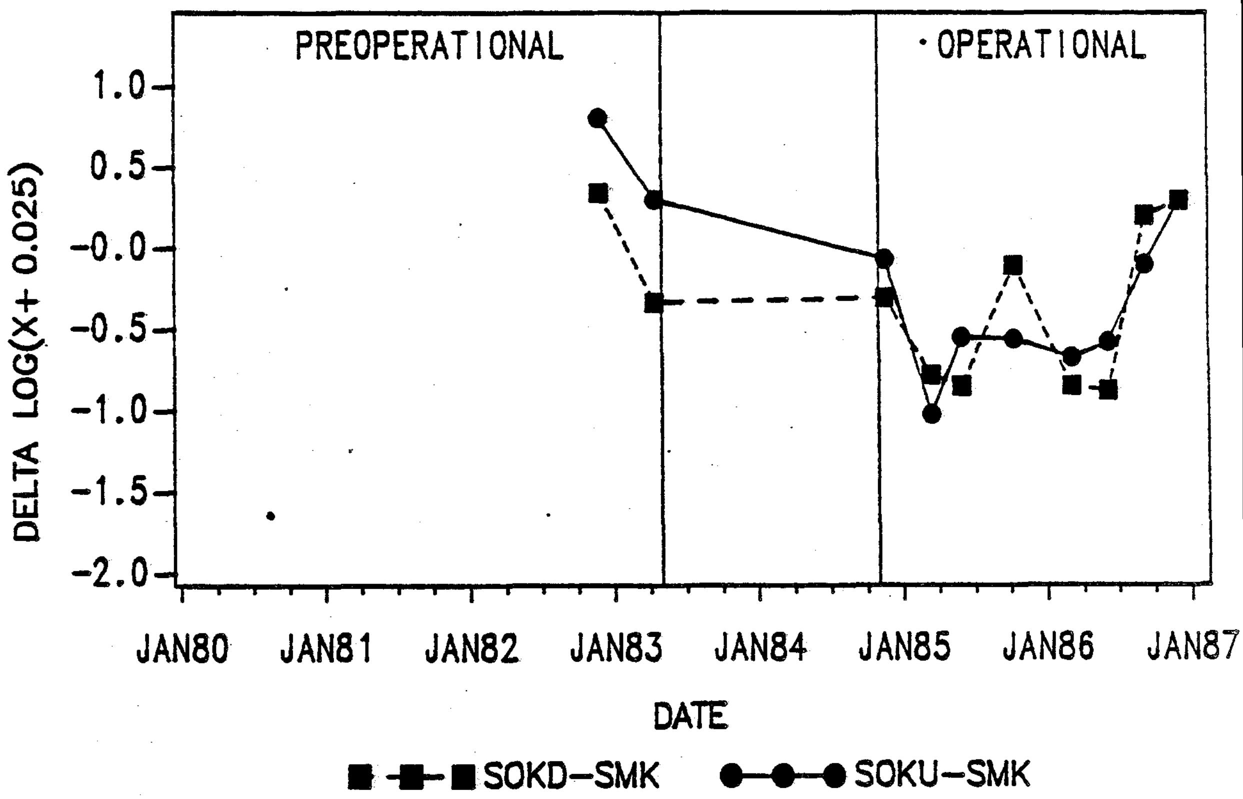


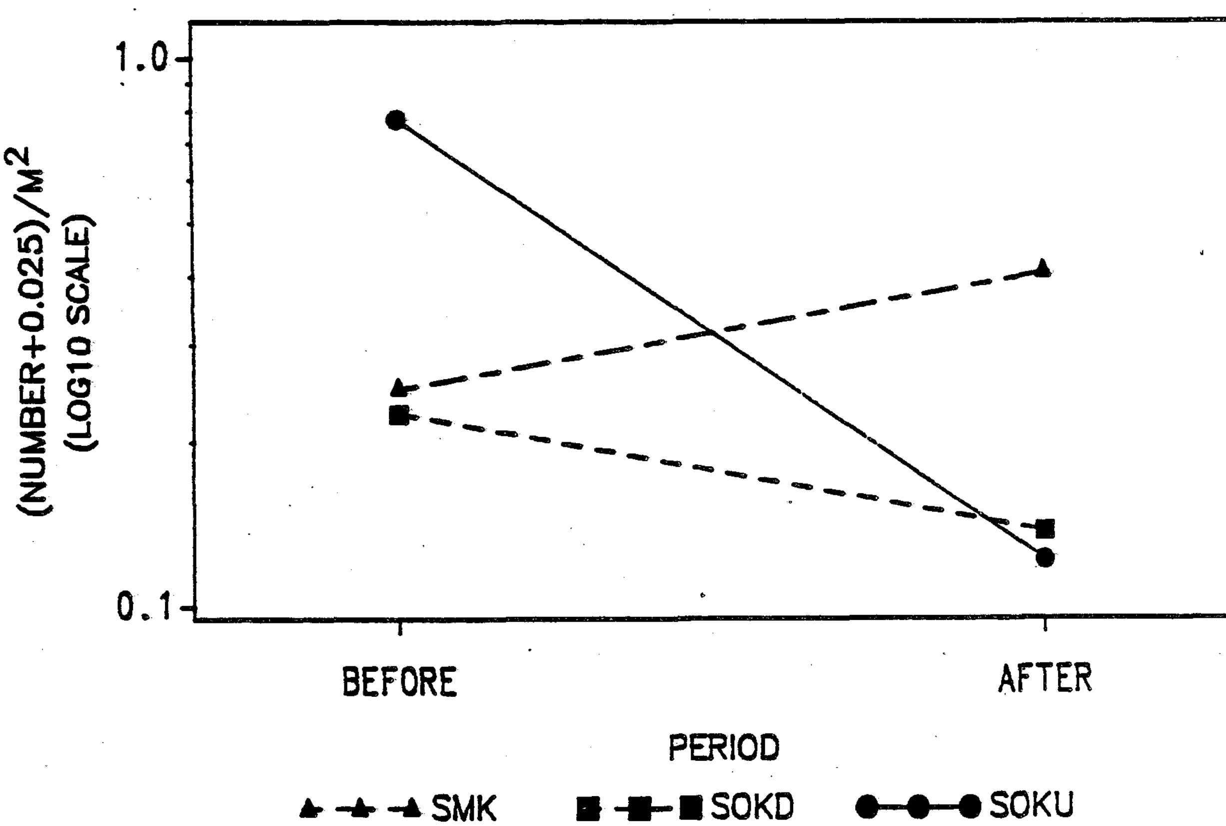
Tegula aureotincta





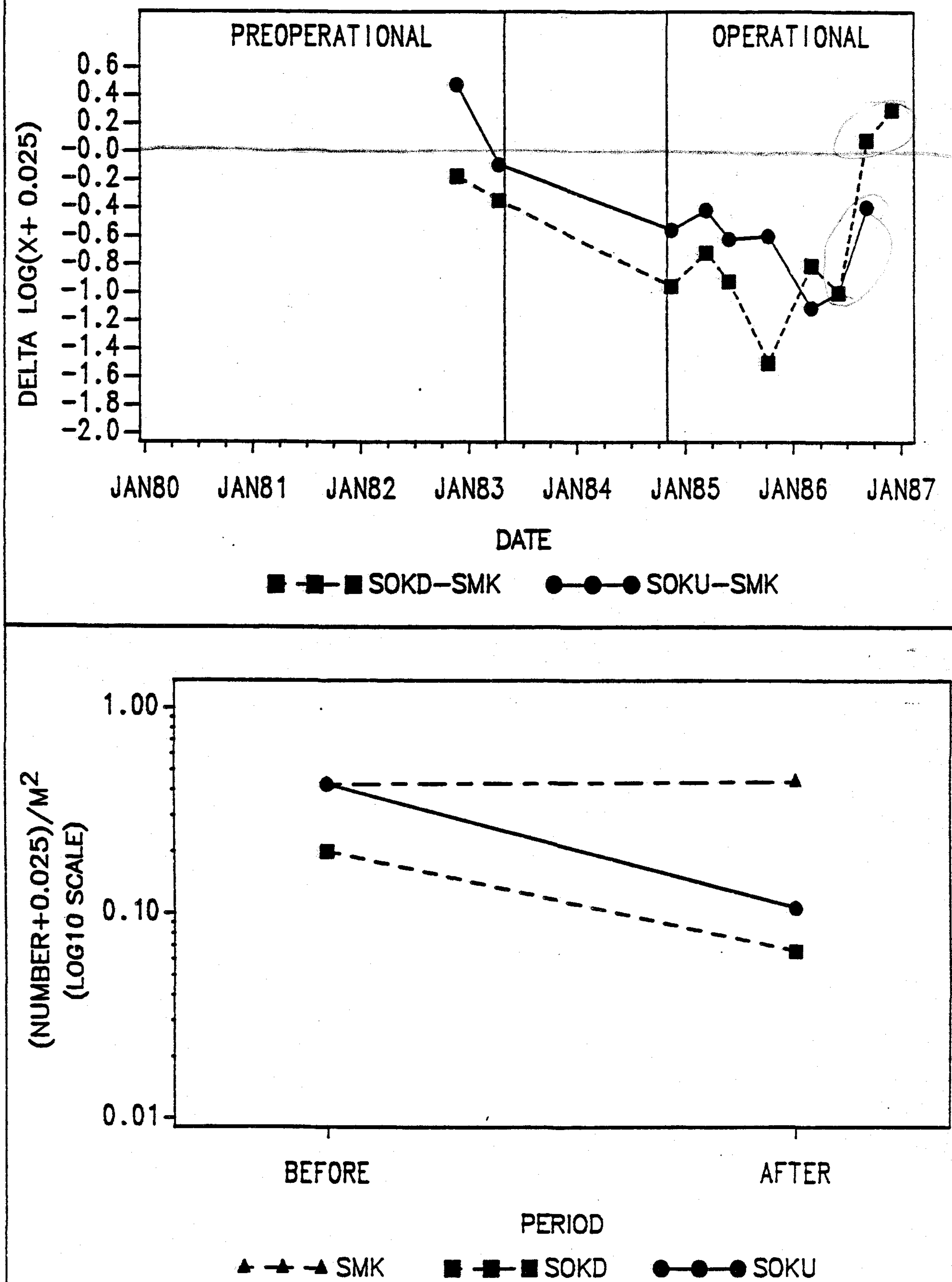
Maxwellia gemma

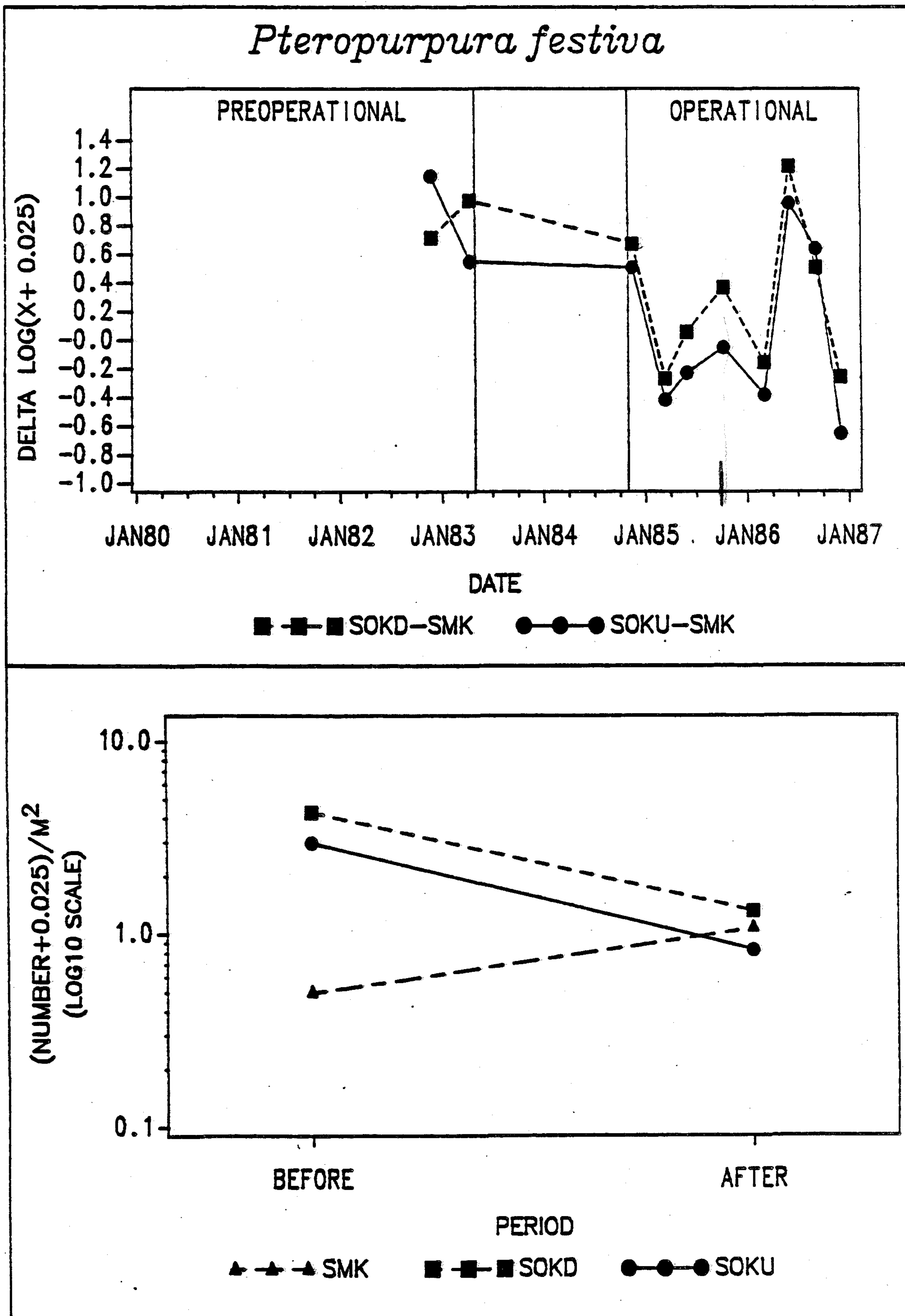




32201

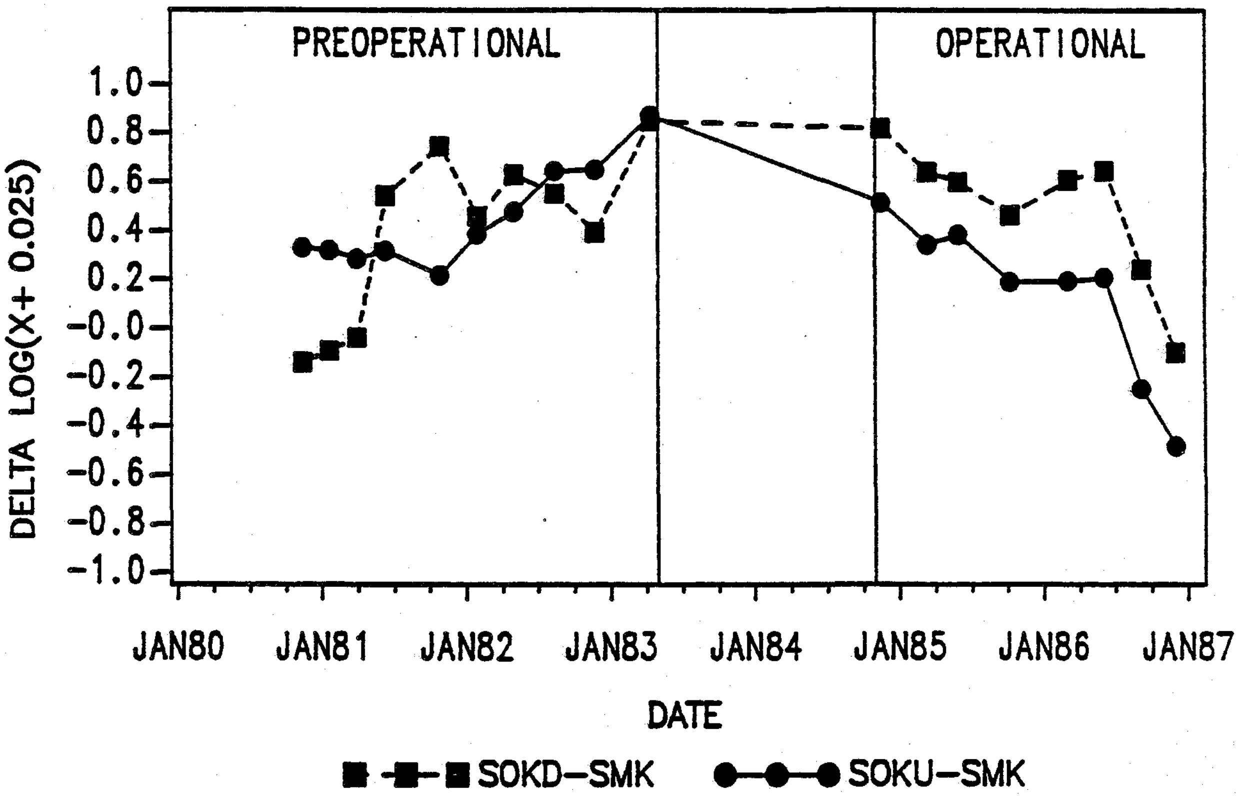
Murexiella santarosana

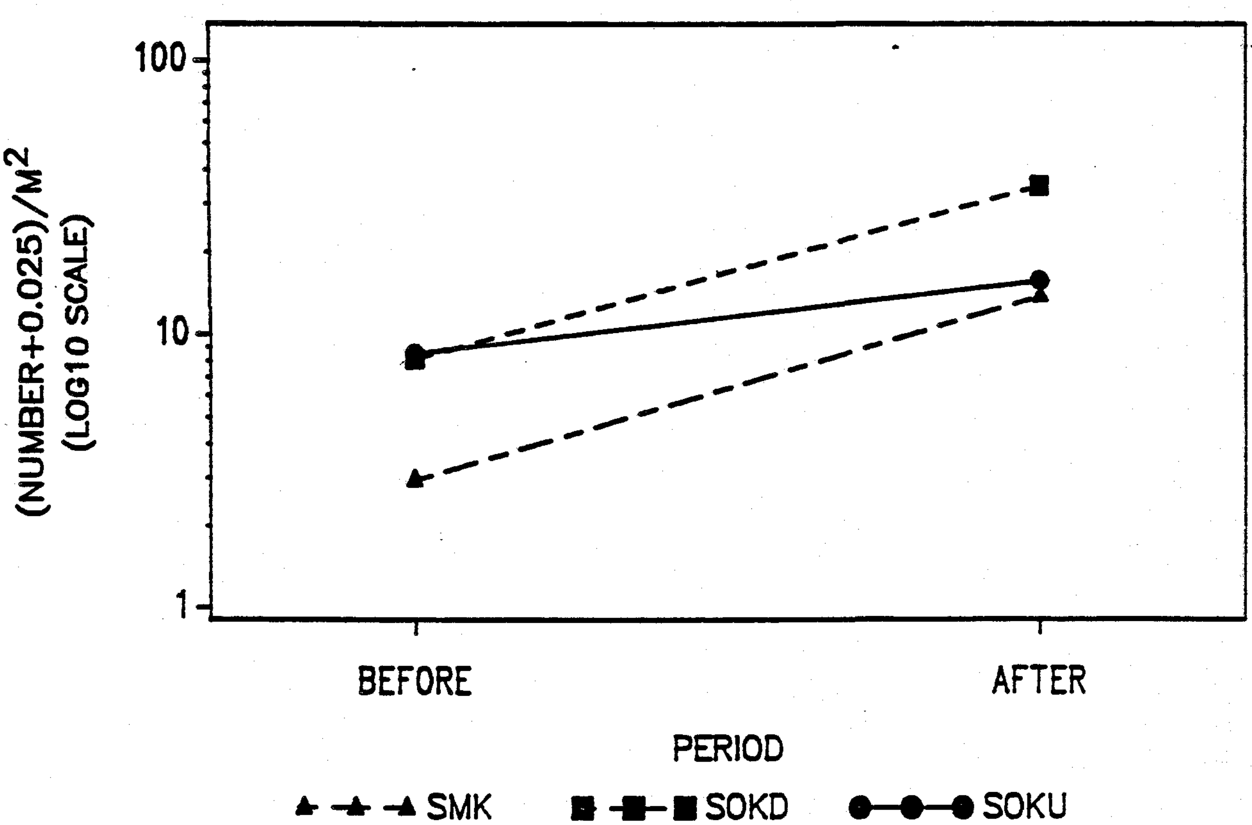




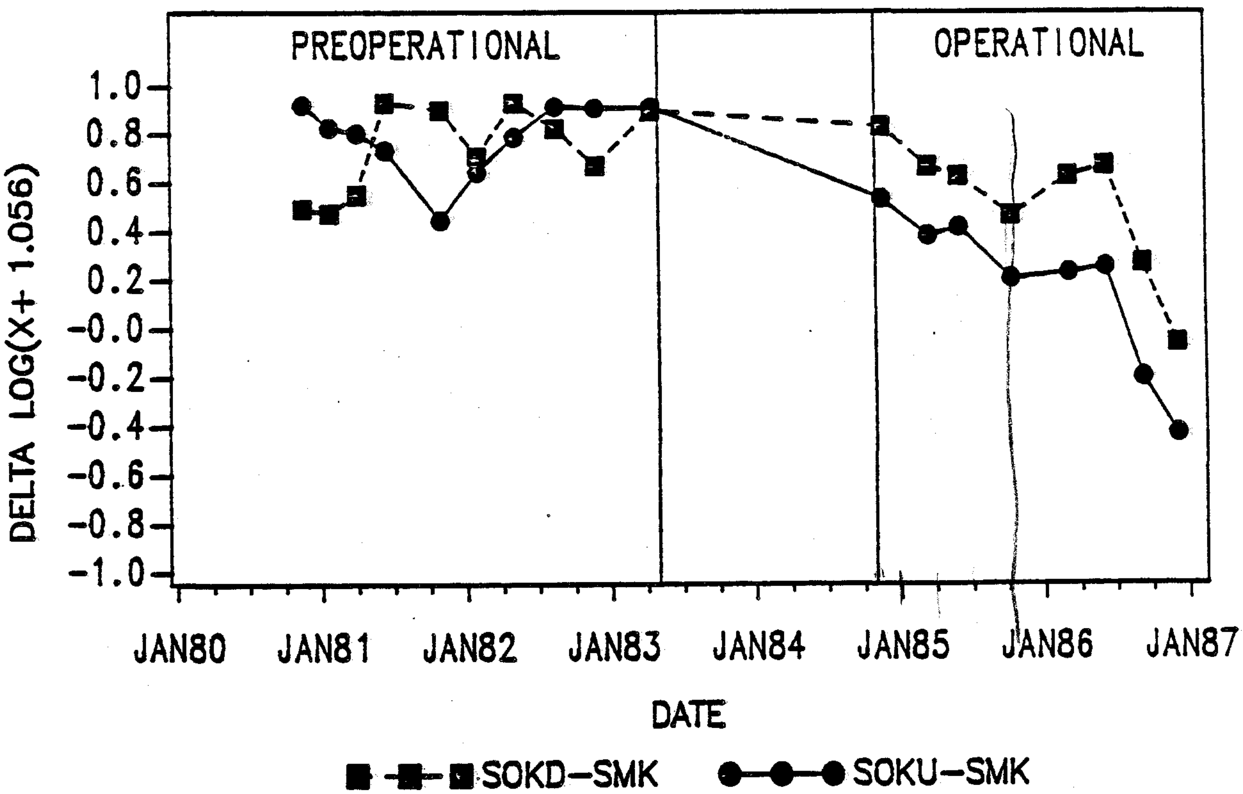
Pteropurpura festiva
PREOPERATIONAL
OPERATIONAL
DELTA LOG(X+ 0.025)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
-0.8
-1.0
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK
(NUMBER+0.025)/M2
(LOG10 SCALE)
10.0
1.0
0.1
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

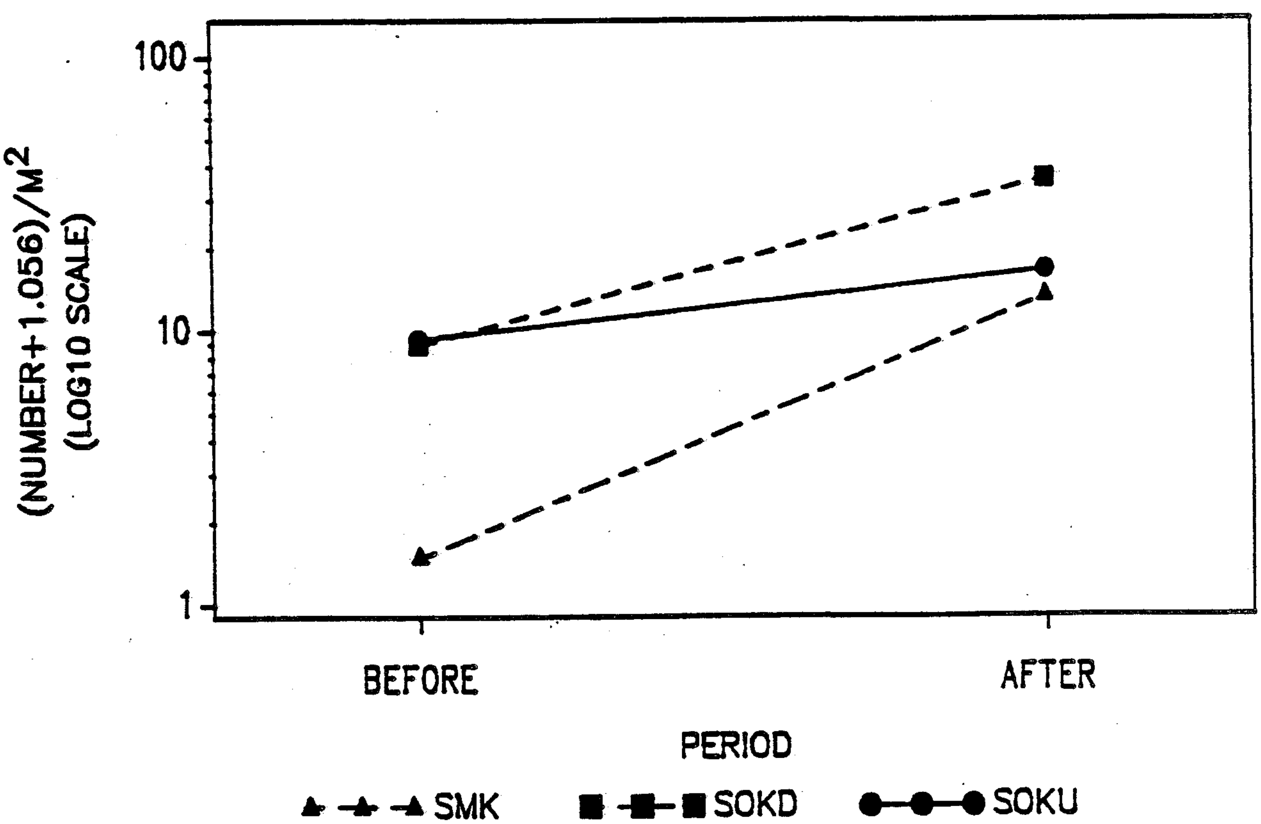
ALL SEA URCHINS





Lytechinus anamesus

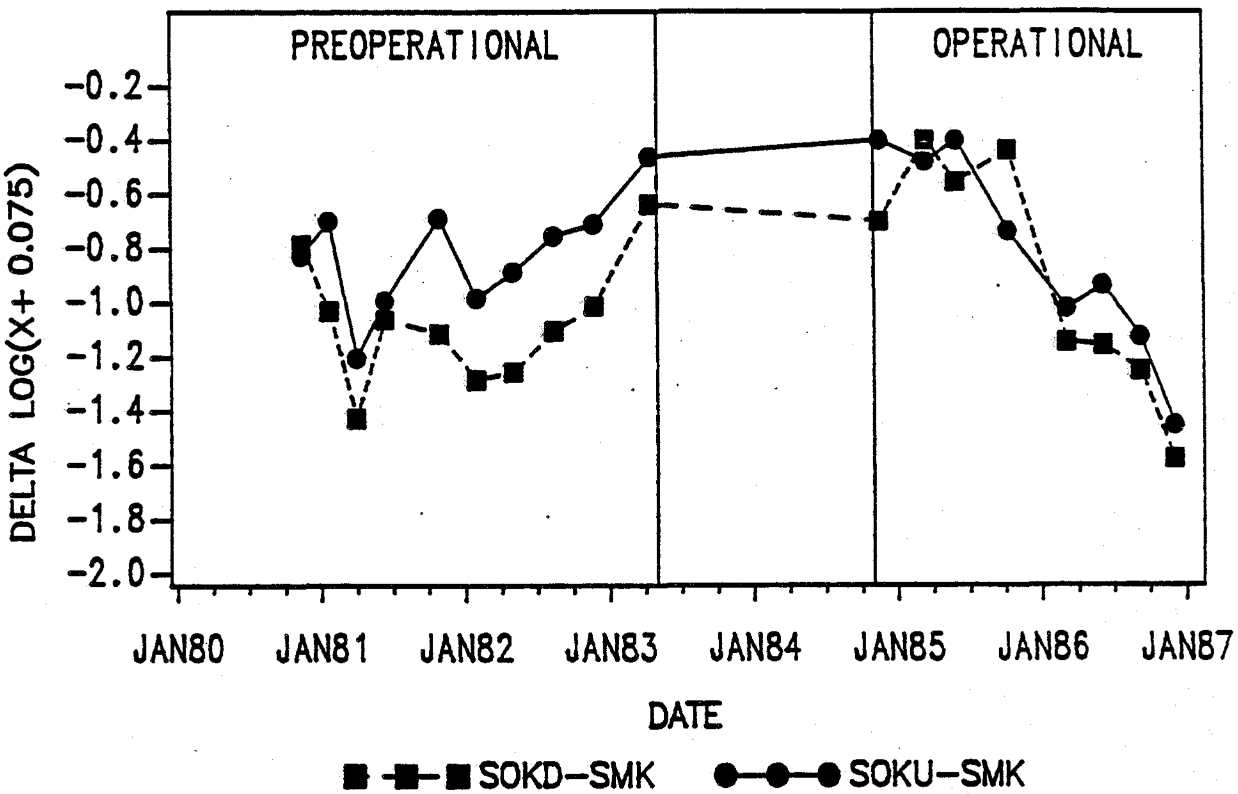


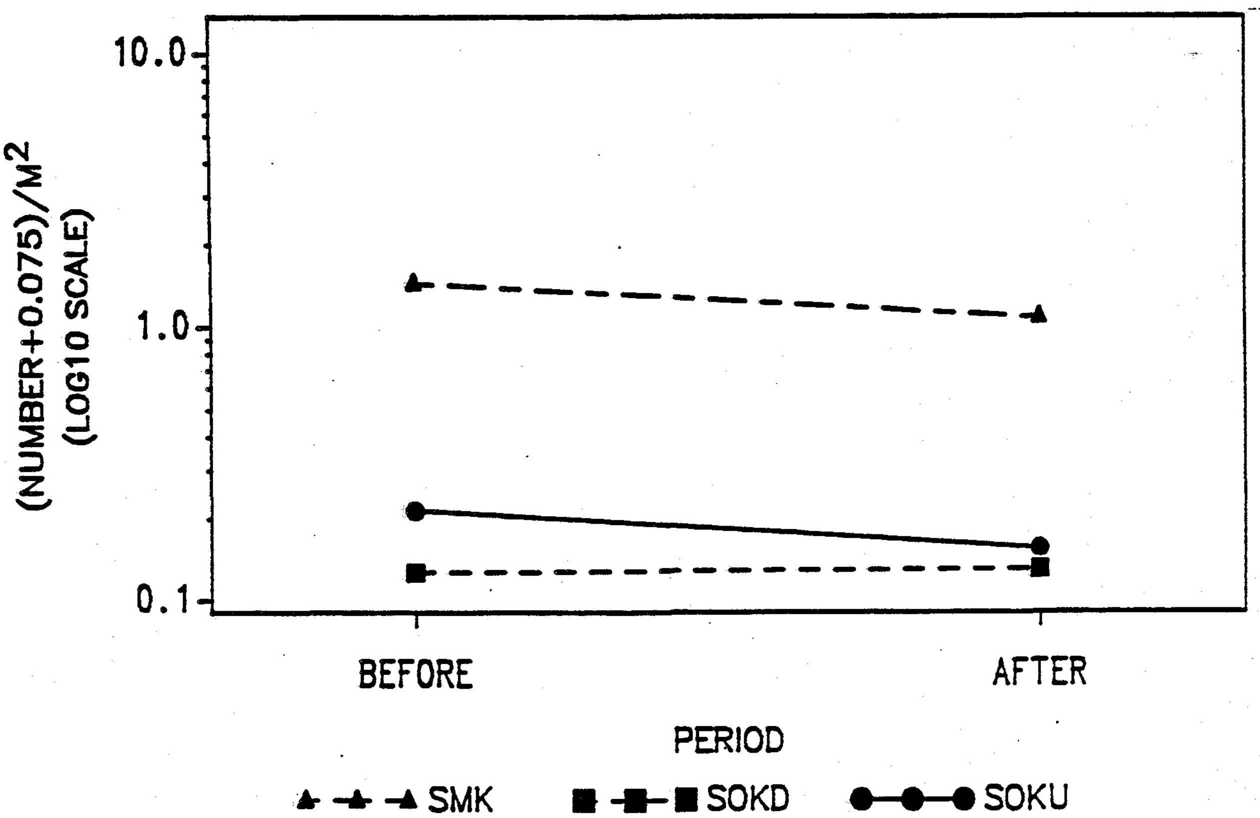


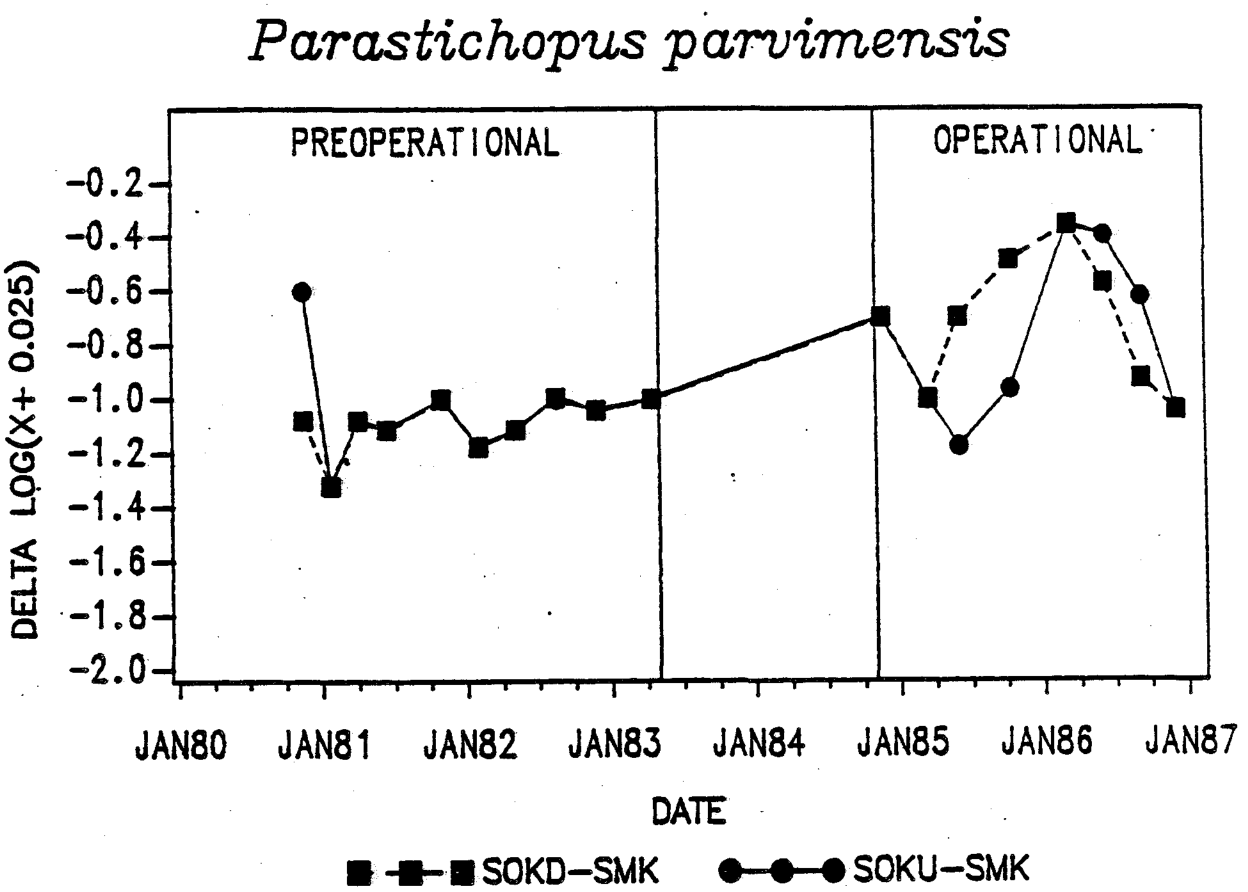
109 ≠ 110 866–885

S

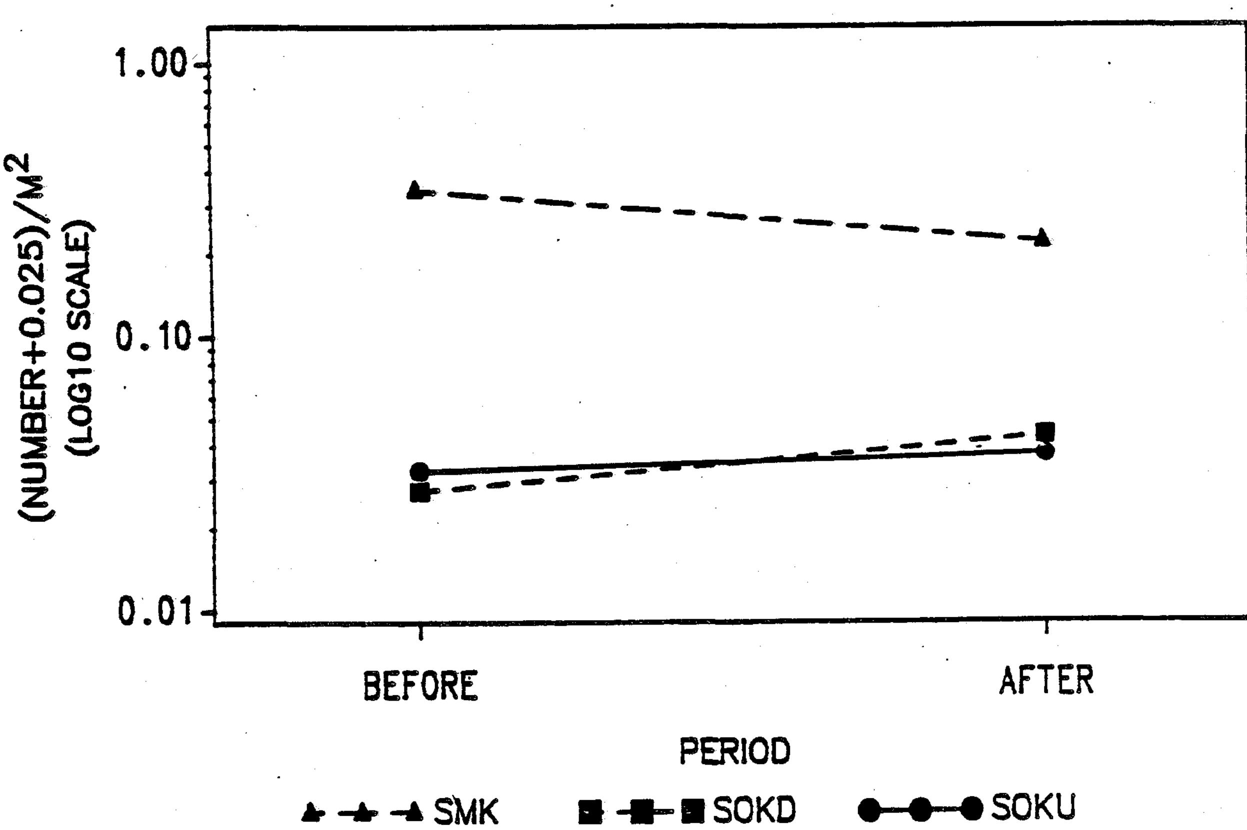
Strongylocentrotus purpuratus





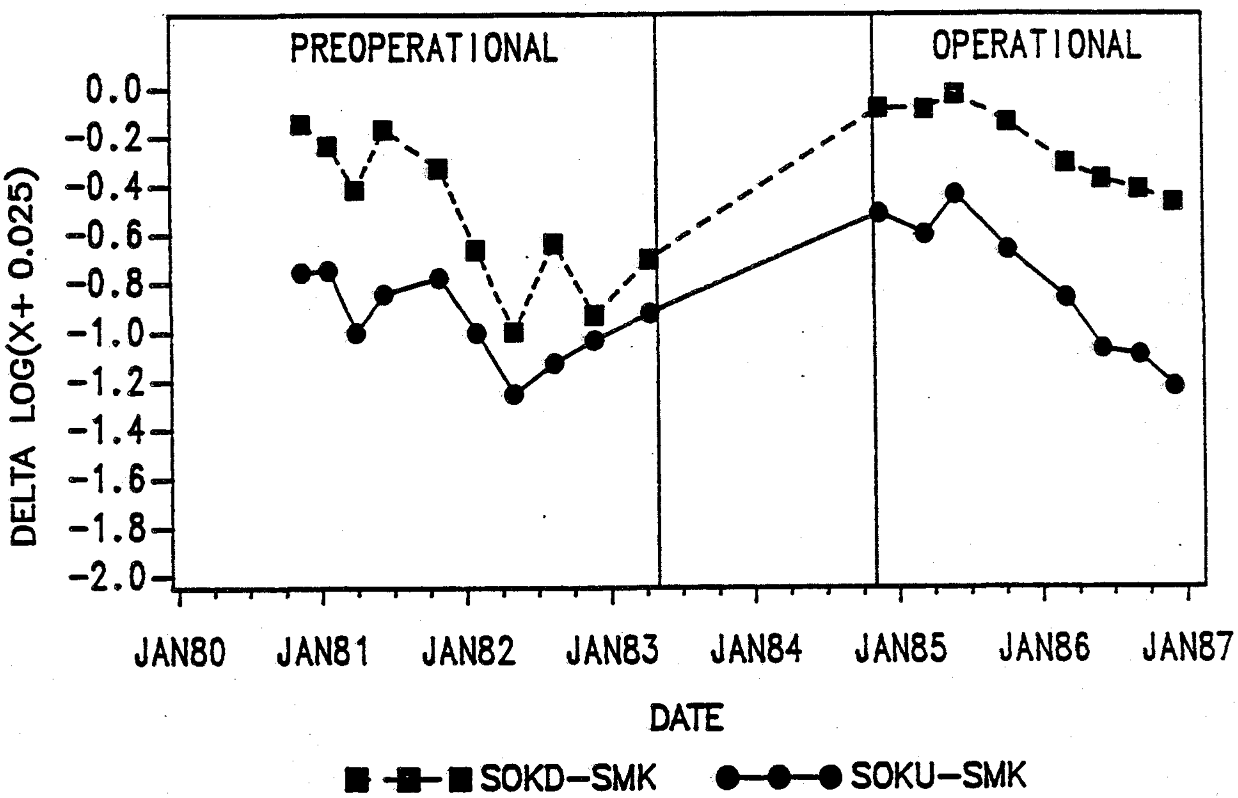


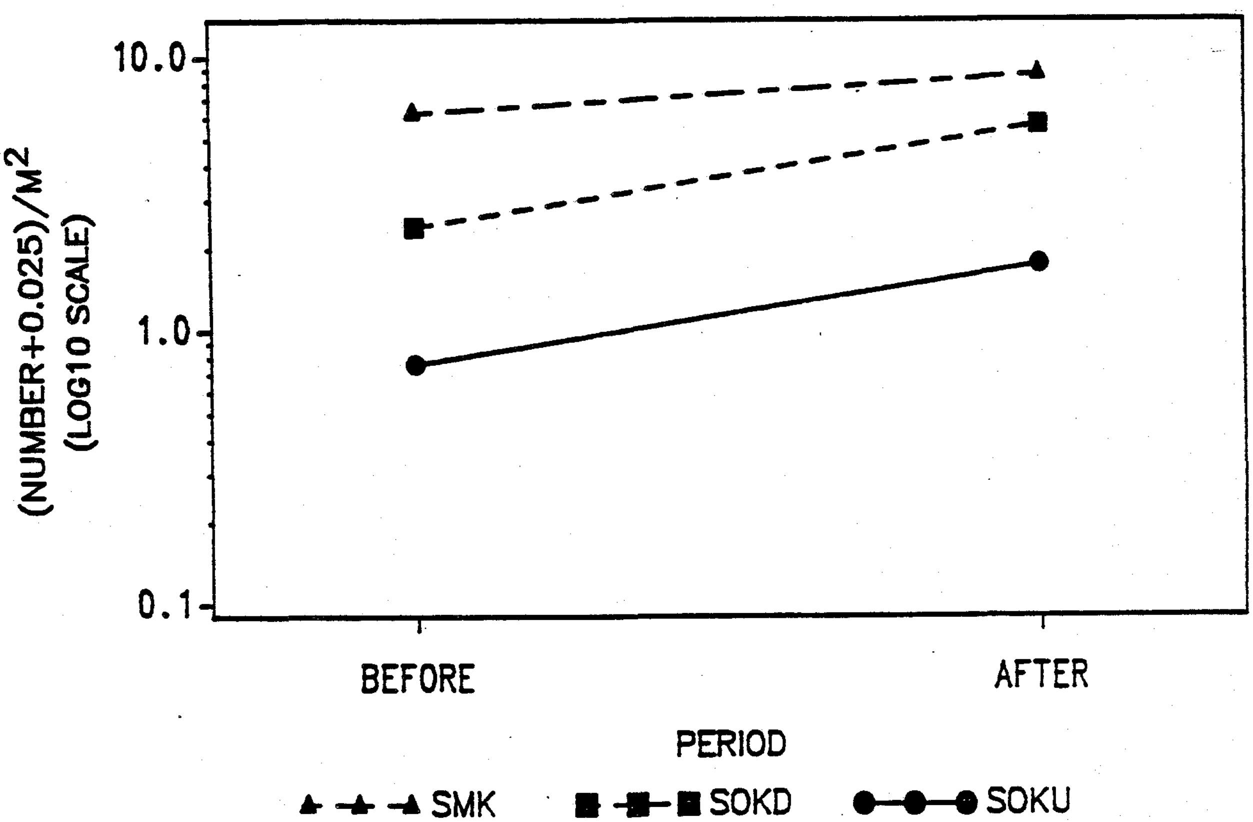
Parastichopus parvimensis
PREOPERATIONAL
OPERATIONAL
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
DELTA LOG(X+ 0.025)
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK



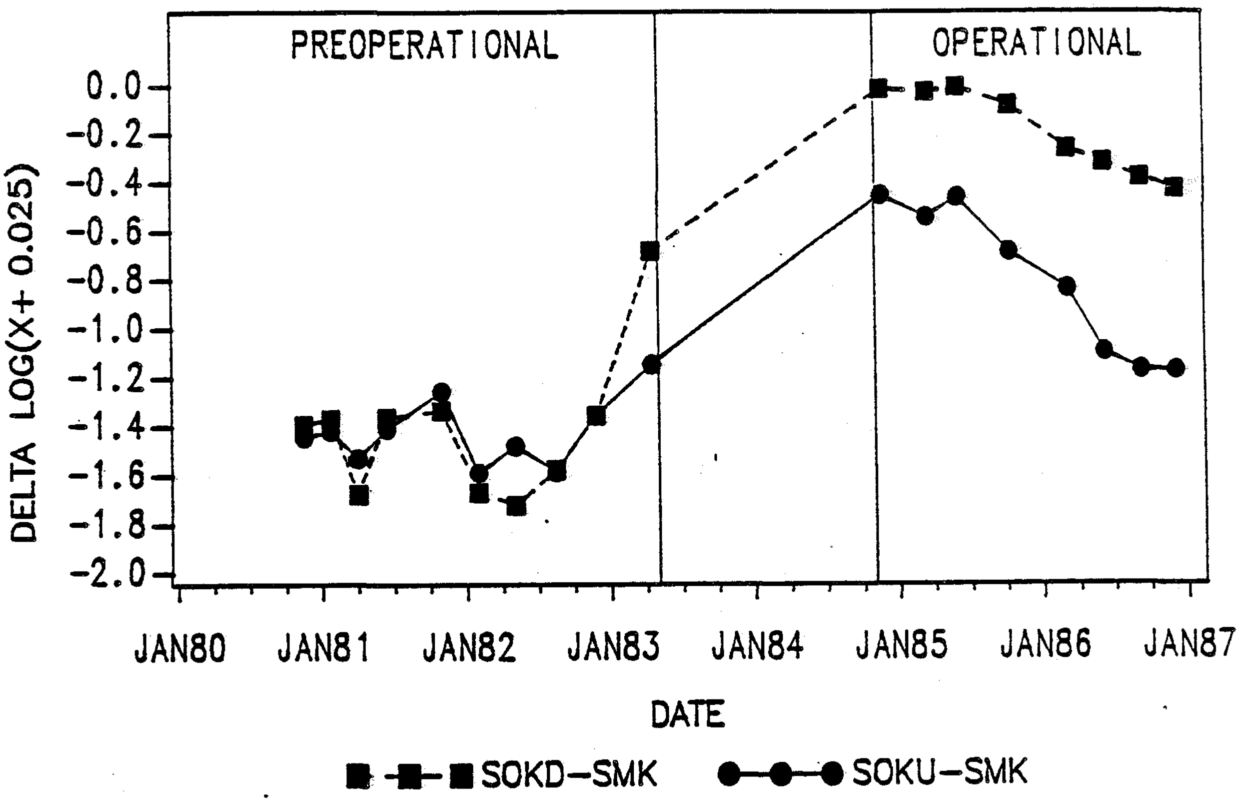
1.00
0.10
0.01
(NUMBER+0.025)/M²
(LOG10 SCALE)
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

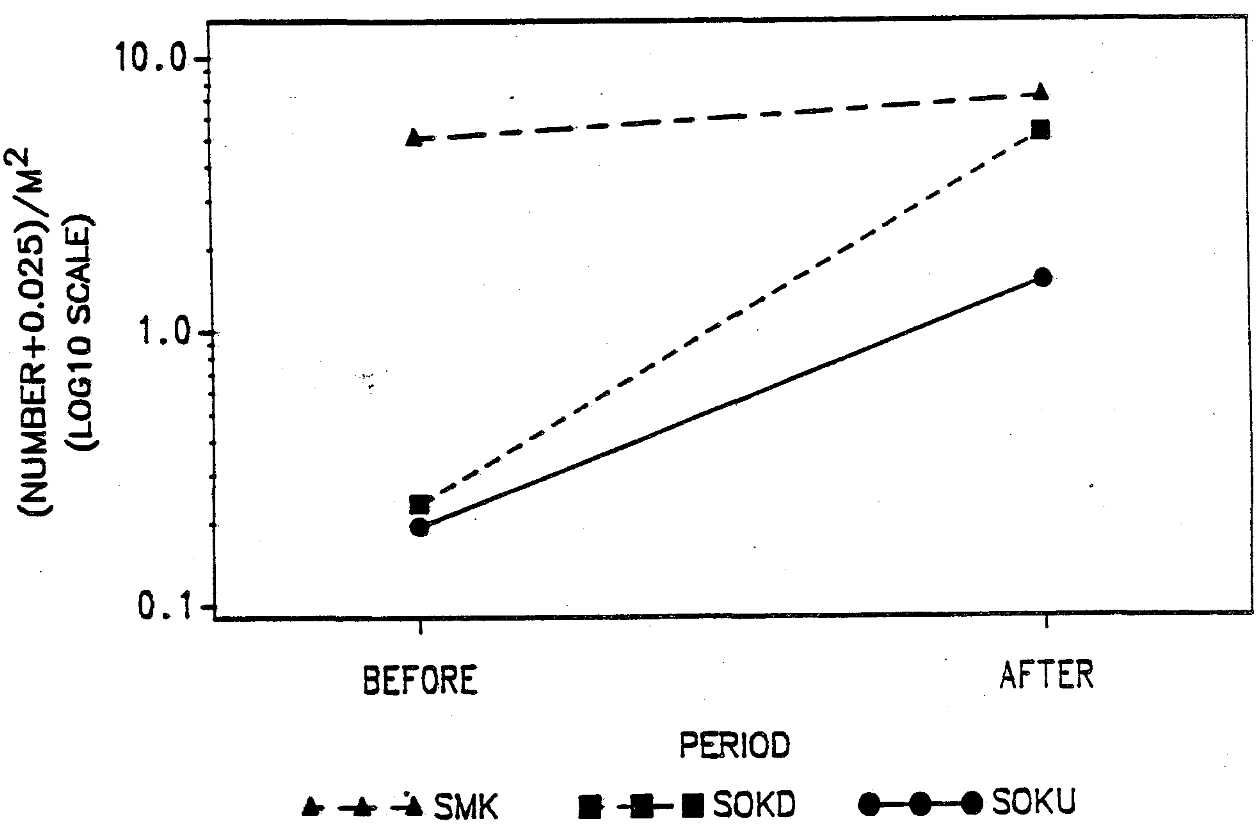
ALL SESSILE SPECIES

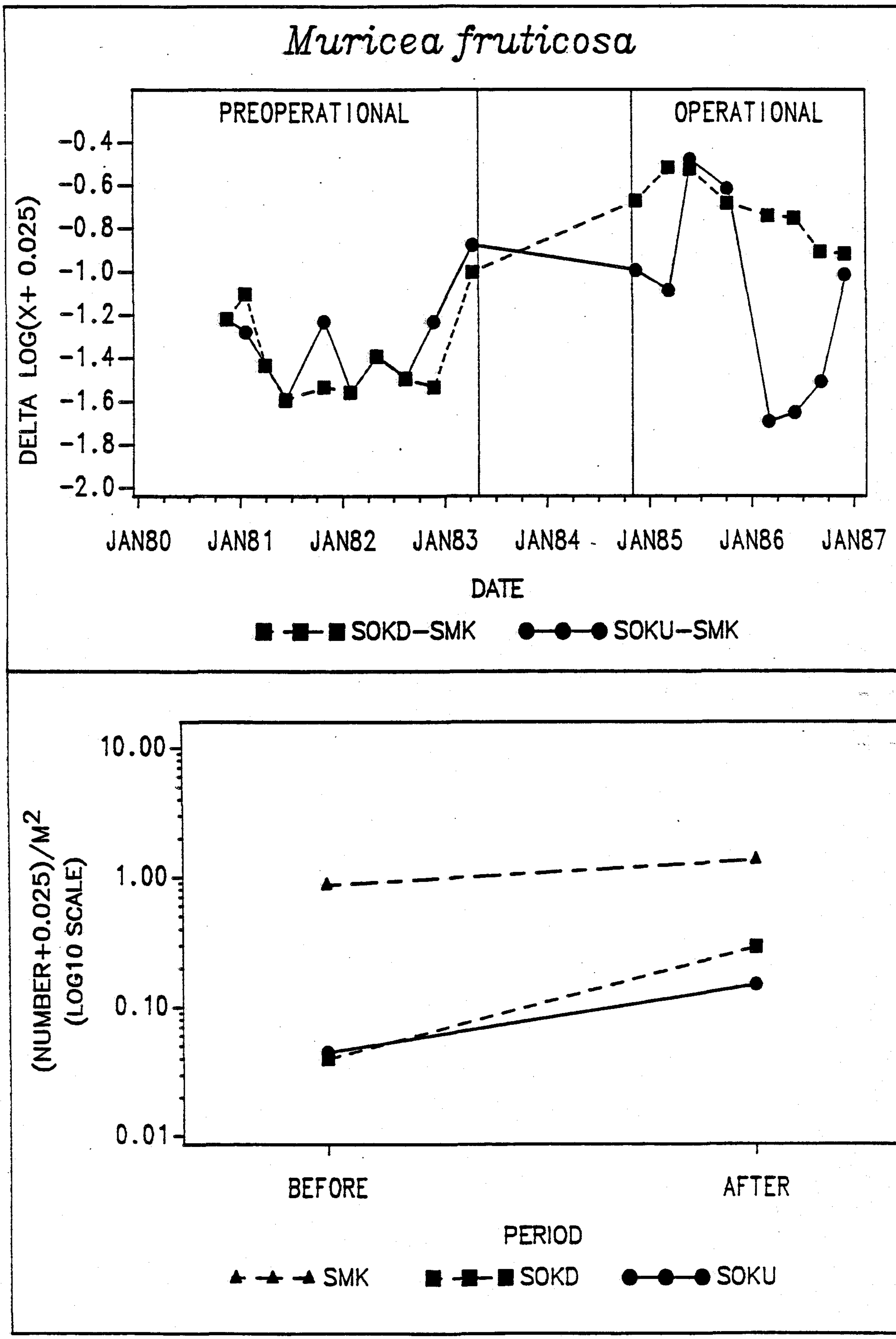




Muricea californica

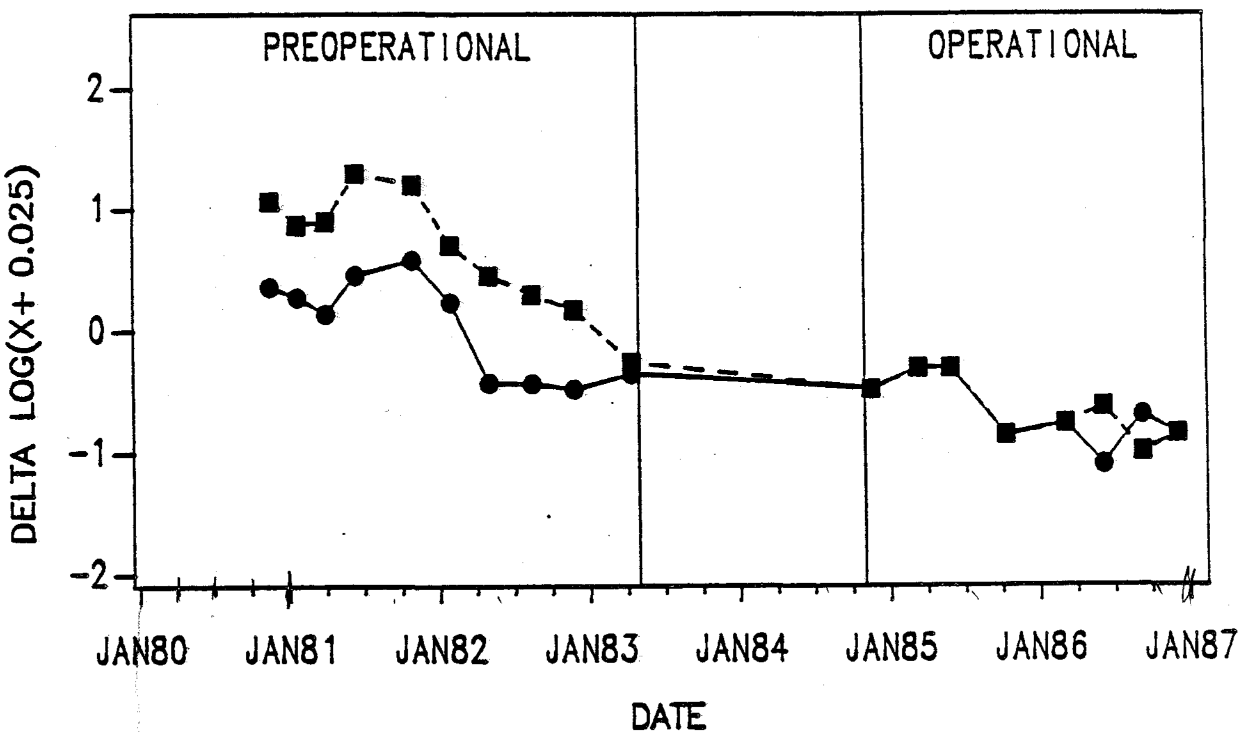




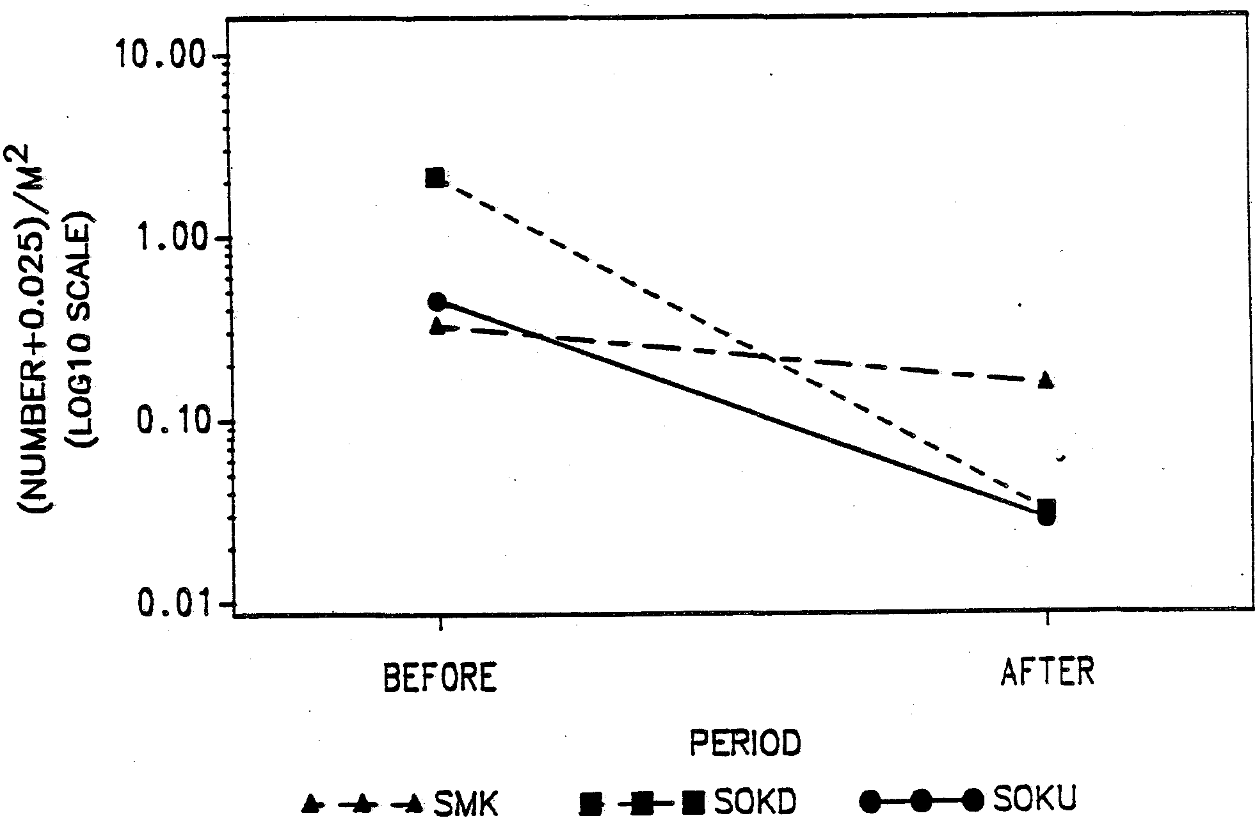

Muricea fruticosa
PREOPERATIONAL
OPERATIONAL
DELTA LOG(X+ 0.025)
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
JAN80
JAN81
JAN82
JAN83
JAN84
JAN85
JAN86
JAN87
DATE
SOKD-SMK
SOKU-SMK
(NUMBER+0.025)/M2
(LOG10 SCALE)
10.00
1.00
0.10
0.01
BEFORE
AFTER
PERIOD
SMK
SOKD
SOKU

x

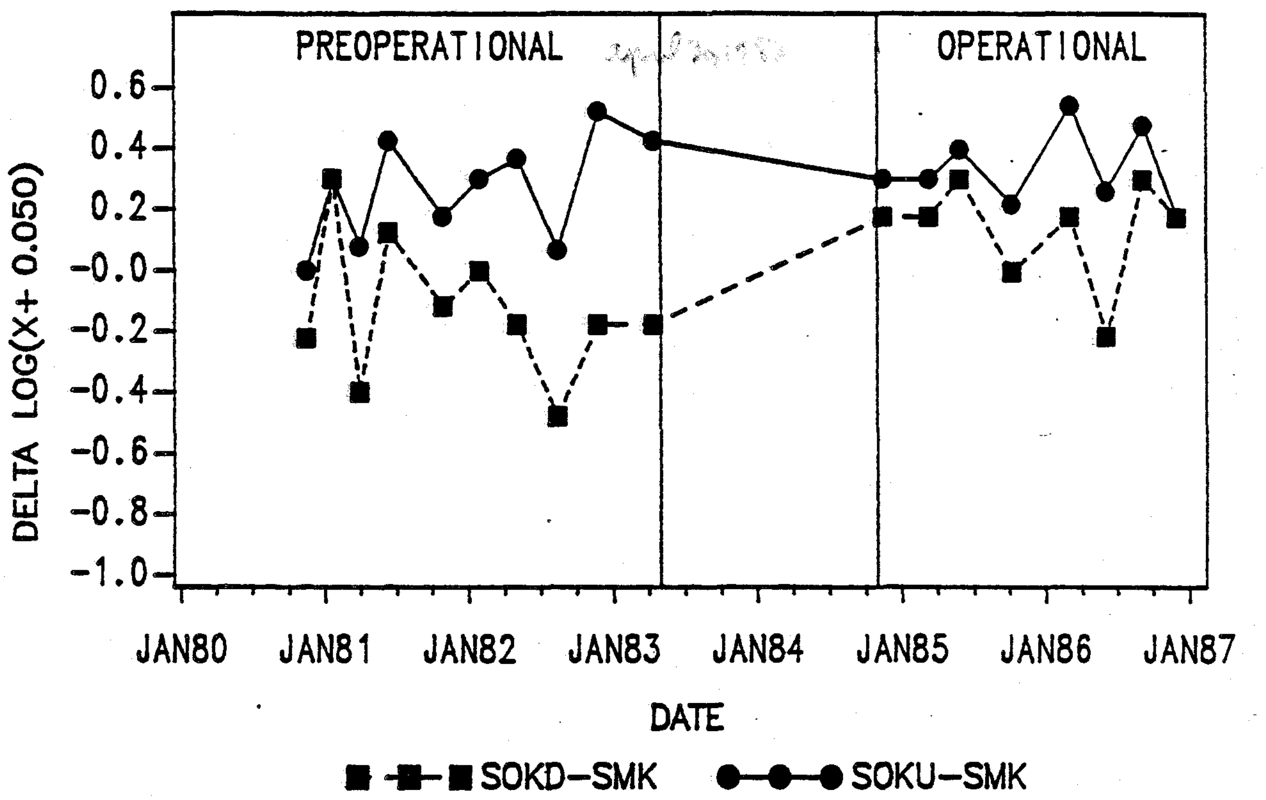
Styela montereyensis

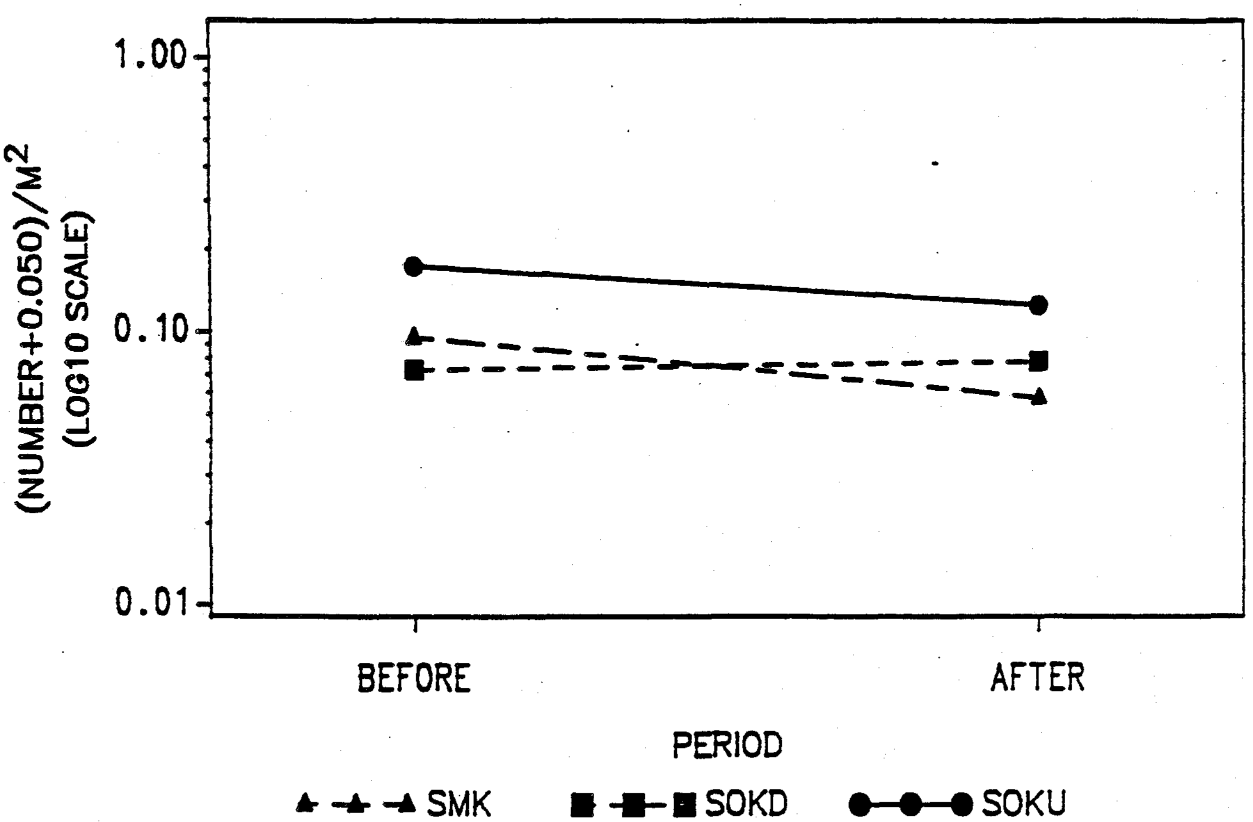


29220 31777



Tethya aurantia





This page intentionally left blank.

Appendix A. Ancillary analyses including Barn Kelp Forest

The primary analyses reported in the main text were repeated using the average density over San Mateo Kelp forest (SMK) and Barn Kelp forest (BK) as the Control. Tables A-1 and A-2 contain these analyses, corresponding to the primary analyses reported in Tables 8 and 9 of the main text of this report. The results are similar to those reported in the main text. The snails generally declined in relative density in SOK from the Before to After periods, with larger declines at the near Impact station=SOKU (Table A-1). Every snail species that could be tested was significantly ($p<0.05$) or nearly significantly ($p<0.15$) affected, as evidenced by either the period or period by station effects (Table A-1). Most of the snails showed negative trends at SOK relative to the Control during the After period, and in three cases these trends were significant (Table A-2). *Parastichopus* again shows evidence of a positive effect (Table A-1), and the sessile invertebrates are statistically intractable (Table A-1). Only for two species (white sea urchins (*Lytechinus* and *Cypraea*) are the results reported in Table A-1 substantially different from those reported in Table 8 in the main text. White sea urchins showed a decline at SOKU, but a substantial increase at SOKD in Table A-1, whereas in Table 8 there were decreases at both impact stations. For *Cypraea* the percent changes were small and not significant in Table A-1, whereas very large relative declines in SOK are reported in Table 8 (although the species was statistically intractable).

Table A-4 contains the mean densities at each of the study sites during the Before and After periods for the species included in Table 8. It is clear from this table that the results using SMK (Table 8) or the average of SMK and BK (Table A-

1) as a control are similar because SMK and BK tracked each other well, and not because the abundances at BK were near zero for all species. The effects that are seen when the Impact sites are compared with a Control are not seen when BK is compared with our primary Control (SMK) using the BACIP analysis (Interim Technical Report 2). In this case there were only three significant and three nearly significant effects out of 16 tests (Table A-3). The direction of changes in relative abundances among snails was mixed (Table A-3), in contrast with the consistent declines seen when actual Impact sites were used in the analysis (Table 8 main text).

There is a significant BK vs SMK BACIP effect for white sea urchins, and *Cypraea*, and this weakens the case for a SONGS effect on these species (but see Discussion). For white sea urchins SOKU, SOKD, and SMK experienced substantial increases in density from the Before to After periods (Table A-4), while densities fell to less than half their Before levels at BK (Table A-4). *Cypraea* were scarce at SOKD during both periods (Table A-4). The densities at SOKU and SMK were about double those at SOKD during the Before period and the density at SOKU increased and the density at SMK declined from the Before to After periods (Table A-4). In contrast with the other sites *Cypraea* were very abundant at BK in the Before period and fell to very low densities there in the After period (Table A-4). It is conceivable that the declines in the density of both *Lytechinus* and *Cypraea* in BK came about because of the loss of giant kelp there (see Discussion).

Table A-1

Results of repeated-measures BACI analysis.

Estimated percent changes at the SOKU (near impact) and SOKD (far impact) sites relative to the average value at the control sites (SMK and BK), and the results of repeated measures analyses. A, SC, and T refer to failure of the additivity, serial correlation, or trends assumptions tests. U indicates that the assumptions tests could not be done. No result (NR) indicates all densities were zero at the test stations. * indicates repeated measures analysis not done due to either additivity or trends in the SOKU-SOKD deltas. -- indicates test could not be done.

SPECIES/ GROUP	% CHANGE SOKU	% CHANGE SOKD	PERIOD F(DF)	PERIOD P	PERIOD X STATION F(DF)	PERIOD X STATION P	POWER (%) PERIOD X STATION
Snails	-83.6^{U}	-72.7^{U}	7.74(1,8)	0.024	2.99(1,8)	0.12	7.6
Non-muricid snails	-78.7^{U}	-64.7^{U}	4.37(1,8)	0.07	4.17(1,8)	0.076	9.7
Astraea undosa	-80.0^{SC,T}	-59.4	--	--	--	--	--
Calliostoma spp.	-78.8^{U}	-3.0^{U}	1.95(1,8)	0.20	9.41(1,8)	0.015	5.1
Conus californicus	-86.8	-74.6	41.60(1,12)	0.0001	16.64(1,12)	0.0015	93.9
Crassispira semiinflata	-89.2	-57.1	6.85(1,11)	0.024	3.94(1,11)	0.073	11.2
Cypraea spadicea	-13.7	1.9^{SC,T}	--	--	--	--	--
Kelletia kelletii	-60.0	-48.5	8.70(1,15)	0.01	2.39(1,15)	0.14	98.0
Mitra idae	-74.5	-44.3	2.38(1,12)	0.15	3.47(1,12)	0.087	28.8
Nassarius spp.	-34.4^{U}	(NR)	--	--	--	--	--
Ophiodermella inermis	-46.2^{U}	-72.5^{U}	5.22(1,8)	0.05	3.59(1,8)	0.095	42.5
Tegula aureotincta	-87.6^{U}	(NR)	--	--	--	--	--
Muricid snails	-90.6^{U}	-82.9^{U}	19.01(1,8)	0.002	2.00(1,8)	0.20	6.0
Maxwellia gemma	-93.3^{U}	-76.6^{U}	11.64(1,8)	0.009	6.00(1,8)	0.04	20.6
Murexiella santarosana	-87.1^{U}	-71.1^{U}	12.82(1,8)	0.007	1.00(1,8)	0.35	9.1
Pteropurpura festiva	-91.3^{U}	-85.4^{U}	13.33(1,8)	0.0065	1.11(1,8)	0.32	5.2
Sea Urchins	-8.5	120.8	1.88(1,15)	0.19	10.56(1,15)	0.005	73.6
Lytechinus anamesus	-38.1^{SC}	47.9^{SC}	0.02(1,15)	0.88	11.63(1,15)	0.004	68.8
Strongylocentrotus purpuratus	11.2	38.6	0.00(1,15)	1.0	2.26(1,15)	0.15	58.2
Holothurians (includes only *Parastichopus*)							
Parastichopus parvimensis	65.2^{U}	113.8^{U}	8.18(1,15)	0.012	1.06(1,15)	0.32	6.1
Sessile invertebrates	25.4^{A,SC,T}	83.6^{A,SC,T}	--	--	--	--	--
Muricea californica	261.6^{A}	1306.1^{A,SC}	--	--	--	--	--
Muricea fruticosa	51.0^{A}	354.0^{A}	--	--	--	--	--
Styela montereyensis	-71.1^{A,SC,T}	-92.7^{A,SC,T}	--	--	--	--	--
*Tethya aurantia**	1.9	58.2^{SC}	--	--	--	--	--

Table A-2

Temporal trends in deltas using combined station values (SMK and BK) as the controls for those species analyzed in the repeated measures BACI test. "+" direction indicates deltas are increasing through time. N.A> indicates not applicable.

Species/Group	Before: SOKU Direction	Before: SOKU P	Before: SOKU N	Before: SOKD Direction	Before: SOKD P	Before: SOKD N	After: SOKU Direction	After: SOKU P	After: SOKU N	After: SOKD Direction	After: SOKD P	After: SOKD N
All Snails	N.A.			N.A.			-	0.025	7	-	0.03	7
Non-muricid snails	N.A.			N.A.			-	0.012	7	-	0.02	7
Calliostoma spp.	N.A.			N.A.			-	0.017	7	-	0.04	7
Conus californicus	-	0.17	5	-	0.52	5	-	0.12	7	-	0.06	7
Crassipira semiinflata	-	0.19	4	-	0.27	4	-	0.25	7	-	0.47	7
Kelletia kelletii	-	0.07	8	-	0.19	8	-	0.07	7	-	0.19	7
Mitra idae	+	0.52	5	+	0.90	5	-	0.03	7	-	0.0008	7
Ophiodermella inermis	N.A.			N.A.			-	0.12	7	-	0.44	7
Muricid Snails	N.A.			N.A.			-	0.33	7	-	0.38	7
Maxwellia gemma	N.A.			N.A.			-	0.66	7	-	0.90	7
Murexiella santarosana	N.A.			N.A.			-	0.02	7	+	0.83	7
Pteropurpura festiva	N.A.			N.A.			-	0.52	7	-	0.41	7
Sea Urchins	-	0.77	8	+	0.62	8	-	0.004	7	-	0.03	7
Lytechinus anamesus	-	0.17	8	-	0.36	8	-	0.004	7	-	0.03	7
Strongylocentrotus purpuratus	+	0.54	8	-	0.52	8	-	0.0009	7	-	0.005	7
Holothurians (includes only *Parastichopus*)												
Parastichopus parvimensis	-	0.49	8	+	0.78	8	+	0.62	7	-	0.47	7

Table A-3

Results of BACIP tests for BK (Impact) versus SMK (Control).

A, SC, and T refer to failure of the additivity, serial correlation, and trends assumptions tests. U indicates that the assumption tests could not be done.

SPECIES/ GROUP	P > T	% CHANGE
Snails	0.774	-13.2[U]
Non-muricid snails	0.472	-28.9[U]
Astraea undosa	0.053	-61.5[U]
Conus californicus	–	250.5[A]
Crassispira semiinflata	0.836	10.3
Cypraea spadicea	0.002	-85.5
Kelletia kelletii	0.415	-21.2
Mitra idae	0.534	41.1
Muricid snails	0.470	86.2[U]
Maxwellia gemma	0.364	174.5[U]
Murexiella santarosana	0.929	12.9[U]
Pteropurpura festiva	0.115	363.6[U]
Sea Urchins	–	–[A,SC,T]
Lytechinus anamesus	0.000	-98.8
Strongylocentrotus purpuratus	0.274	-35.5
Holothurians (includes only *Parastichopus*)		
Parastichopus parvimensis	0.387	14.1
Sessile invertebrates	–	14.3[SC,T]
Muricea californica	–	26.0[SC,T]
Muricea fruticosa	–	2.7[T]
Styela montereyensis	0.042	-49.6
Tethya aurantia	0.061	40.6

Table A-4

Mean densities at each sampling station for each period, for taxa reported in Table 2.

TAXON	SOKU MEAN	SOKU S.E.	SOKU N	SOKD MEAN	SOKD S.E.	SOKD N	SMK MEAN	SMK S.E.	SMK N	BK MEAN	BK S.E.	BK N
BEFORE												
Snails	10.45	1.20	2	10.96	6.79	2	4.35	3.13	2	2.75	1.70	2
Non-muricid snails	6.31	1.21	2	6.24	3.61	2	3.19	2.31	2	2.20	1.35	2
Astraea undosa	0.02	0.007	10	0.02	0.005	10	0.03	0.01	10	0	0	9
Calliostoma spp.	0.13	0.05	2	0.06	0.04	2	0	0	2	0	0	2
Conus californicus	4.41	0.59	6	2.91	0.52	6	0.66	0.20	6	0.60	0.49	6
Crassispira semiinflata	0.14	0.03	5	0.10	0.03	5	0.02	0.02	5	0.11	0.05	5
Cypraea spadicea	0.07	0.01	10	0.03	0.01	10	0.07	0.02	10	0.16	0.05	9
Kelletia kelletii	2.88	0.37	10	2.90	0.42	10	2.50	0.50	10	0.88	0.19	9
Mitra idae	0.74	0.23	6	0.32	0.06	6	0.05	0.02	6	0.20	0.08	6
Nassarius spp.	0.34	0.31	2	0.73	0.73	2	0.20	0.20	2	0.09	0.09	2
Ophiodermella inermis	0.06	0.01	2	0.08	0.00	2	0	0	2	0.01	0.01	2
Tegula aureotincta	0.16	0.09	2	0	0	2	0	0	2	0.01	0.01	2
Muricid snails	4.14	0.01	2	4.73	3.18	2	1.16	0.81	2	0.55	0.35	2
Maxwellia gemma	0.75	0.03	2	0.20	0.05	2	0.23	0.13	2	0.06	0.06	2
Murexiella santarosana	0.40	0.20	2	0.18	0.15	2	0.40	0.35	2	0.31	0.11	2
Pteropurpura festiva	2.95	0.23	2	4.26	3.11	2	0.48	0.28	2	0.16	0.16	2
Sea Urchins	8.53	1.15	10	8.13	1.43	10	2.94	0.34	10	4.18	1.46	9
Lytechinus anamesus	8.35	1.15	10	7.89	1.43	10	0.44	0.20	10	3.89	1.50	9
S. purpuratus	0.14	0.02	10	0.05	0.02	10	1.37	0.15	10	0.17	0.06	9
Holothurians												
Parastichopus parvimensis	0.008	0.005	10	0.003	0.003	10	0.32	0.03	10	0.26	0.05	9
Sessile Invertebrates	0.74	0.10	10	2.38	0.52	10	6.24	0.26	10	7.36	0.21	9
Muricea californica	0.17	0.01	10	0.21	0.06	10	5.04	0.24	10	4.76	0.16	9
Muricea fruticosa	0.02	0.007	10	0.02	0.007	10	0.85	0.05	10	1.93	0.12	9
Styela montereyensis	0.43	0.10	10	2.13	0.52	10	0.30	0.05	10	0.47	0.07	9
Tethya aurantia	0.12	0.01	10	0.02	0.01	10	0.05	0.009	10	0.20	0.02	9
AFTER												
Snails	4.33	0.84	8	6.21	1.33	8	7.31	1.44	8	4.97	1.17	8
Non-muricid snails	3.32	0.72	8	4.74	1.13	8	5.44	0.94	8	3.51	0.84	8
Astraea undosa	0.01	0.007	8	0.08	0.02	8	0.46	0.19	8	0.03	0.02	8
Calliostoma spp.	0.03	0.01	8	0.12	0.14	8	0.01	0.007	8	0.02	0.008	8
Conus californicus	1.11	0.37	8	1.67	0.51	8	1.74	0.75	8	1.65	0.57	8
Crassispira semiinflata	0.03	0.02	8	0.07	0.02	8	0.04	0.02	8	0.18	0.04	8
Cypraea spadicea	0.05	0.009	8	0.03	0.01	8	0.19	0.06	8	0.02	0.009	8
Kelletia kelletii	1.00	0.15	8	1.44	0.26	8	2.32	0.21	8	0.79	0.14	8
Mitra idae	0.75	0.25	8	0.78	0.20	8	0.19	0.05	8	0.73	0.17	8
Nassarius spp.	0.21	0.09	8	0.43	0.22	8	0.19	0.06	8	0.08	0.03	8
Ophiodermella inermis	0.04	0.02	8	0.009	0.005	8	0.006	0.004	8	0.02	0.009	8
Tegula aureotincta	0.009	0.005	8	0.02	0.01	8	0.05	0.02	8	0	0	8
Muricid snails	1.01	0.18	8	1.48	0.27	8	1.88	0.60	8	1.46	0.39	8
Maxwellia gemma	0.10	0.03	8	0.11	0.05	8	0.38	0.12	8	0.23	0.08	8
Murexiella santarosana	0.08	0.03	8	0.04	0.01	8	0.41	0.10	8	0.57	0.14	8
Pteropurpura festiva	0.80	0.15	8	1.29	0.25	8	1.05	0.40	8	0.70	0.19	8
Sea Urchins	15.74	1.09	8	34.96	0.83	8	13.83	3.94	8	1.65	0.43	8
Lytechinus anamesus	15.61	1.08	8	34.90	0.84	8	12.31	3.70	8	1.58	0.43	8
S. purpuratus	0.08	0.03	8	0.06	0.03	8	1.01	0.27	8	0.03	0.01	8
Holothurians												
Parastichopus parvimensis	0.01	0.007	8	0.02	0.008	8	0.20	0.03	8	0.19	0.03	8
Sessile Invertebrates	1.73	0.45	8	5.64	1.07	8	8.62	0.66	8	11.68	0.42	8
Muricea californica	1.51	0.41	8	5.27	0.99	8	7.14	0.49	8	8.65	0.37	8
Muricea fruticosa	0.13	0.04	8	0.27	0.07	8	1.34	0.22	8	2.79	0.11	8
Styela montereyensis	0.003	0.003	8	0.006	0.006	8	0.13	0.03	8	0.11	0.04	8
Tethya aurantia	0.08	0.01	8	0.03	0.006	8	0.007	0.005	8	0.13	0.01	8

APPENDIX B.

FLOW CHARTS OF DATA ANALYSIS

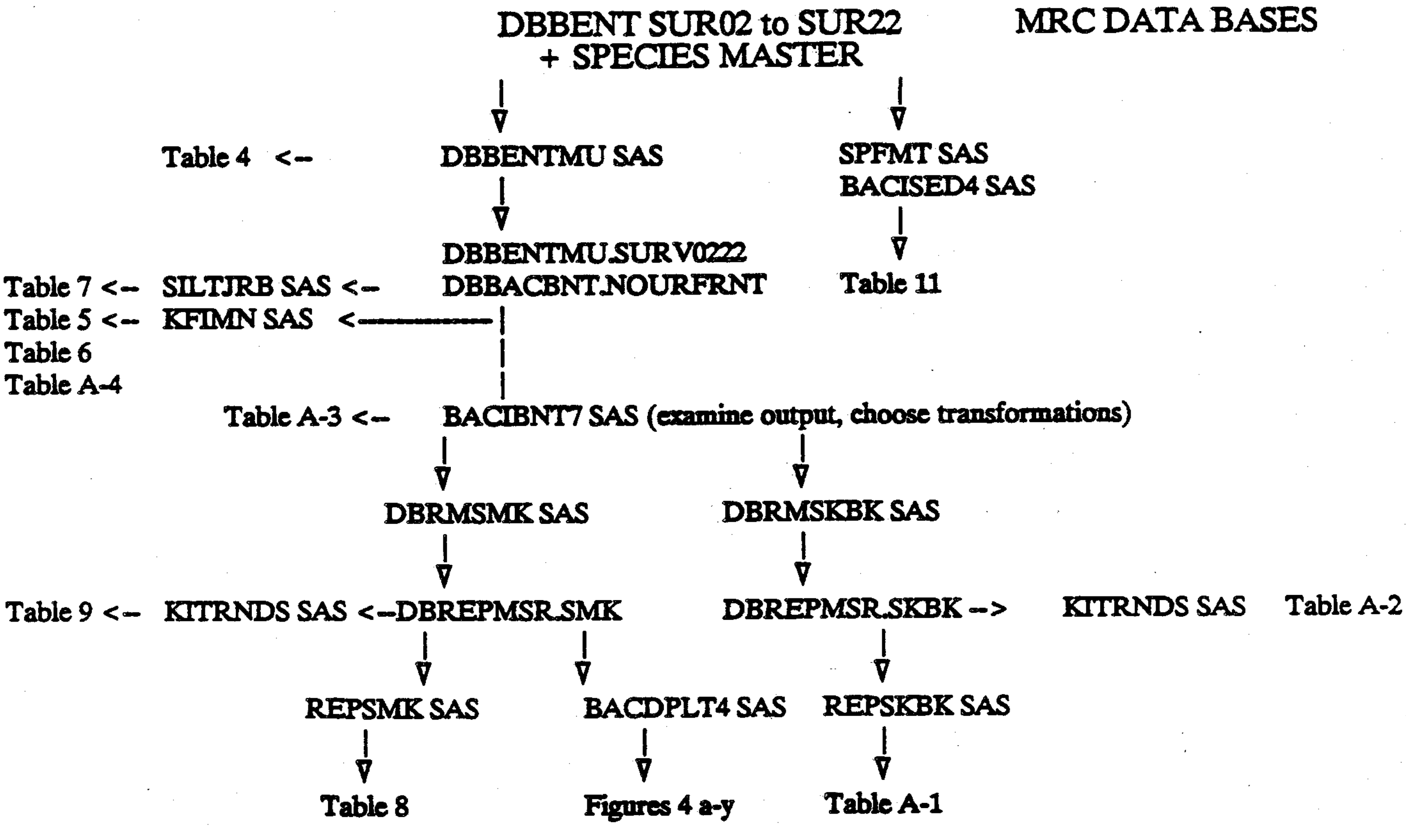
DBSONGS YR76 to YR88 → OPHISTI SAS → Table 2

MRC DATA BASES

GRAINSZ DATA → DBGRAIN SAS → Table 3

CARBON DATA → DBCARBON SAS → Table 3

RAW FILES



DBBENT SUR02 to SUR22
+ SPECIES MASTER
MRC DATA BASES
Table 4 <--
DBBENTMU SAS
SPFMT SAS
BACISED4 SAS
DBBENTMU.SURV0222
DBBACBNT.NOURFRNT
Table 11
Table 7 <--
SILTJRB SAS <--
Table 5 <--
KFIMN SAS <
Table 6
Table A-4
Table A-3 <--
BACIBNT7 SAS (examine output, choose transformations)
DBRMSMK SAS
DBRMSKBK SAS
Table 9 <--
KITRNDS SAS <--DBREPMSR.SMK
DBREPMSR.SKBK -->
KITRNDS SAS
Table A-2
REPSMK SAS
BACDPLT4 SAS
REPSKBK SAS
Table 8
Figures 4 a-y
Table A-1