TECHNICAL REPORT TO THE CALIFORNIA COASTAL COMMISSION

A. Sand Crabs

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This report analyzes and presents the results of scientific studies of sand crabs, which were done on behalf of the MRC over the period 1976-1987. The data were first reported by:

> Ms. Janice S. H. Auyong "Comparison of population structure of sand crabs (*Emerita analoga* Stimpson) living at increasing distances from a power plant (M. A. Thesis, University of California at Santa Barbara, 1981)
>
> Dr. Adrian Wenner's Final Report to the MRC "Sand Crab Population Structure Report" (1 July 1981)
>
> Marine Ecological Consultants' Final Report to the MRC "MEC 1983 Sand Crab Project" (5 October 1984), Principal Investigator Arthur M. Barnett, Chief Scientists Karen D. Green and Linda G. Gleye

which provided the starting point for the analyses in the present report.

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SUMMARY

In this report, we evaluate the evidence for whether the San Onofre Nuclear Generating Station (SONGS) has impacted sand crab populations. We do this by examining spatial and temporal patterns in the biology of sand crab populations based on data collected intermittently from 1976 through 1986.

A common feature of the sand crab studies was that samples were collected at a number of beaches varying in distance from the generating station. This enabled us to implement a protocol for objectively determining whether attributes of sand crabs in the vicinity of SONGS differ from sand crabs at more distant beaches. Such differences are termed "location effects" and, in principle, might or might not be related to SONGS. We used two distinct analytical approaches to test for the existence of location effects. In the first, we looked for trends in biological variables with increasing distance from SONGS, restricting these analyses to beaches within 20 km of SONGS (SONGS beaches). In the second, we compared the mean value of biological variables at Near beaches (6.5 km or closer to SONGS) with the mean value at Far beaches (farther than 6.5 km from SONGS).

In order to more directly test for an effect of operations of SONGS on sand crab biology, we examined relationships between the values of biological variables at an Impact site (relative to their values at a Control location) and the volume of water flowing through SONGS' cooling system. (We use as our dependent variable the difference between values at Impact and Control sites to factor out temporal variability which influences both sites in the same way.) These analyses are based on the hypothesis that an effect of SONGS should be accentuated when the power plant is pumping more water, since it is plausible that a SONGS impact would arise

from exposure to the station's effluents, or from other effects of high discharge volumes.

Although some location effects were identified, they do not appear to be related to processes associated with the flow of water through SONGS' cooling system. The few significant correlations between biological variables at the Impact site and flow volume did not help explain observed location effects.

The best evidence for "location-effects" was in the scarcity of larger female sand crabs and the prevalence of the "spent" and "partially spent" conditions near SONGS. Most of the location effects were not consistent through time or in spatial scale. Large female sand crabs, however, tended to be less abundant in samples collected at beaches within a few kilometers of SONGS in comparison with other beaches. This was most obvious during 1976-1978 in comparison with the other studies from which catch per unit effort (CPUE) data are available. These differences among studies may reflect real variation among years, or it might be an artifact due to the different methods used to estimate CPUE in the different studies. Maximum male and female size showed the same location effect as CPUE of large crabs, and the data needed to calculate this variable was collected across more of the studies than data on CPUE were. We take this as corroborating evidence that larger sand crabs were scarce at several of the beaches nearest SONGS.

The spent and partially spent conditions occur when ruptured egg cases are present on the pleopods of females. (It is possible for the spent condition to arise either through the normal hatching of eggs or through premature rupture, while the partially spent condition more strongly indicates that some eggs have ruptured prior to hatching.) The spent and partially spent conditions tended to be more prevalent over a broader region about SONGS, extending at least six km up and down coast from the generating station. This pattern was seen clearly for the spent condition in 1981 and 1983. In 1986 there was only one survey and no obvious location effect was detected for the spent condition. The pattern in the partially spent condition was also marked in 1983, and evident, but to a lesser extent (and for only one size class) during the 1986 survey.

The evidence is much weaker for location effects on other biological variables. In particular, the fraction of females carrying clutches of eggs was not generally lower near SONGS than at other sites. A summary of detected location effects is presented in Table 1.

Possible explanations for these location effects include natural environmental differences, differences associated with the construction of Units 2 and 3 (and those arising from other perturbations), and the release of metals and radionuclides by SONGS at levels not well correlated with the rate of flow of water through the station's cooling system. The most plausible of these explanations is the natural difference in beach environments: beaches nearer SONGS had more cobble than the beaches in other locations. The composition of beach substrate is known to have a potentially marked affect on sand crab biology.

Data on metal concentrations in sand crab tissues were collected twice in 1983 and once in 1986, and the detected concentrations of metals near SONGS were generally low. Metal concentrations were also low in beach sediment samples examined in 1983. This conclusion was supported by metal concentrations monitored in mussels by the MRC in 1976 and 1986, and by the State Mussel Watch Program in 1985. The metal levels found in mussels near SONGS were also low;

and MRC studies indicated that these levels tended to decline southwards from a station at the mouth of San Mateo Creek, approximately 4.5 km North of SONGS. Thus, it does not appear that SONGS is the most significant source of chromium, or other metals, in the local area. Although a relatively high value of chromium was seen in one category of sand crabs at one beach near SONGS on one of these surveys relative to other beaches that were sampled, the available evidence suggests that chromium concentrations were not high enough to produce significant adverse effects on sand crabs, and there was no clear pattern of correlations between biological variables and tissue chromium concentrations. In addition, location effects occurred in sand crabs both during periods when measured metal concentrations were low in sand crabs or mussel tissues, and at times when metal concentrations in tissues were higher. Although the available data cannot rule out the possibility that intermittent pulses of metallic releases from SONGS have some adverse effects on sand crabs, there is little evidence supporting this possibility.

The MRC evaluated radionuclide activity in sand crabs only during 1986. However, the values detected were several orders of magnitude below the levels likely to produce measurable biological effects. In conjunction with activity levels reported in the NRC monitoring program, these data indicate that it is very unlikely that location effects in sand crabs are due to releases of radionuclides by SONGS.

1. INTRODUCTION

The intertidal area adjacent to SONGS is a mixed, sand and cobble beach. In 1976, the MRC began studies of sand crabs (*Emerita analoga*), a common component of biological communities on high wave energy sandy beaches in Southern California (e.g. Cox and Dudley 1968). With the exception of very limited work on fishes occupying the surf zone, the MRC's studies on sand crabs represent the only investigations of SONGS' potential impacts on organisms in the intertidal zone.

Unlike other MRC programs, the intent of these studies was not to evaluate the impact of SONGS by collecting data at Control and Impact stations Before and After SONGS Units 2 and 3 began operation. As described below, the various studies on sand crabs were designed with different purposes, were done by several different contractors, and varied greatly in their temporal and spatial sampling designs. However, similar types of biological information were collected in each of a number of years. He analyze all pertinent MRC data on sand crabs using a consistent set of methods, in order to evaluate comprehensively the evidence for impacts of SONGS' operations on populations of this species.

We first examine the sand crab data to determine whether there are differences in biological variables between populations from beaches near, and those less proximate to SONGS. Such differences we term "location effects" to distinguish them from effects known to result from the operation of SONGS, and we recognize that differences among populations of sand crabs can arise for reasons unrelated to, as well as related to, SONGS' operations. We look for location effects on sand crab abundance, reproduction, size, and growth. We then evaluate whether differences in sand crab biology between beaches designated as Control and Impact sites were more pronounced during periods of heavier operations by SONGS, to try to determine if the differences are caused by SONGS. We also evaluate, in two appendix reports, the results of special studies designed to relate sand crab biology to properties of the physical environment (Appendix C) or to determine whether releases of metals or radionuclides by SONGS might be the cause of observed location effects (Appendix B). These studies were designed to examine potential causes for observed location effects, both due to SONGS and to other aspects of the environment. The results of these studies are also summarized in the Results (below). For the reasons discussed below (Sand Crab Life History and Biology), we consider special studies of the temporal pattern of reproduction in sand crab populations in a third appendix report (Appendix D).

Factors other than SONGS' operations (such as physical characteristics of the beach) certainly influence sand crab biology, and they vary in time and space. In particular, they may contribute to differences between sand crab populations near and far from SONGS. However, we have no reason to believe that any differences they cause will change through time in relation to the level of SONGS' operations. Thus, we believe that changes near and far from SONGS linked to SONGS' operating status, could reasonably be attributed to SONGS. Conversely, broad scale environmental changes from one year to another do not invalidate our search for effects linked to SONGS operation. For example, although the 1983 study was done during the height of a major El Nino, and this event probably influenced sand crab populations in the Southern California Bight (Barnett and Green 1984), we do not believe that this invalidates the results of that study or our analyses that include data from that year.

Our choice of characteristics of sand crab populations to be used in the analyses is largely dictated by the available data, but each of the characteristics is also of interest in its own right. Examination of potential effects on abundance or catch per unit effort is of obvious interest, and is consistent with the emphasis of other MRC programs. Sand crab reproduction in the San Onofre region has been termed abnormal in published accounts (Siegel and Wenner 1984, Wenner *et al.* 1987), so it is of interest to determine whether SONGS has disrupted reproduction by sand crabs. Growth, and characteristics of a sand crab population's size distribution are both potential assays of the degree of favorability of the environment (Wenner *et al.* 1974, Auyong 1981, Wenner *et al.* 1985). These attributes have been reported to differ near SONGS from those seen at beaches elsewhere (Auyong 1981, Wenner *et al.* 1985, Wenner *et al.* 1987).

We conclude this Introduction with a brief review of sand crab biology, a short discussion of potential mechanisms by which SONGS might impact sand crab populations, and a history of the MRC's sand crab studies. These presentations are intended to place the results that follow in a broader context.

1.1. Sand Crab Life History and Biology

Sand crabs (*E. analoga*) are found intertidally on the west coast of the Americas. In North America they extend from Alaska to Baja California (Efford 1970). When undisturbed they are typically found in the top 10 cm of the sand where they feed by straining food particles from the wave wash with their antennae (Efford 1966). They are fed upon by a number of predators including other crabs, and are an important part of the diet of some fishes and shore birds (MacGinitie 1938, Young 1938, Dudley 1967).

The life history of the sand crab is quite variable, with substantial differences occurring even between populations within several km of one another. These include differences in the timing of recruitment and reproduction, the duration of the reproductive season, the number of clutches per female, and the life span of female sand crabs (Barnes and Wenner 1968, Cox and Dudley 1968, Efford 1970, Diaz 1980, Fusaro 1980, Siegel 1984, Wenner *et al.* 1985, Wenner 1988).

Female sand crabs typically extrude one to four clutches of eggs during late spring and summer (Cox and Dudley 1968, Barnes and Wenner 1968, Efford 1969, Fusaro 1978, Diaz 1980). The number of clutches produced per female appears to vary both geographically and between nearby beaches. Factors that appear to influence the number of clutches produced include variation in egg development time (e.g. Cox and Dudley 1968), variation in population size and/or age structure of females (e.g. Diaz 1980), and differences among beaches that influence the timing of the onset and end of the reproductive season (for example, variation among beaches in the timing of pulses of planktonic food for sand crabs (e.g. Siegel 1984). Cox and Dudley (1968) also noted that occasionally females reproduce only once during their first year on a beach.

Some populations of *Emerita* appear to reproduce in a synchronous fashion with two or more peaks and troughs of reproduction during the season (Osario *et al.*

1967, Diaz 1980). Synchronous molting and development of a cohort of sand crabs on a southern California beach have been reported by Siegel (1984).

Females reproduce by extruding a mass of eggs which they carry externally, attached to the pleopods. Upon extrusion, the eggs are bright orange in color. As they develop, yolk is used up and they change to a burnt orange color. As additional yolk is consumed they darken further in color and become gray in appearance prior to hatching. Usually all viable eggs within a clutch hatch within a short time period on the same day. Egg-hatching leaves behind empty or "spent" egg cases attached to the crabs' pleopods.

It was believed, prior to some of the research reported here, that empty (spent) egg cases normally remain attached to the pleopods for only a day or two (Siegel and Wenner 1984). Studies done by Marine Ecological Consultants (MEC) on the behalf of the MRC, have since shown, however, that spent egg cases are probably retained for substantially longer periods, at least towards the end of the reproductive season. The results of these studies are included as Appendix D and are summarized in the Results section below.

The temporal pattern of egg development in a population of sand crabs is important to our interpretation of two reproductive characteristics. The "spent condition" refers to a female still carrying empty egg cases. If a large fraction of the population is in this condition, it might imply one of several things: (a) reproduction is synchronized and has just occurred, (b) an abnormal disruption or bursting of egg cases has just occurred, or (c) empty (spent) egg cases are retained on the pleopods for more than a few days, either after normal reproduction or disruption, which may or may not be synchronous. Siegel and Wenner (1984) have interpreted a high fraction of the population being in the spent condition near SONGS as abnormal reproduction. A second reproductive category, the "partially spent" condition, was discovered in later studies by MEC for the MRC. Here, spent or empty egg cases occur within a clutch containing some intact and apparently viable eggs. Because eggs within a clutch hatch together, this condition probably indicates that some eggs ruptured prior to hatching, and we interpret it as indicating less successful reproduction.

Sand crab reproduction typically occurs between April and October, and hatching of eggs often peaks in August. Sand crab megalopae (i.e. recruits from the plankton) typically start arriving in number on Southern California beaches during late March and early April. Usually recruitment to the beach peaks during June (Efford 1965, Fusaro 1977, Auyong 1981, Siegel 1984), although considerable variability in the timing of *Emerita* recruitment exists (Diaz 1980), and heavy recruitment has even been noted in November (Barnes and Wenner 1968). The time between heavy release of larvae into the plankton and heavy recruitment to beaches suggests planktonic larval durations as long as nine months, although some laboratory studies, and examination of larval morphology in field collections suggest shorter durations (Johnson 1940, Rees 1959, Knight 1966, Hanson 1969). Efford (1970) noted, however, that laboratory studies may underestimate larval duration.

Most investigators agree that few male sand crabs live more than one year, while some females can live as long as three to five years (Dudley 1967). In almost all cases, however, new recruits to beaches far outnumber overwintering adults (Efford 1965, Barnes and Wenner 1968, Cox and Dudley 1968, Wenner *et al.* 1974), and consequently total abundance typically peaks in June, after most recruitment has occurred. Abundances, especially of larger females, drop sharply in the fall. By late fall, larger females are usually rare in the intertidal zone. All size classes of sand crabs are scarce on beaches during winter (Efford 1965, Barnes and Wenner 1968, Eickstaedt 1969). This may be partially attributable to crabs moving to the subtidal zone during the fall, a possibility supported by the fact that their contribution to the diet of surfperch does not decline during the winter even when they are scarce on the beach (Carlisle *et al.* 1960). They have also occasionally been observed (even during the summer) occupying subtidal areas (Auyong 1981, Barnett and Green 1984). On some beaches female *Emerita* do not successfully overwinter from one year to the next (Efford 1970, Diaz 1980). The extent to which intertidal and subtidal populations move in the longshore direction is unknown.

1.2. Potential Impacts of SONGS on Sand Crabs

SONGS takes in, circulates, and then returns water to the ocean. This process is necessary to dissipate heat generated by the controlled fission reactions. Although all plankton actually circulated through SONGS' cooling system are probably killed, the heating of the environment by this water appears to only have minor effects (Final Technical Report L). Other potential effects of circulating water are discussed below. Additional detail on the mechanics of SONGS' operations is described in Interim Technical Report 1.

An understanding of how SONGS could impact sand crabs requires some knowledge of plant related events that occurred during the studies on sand crabs, and major events encompassing this period are listed in Table 2. At the beginning of the MRC's studies in 1976, SONGS Unit 1 was already commercially operational, although the extent to which it operated varied through time. Construction of the new units (2 and 3) began in 1974 and extended through 1980. Unit 2 first pumped water during early 1980, while Unit 3 first pumped water in early 1982. This early pumping was part of the testing of Units 2 and 3, but they did not begin producing power until October 1982 and September 1983, respectively. These Units did not reach levels of water circulation approximating their long-term expected operating levels until mid-1983. At full capacity these Units, in combination, pump water at approximately five times the rate of Unit 1.

Sand crabs are unique in MRC studies in that putative effects were seen when only Unit 1 was operating. (Nothing more than minor, and highly localized effects of Unit 1 were seen for any other organism (MRC 1979)). If SONGS caused effects during the initial 1976-1978 study they must have resulted from the operations of Unit 1 or the construction of Units 2 and 3. If regular operations of SONGS Units 2 and 3 were responsible for any effects observed prior to 1983, it is reasonable to expect that effects in the later studies, done for the MRC during 1983, 1984 and 1986, should be at least as large, as the new units were operating at much higher levels, and had begun producing power.

Here we discuss previously proposed mechanisms and other potential mechanisms that seem most likely to affect sand crab populations in the vicinity of SONGS.

Some larval sand crabs almost certainly pass through SONGS' seawater cooling system and are killed. In its predictions to the CCC, the MRC reported that intertidal organisms are at higher risk than most other benthic organisms because their larvae must pass through the intake depth to reach the beach (MRC 1979). However, it seems unlikely that this could cause reductions of more than one or two percent in recruitment to beaches near SONGS since on average only a small percentage of the water reaching these beaches passes through SONGS' cooling system, even when all the Units are operating continuously (Final Technical Report L).

Barnett and Green (1984) suggested that detritus discharged by SONGS, if of an appropriate size, could interfere with the filter feeding of sand crabs. There is no evidence in support of this mechanism. Auyong (1981) found that total organic carbon was not higher in beach sediments closest to SONGS during the 1976 -1978 period when only Unit 1 was operating. Data collected in 1983 indicate that seston at SONGS' beaches is not higher than elsewhere (Barnett and Green 1984).

Siegel and Wenner (1984) have suggested that metals released by SONGS might negatively impact sand crabs. Unit 1 did release a number of metals, including relatively large amounts of copper as a result of corrosion of condenser tubing (USAEC 1973). Copper has been shown to reduce larval growth of another crab species (Sanders *et al.* 1983) at levels not far above ambient sea water concentrations. This condenser tubing was replaced in 1981 with corrosion-resistant titanium and concrete. It seems conceivable, then, that releases of copper by SONGS could have impacted sand crabs in studies prior to 1981. It has also been argued that if the concentration of chromium released by Units 2 and 3 were as high as the detection limit of the monitoring program for it, it might be sufficiently high to impact sand crabs (see Final Technical Report E). The possibility that metals have produced impacts on sand crabs is therefore evaluated in this report. Radionuclides have also been suggested as a possible mechanism by which SONGS could impact sand crabs, and this possibility is also evaluated here.

Increases of sand and other sediments in the wash zone could also interfere with sand crab feeding (Efford 1967). Construction activities around SONGS from 1974 to 1981 almost certainly increased sand flow along beaches near the plant (Wanetick and Flick 1986), and normal sand transport was interrupted from 1974 to 1984 by a temporary sea wall (the sand pad) (Table 2). The release of the construction sand pad in 1984 also influenced local sand transport (Inman 1987, Wanetick and Flick 1986). Temporary changes or more permanent changes in sand flow could have produced impacts on sand crabs.

As we noted above, sand crabs near SONGS might also differ from sand crabs in other areas for reasons unrelated to the power plant. For example, the beaches near SONGS are generally rockier than other sampled beaches, and this could affect various characteristics of the sand crab populations.

1.3. A Short History of MRC Studies of Sand Crabs.

The MRC first began studying sand crabs in 1976. The original 19 month study (fall 1976 to spring 1978) was done by Ms. Janice Auyong, and formed the basis of her M.A. thesis at the Univ. of Calif., Santa Barbara (Auyong 1981). The stated purpose of her study was to determine whether or not differences in size structure or reproduction among populations of sand crabs were correlated with distance from SONGS Unit 1. She concentrated her sampling in a "cell" extending

6.5 km north and south of the plant, but also sampled "control" beaches 16 and 65 km (La Jolla) from SONGS (Fig. 1) . In addition to her thesis, the results of her study are reported, in part, in MRC (1977), Wenner and Haley (1981), Wenner (1982), Wenner *et al.* (1985), Wenner *et al.* (1987), and Wenner (1988). Her surveys generally involved collecting a known number of cores from a beach. She supplemented these samples with sand crabs collected by shovel. In the laboratory she also assayed the growth of sand crabs she collected.

Auyong's study suggested that crab size increased with distance from SONGS out to 6.5 km. Additional studies were therefore planned for 1980 during a period when SONGS' Unit 1 was scheduled to be nonoperational, so that the results could be compared with Auyong's. The MRC's plan was that the results of such a study would allow the spatial patterns seen within 6.5 km of SONGS during the 1977 "on" period to be compared to spatial patterns in the same region during a 1980 "off" period. The disappearance of the relationship between size and distance in an off period would be relatively strong circumstantial evidence that operations by Unit 1 were the cause of the relationship observed in 1977. Dr. Adrian Wenner of the University of California at Santa Barbara was contracted to study the potential impacts of SONGS during 1980. The methods differed from Auyong's in that all samples were "opportunistic", and no laboratory growth experiments were done. Most critically, the sampling design did not replicate the earlier design used by Auyong. Most sampling occurred at three locations spread out over 250 miles of southern California coast, with only one of these main sites within 6.5 km of SONGS (Fig. 2). In general, sampling was done at only a few beaches in any given month. This is also a problem because other studies, quoted above, have shown that sand crab biology varies through the season. Further complicating the issue, SONGS

Unit 1 was not completely non-operational during the 1980 study, and actually circulated an average of about one million m^3 of water per day during the spring and summer of that year (in comparison with approximately 1.6 million m^3 during 1977).

In part because of the problems experienced during 1980, the MRC contracted with Dr. Wenner to resample Auyong's original beaches near SONGS in 1981, along with control beaches near La Jolla and Goleta (see Figs. 1 and 2). During this study each of the beaches was sampled within the same month, and over several different months. Unit 1 had not been operating through the spring of that year, but by mid-summer was operating at the same levels as during 1977.

Starting in late July 1981, a new variable, the fraction of sand crabs carrying "spent egg cases", was recorded and Wenner reported higher fractions of the population in this condition at SONGS beaches than at control beaches (Wenner 1982). This spent condition occurs when clutches of empty (ruptured) egg cases are found on the pleopods of female crabs (see above). It has been argued that this represents an "abnormal" condition (Siegel and Wenner 1984), but it could result from the normal hatching of eggs (Barnett and Green 1984). These alternatives are addressed in this report.

The MRC remained unsure, following the reports of the 1980 and 1981 studies, whether it had been reliably established that sand crabs near SONGS were different from those elsewhere, and whether such differences, if they occurred, were related to the operation of the plant. Marine Ecological Consultants (MEC) was contracted to study sand crabs during 1983. Because of perceived weaknesses in the earlier studies, the major purposes of the new study were 1) to see if the biological attributes of sand crabs at beaches near SONGS were within the range of variation found on other Southern California beaches, and 2) to attempt to explain among-beach differences in sand crab biology based upon physical-chemical variables, including metal concentrations in sediments. Auyong's original beaches near SONGS were sampled during this study together with several additional beaches within 20 km of SONGS. A number of beaches more than 20 km from the plant were also sampled (Fig. 3). The study differed from earlier MRC work on sand crabs in that a variety of physical/chemical measurements were made and quantitative samples designed to estimate crab abundance were taken. During the 1983 study, MEC also collected sediment and sand crabs for metal analyses. It was during this study that data on the reproductive condition "partially spent" (see above) were first taken.

During 1984, MEC sampled four beaches (three at 6.5 km or closer to SONGS, and La Jolla) to test whether high levels of spent eggs near SONGS might be due to synchronous reproduction and/or retention of spent egg cases at the end of the reproductive season. Since their study was not designed to measure abundance, but was aimed at describing temporal variability in reproductive condition, "opportunistic" samples were taken at weekly intervals.

During 1986, a single sand crab survey was done during August by MEC. The primary purposes of this study were to collect additional information on spatial variability in the reproductive status of sand crabs by sampling a large number of closely-spaced beaches in the vicinity of SONGS, and to determine whether the levels of metals or radionuclides in sand crab tissues were higher at the beaches more proximate to SONGS.

2. METHODS

2.1. Field and Laboratory Methods

Brief descriptions of the various sand crab studies are presented here so that a reader can determine the nature and source of data used in the analyses that follow. Detailed descriptions of the methods used during each field study are in the various contractor's original reports. Some additional information not contained in those formal reports is found in memos and work statements, and is reproduced in Appendix H. The locations of the beach sites are shown in Figs. 1-3, and additional beaches are indicated by name and by distance from SONGS when referred to. A listing of the months during each study when data were collected at each beach site is in Appendix A.

2.1.1 The 1976 - 1978 Study

This study lasted from September, 1976, through March, 1978, and was done under the direction of Ms. Janice Auyong. The methods used in this study are documented in her thesis (Auyong 1981). The 6 main study sites were located 6.5 kilometers north and south of SONGS (6.5 K North and 6.5 K South), 1.5 kilometers north and south of SONGS (1.5 K North and 1.5 K South), 400 meters north of the plant (0.4 K North), and 16 kilometers south of SONGS (16 K South) (Fig. 1). The beaches 6.5 km or closer to SONGS were termed "experimental" beaches, and the beach 16 km south was called a control in Auyong's thesis. These beaches were sampled at two-week intervals throughout most of the study. Samples were also occasionally taken at beaches 48 km and 65 km south of the plant.

Although only data from September, 1976, through August, 1977, are discussed in detail in Auyong (1981), she provided the MRC with data for the entire September 1976 - March 1978 period.

Two collections were made within three days at each beach for each survey. In general, all beaches were sampled within the same night for each collection. She sampled sand crabs by taking cores within the visible band of sand crabs on the beach. Cores were obtained with a 10 cm diameter aluminum "clam gun", marked to take a core of ten cm depth. The numbers of sand crabs within each core were counted, then the crabs were pooled and sorted into size and reproductive categories. Sand crabs were sized by sieving them through a series of tubs with graded openings. Length of sand crabs retained in each tub is obtained using a regression equation. Individuals were classified as megalopae, females, or males. Females were classified as having or not having eggs. Additional "qualitative" samples were collected by shovel when few sand crabs were collected in the cores.

A relatively small set of physical-chemical measurements was made when sand crabs were collected (water temperature, ash-free dry weight of water samples, beach slope, and data on wave patterns). Auyong (1981) found no relationship between sand crab biology and these variables. Because important variables such as cobble composition were not recorded, the physical-chemical data are not used in analyses presented here.

Laboratory assays of growth rate were also done. Sand crabs collected in the field were kept in the laboratory for four days in a flow-through seawater system. Each day the size of each molt increment, for crabs that molted, was recorded.

While Auyong (1981) states that when possible, a total of at least 30 individuals from each of seven selected size classes for each beach site were taken from the field collection for the growth studies, examination of the data suggests that on most dates this goal was not reached. Consequently, analyses in this report are done on broader size classes, and for data pooled over monthly periods often consisting of two surveys. Auyong (1981) adopted a similar procedure.

2.1.2 The 1980 Study

Methods for this study are considered briefly in the final report by Dr. A. Wenner (1982). Some further detail of the methods can be found in the correspondence between the MRC and its consultants, and Dr. Wenner (Appendix H).

During 1980, the three main study beaches were 0.4 K North, La Jolla (65 K South) and Goleta (253 km North) (Fig. 2). These beaches were sampled a number of times during April - November. Samples were not always taken at all beaches on each survey, and the period of time between samples varied through the season. Various other beaches were sampled, but data were collected at most of these only once midway through the study.

Regular sampling was of the "opportunistic" type, using a shovel. Essentially the same sorting and categorization procedures (by size and reproductive condition) were used in 1980 as in 1976-1978. Water temperature was recorded, but not at all beaches or on all dates, and these data are not considered further.

2.1.3 The 1981 Study

A description of the methods for the 1981 study is in Wenner (1982), and additional detail is contained in correspondence between the MRC and Dr. Wenner (Appendix H).

The five "experimental" study sites near SONGS sampled during 1976-1978 were also sampled in 1981 (Fig. 1). Other regular sampling sites during 1981 were at La Jolla, and at sites near Goleta (Fig. 2). The contractor also supplied the MRC with some data from other sites, although these were not regularly sampled. The experimental beaches were sampled during seven surveys, La Jolla was sampled four times, and the sites near Goleta were sampled five (Goleta Pt.) and three (Goleta Pier) times. Regular sampling was of the "opportunistic" type. Size sorting of crabs was done in the same way in 1981 as in 1980. In the studies prior to 1981 female sand crabs were categorized as having eggs or not. Starting in mid-July 1981, data on a new category, which we call the "spent condition", were recorded. Sand crabs in this condition are carrying clutches of ruptured eggs on their pleopods. This condition is described in greater detail above in Section 1.3.

2.1.4 The 1983 Study

The methods used in the 1983 MEC sand crab study are documented in their final report (Barnett and Green 1984). During 1983, there were three main surveys done during June, July, and August at 15 beaches. One additional beach was sampled on the August survey. Beach sites included the five original "experimental" beaches, 4 additional beaches out to 18 kilometers both up and down the coast from SONGS, and beaches further from the plant, including La Jolla (Fig. 3).

Sampling of sand crabs at each beach followed a stratified-random design. First, the area of each beach that was inhabitable by sand crabs (containing less than 80% cobble), and the subset of this area with sand crab aggregations was estimated visually. Sand crabs were collected by towing a sled device with an attached net through visible patches (aggregations) of sand crabs, and in interpatch areas within the inhabitable zone of the beach.

Sand crabs were sorted through sieves as in earlier studies, and classified by sex and reproductive condition in the laboratory with the aid of a dissecting microscope. Female sand crabs were classified as being in the spent condition, without eggs, or with eggs. Clutches of eggs were classified by color as an indication of the stage of development. Data on "the partially spent condition" were also recorded for the first time during this study. This condition is defined by the occurrence of ruptured eggs within clutches also containing apparently viable eggs. This condition was recorded only for the subset of female sand crabs for which the intact eggs were bright orange in color (originally this was done by MEC to estimate clutch size). The numbers of crabs evaluated for this condition were relatively low, especially for June. (Few crabs were evaluated for this condition in June because few reproductive individuals could be collected during that month.)

During the July and August surveys, sand crabs and sediments were collected and supplied to Science Applications International Corporation (SAIC) for assay of metal concentrations.

To document the end of the reproductive season, additional abbreviated surveys were made in late August and September. No physical-chemical measurements were taken, and three patches per beach were sampled by shovel from a subset of the beaches. These data are only used in the analyses presented in Appendix D. In these surveys, females were only classified as without eggs, with eggs, or in the spent condition.

2.1.5 The 1984 Study

During 1984, MEC collected sand crabs near SONGS (0.4 K North and 1.5 K North), at 6.5 K North, and at La Jolla each week, beginning in July, and continuing until few female sand crabs were reproducing on each beach. Since this study was designed to estimate the proportion of sand crabs in the various reproductive classes, large "opportunistic" samples were collected by shovel. Crabs were sorted into two size classes (10-13 mm and > 13 mm carapace length) in the laboratory. Sand crabs were also categorized by sex, and females were further classified by whether they were in the spent or partially spent conditions, or carrying intact clutches of eggs. The color of intact eggs was also recorded. No physical-chemical measurements were made during 1984. Because data were collected from only a few beaches during 1984, they are not used in the tests for "location effects". They are used in examining relationships between biological variables and SONGS' operating status (see below), and for work on clarifying the biological meaning of the spent and partially spent conditions (Appendix D). Additional detail on methods is contained in work statements and memos from MEC (Appendix H).

2.1.6 The 1986 Study

During 1986 only a single survey was done during August by MEC. Sand crabs were collected at 29 locations. Twenty-seven of these locations were within 20 km of SONGS, and La Jolla and Moonlight Beach (45 km south of SONGS) were sampled as well. Because the purpose of this study was to evaluate the reproductive condition of the female sand crab population all sampling was "opportunistic". At each sampling location, sand crabs were collected within an approximately 0.5 km long "search zone". A "sand crab catcher", a hand-held sieving device commonly used by fishermen, was used to collect the large number of sand crabs required for the various metal and radionuclide analyses. The effort expended in capturing sand crabs (in terms of person-hours of effort) was recorded for each sampling location. Female sand crabs were sorted into three size categories, 7-10 mm, 10-13 mm and greater than 13 mm in carapace length. The 7-10 mm sand crabs were not examined because females of this size often are not yet reproducing.

The sand crabs were categorized in the laboratory as to reproductive condition, by examination under a dissecting microscope. Field observations on reproductive condition of sand crabs were also made to allow the rapid categorization of sand crabs to be used in metal analyses. Because the "partially spent condition" (see below) was defined differently for these field observations than it was in the laboratory during 1984 and 1986, and also because of the difference in methods, the field observations were only used to define categories for metal analyses and the lab determinations were used in the statistical analyses that follow.

When locations were sampled, beach slope was measured, and percent of cobble in the wave wash zone was estimated. Also, sediment samples were collected and the distribution of particle sizes was evaluated.

Sand crabs in the 10-13 mm size class were assayed for concentrations of iron, manganese and chromium since these were the metals that preliminary analyses had indicated might be at higher concentrations in sand crabs near SONGS. Sand crabs in the 10-13 mm and greater than 13 mm size classes were supplied to Thermo Analytical Inc. for radiological analyses under SCE funding.

Additional details on methods for the 1986 study are contained in work statements and memos from MEC (Appendix H).

2.2. Analytical Methods

Here we describe the statistical and quantitative methods used to analyze the sand crab data. Most of the Statistical Analysis System (SAS) programs used in these analyses were permanently saved on the sand crab report disk using the MRC's Disk Inventory Control System (Titan 1988). SAS programs generated in late 1988 were saved on the MRC report disk using the same system. A few additional SAS programs written during 1989 are currently saved on a write only space on the University of California at Santa Barbara's computer system and will be archived onto computer tape. Flow charts of the programs used in the analyses are in Appendix G.

2.2.1 Biological Variables Used in Analyses

As described below, biological variables were analyzed for "location effects" and for correlations with the volume of water flowing through SONGS' cooling system. The biological variables used in tests of location effects are presented in Table 3, which also lists the studies in which data appropriate for these tests for each variable were collected. Appendix A contains a list of the months for which each of these variables could be estimated at each beach. A list of the biological variables used in correlations with SONGS' flow volume for Unit 1 and Units 2 and 3 is in Table 4. Details on the data used and the methods of calculating the values for each variable follow.

2.2.1.1 Catch per unit effort (CPUE)

Quantitative sampling of sand crab CPUE was undertaken in three different studies during the years 1976-1978, 1983 and 1986 (Table 3). Unfortunately, due to the shifting emphases of the investigations from year to year, researchers employed different sampling methods in each of these studies, so that CPUE estimates of sand crabs are not quantitatively comparable across studies (see Section 2.1). While the derived variables are all measures of the numbers of crabs collected per unit effort at beaches, they each reflect different aspects of local abundance. The algorithms used to construct the CPUE estimates, and their rationales, are described below.

In 1976-1978, a "clam gun" was used to collect core samples from the intertidal zone. For our purposes, the data from all cores taken at a site during a given month were pooled. Then CPUE was calculated as the mean numbers of crabs per core, for females from five size classes, males, megalopae, and overall totals. The standard error of our estimate of CPUE for a beach was, on average, 15% of the mean.

For the 1976-1978 study, correlations of CPUE with distance from SONGS were done using only beaches 6.5 km or closer to SONGS, and t-tests on CPUE, comparing Near and Far beaches, are not presented. This was done, because no appropriate data on CPUE were collected from beaches further than 6.5 km from SONGS (see Auyong 1981).

In 1983, a stratified-random sampling method was used (see Field and Laboratory Methods). In general, areas of high crab density (patches) and areas of low or zero density (inter-patches) were demarcated, and their total longshore extent tallied, yielding proportions of the inhabitable beach comprised of patches or inter-patches. A specially designed sled was then used to sample completely through the cross-shore widths of sand crab patch areas. Estimates of sand crab CPUE (density), for females of five size classes, and overall total for males, were then calculated as weighted averages of the mean abundances per sled tow found in each of the two habitat types. Thus, the mean number per tow from within each habitat was multiplied by the proportion of the entire (inhabitable) beach comprised of that type, and these products were then summed over the habitat types. Data from 1983 came from only three surveys done during June, July, and August. The standard error of our estimate of CPUE was, on average, 43% of the mean. (The standard error was calculated as the square root of $(p_i^2 s_i^2 + p_p^2 s_p^2)$, where p_i and p_p refer to the proportions of the inhabitable beach that were patch or inter-patch, and s_x is the standard error of the mean numbers per tow within habitat type x.)

During 1986, there was only one survey during August, and sampling was done "opportunistically", with investigators collecting crabs over approximately a 400 m stretch of beach for a measured time period. The total numbers of female crabs caught within two size classes were then divided by the numbers of person-hours of effort required to collect them. The primary purpose of this survey was to collect sufficient crabs for metal and radionuclide analyses; consequently beaches where sand crabs were collected at a slower rate were sampled for a longer period of time. No estimate of the precision of these CPUE estimates is possible because there was no within beach replication. Clearly, however, with these kinds of data only very large differences in CPUE are likely to be distinguished or should be given much weight.

2.2.1.2 Fractions reproductive, spent and partially spent

Some data on one or more of these reproductive variables are available from studies done during 1976-1978, 1980, 1981, 1983, 1984 and 1986 (Table 3). For each month, the estimates of fractions reproductive, spent and partially spent were calculated at a given beach for a given size class by pooling all samples from that beach during that month. In all cases, fractions based on sample sizes of five or less were treated as missing values. Separate analyses were done for each size class. Sand crabs were categorized into four size classes based on carapace length: ≤ 7 mm (small), 7-10 mm (medium - small), 10-13 mm (medium - large), and > 13 mm (large).

For the 1976-1978 study, the fraction reproductive was calculated by dividing the number of females with eggs by the total number of female crabs. No appropriate data were available for "fraction spent" and "fraction partially spent" from this study since data on these conditions were not taken prior to 1981.

During the 1980 and 1981 studies the data were similar to those collected during 1976-1978 in that the same reproductive variables could be estimated. An additional reproductive category, the "spent condition", was added starting in July 1981. These individuals still retained their egg masses, even though the egg cases were empty (either through natural hatching or premature rupture). During 1981 and all later studies, the fraction reproductive was calculated by dividing the number of females with eggs (the spent condition was excluded from this category) by the total number of female crabs. Fraction spent was found by dividing the number of female crabs with spent egg masses by the total number of female sand crabs. No appropriate data for the fraction partially spent were available from these studies.

During 1983, there were three main surveys within which almost all beaches were sampled over a short time period (a few days). Each of the surveys is treated as a single time period. On several additional "abbreviated" surveys, samples were collected at a subset of the beaches as the reproductive season ended. Because these data from the "abbreviated" surveys were collected for a special purpose, they are analyzed separately (see Appendix D).

Starting in 1983 the category "female crabs with eggs" (used to calculate the fraction reproductive) is taken to include females carrying bright orange eggs, burnt orange eggs, gray eggs and partially spent clutches (which contain some intact eggs of one of these colors), with the color of the eggs indicative of their stage of development. During 1983, only a limited amount of data was collected on the partially spent condition, and only females with bright orange egg masses were classified as to this condition. Because the data are so limited, we do not stratify our analysis of the partially spent condition by size for this year. We include in the partially spent category crabs classified by MEC as having few spent egg cases or several spent egg cases within clutches of bright orange eggs. The total number of females with bright orange eggs was used as the denominator for "fraction partially spent". Because only a small subset of the crabs was classified as to whether they were partially spent, and most of these data were collected during the July and August surveys, we analyze only data from July and August, and pool the data from these two months.

The 1986 samples were taken only during August. Samples were collected at a greater number of beaches than in any other study year, with most beaches located within 20 km of SONGS. Crabs were divided into two size categories based on carapace length, for both lab and field data: 10-13 mm (medium-large) and > 13 mm (large). Again the category "female crabs with eggs" includes all females carrying partially spent or intact clutches of eggs. The category "female crabs with partially spent clutches" includes females carrying clutches with some intact bright or burnt orange eggs and greater than 15% spent eggs. The denominator in our calculation of the fraction partially spent only included females with intact or partially spent clutches where the intact eggs were bright orange or burnt orange in color. We excluded crabs carrying gray eggs from the calculation because gray eggs contain fully developed larvae that are nearly ready to or in the process of hatching, and thus spent egg cases are sometimes naturally present in such a mass. The "spent" category includes females carrying clutches composed almost entirely

(>85%) of spent eggs. These spent individuals were not included in the reproductive category of female crabs.

2.2.1.3 Variables derived using size distribution data: mean maximum size and mean minimum size of reproduction

Two variables were estimated using the size distribution data: "mean maximum size" for male and female crabs, and the "mean minimum size of reproduction" for female sand crabs. We use mean values rather than actual observed maximum and minimum values because the latter are well known to be sensitive to sampling effort (e.g. Larsen and Marx 1981). This same approach was used in other studies that examined these variables (e.g. Auyong 1981, Wenner *et al.* 1985). Estimates are generated for data from the 1976-1978 study, the 1980-1981 study and the 1983 study (Table 3). Data from 1984 and 1986 are not appropriate for these analyses because during these studies sand crabs were only categorized into broad size classes.

The mean maximum sizes were estimated separately by sex, and represent the mean of the largest mode in the male and female size distributions. These estimates were obtained by applying a "finite mixture" method which is described in detail in Appendix A, and based on a method developed by Brownie *et al.* (1983). The mean minimum size of female reproduction represents an estimate of the size at which 50% of the females are carrying eggs. This size was estimated by probit regression, and details of the technique are included in Appendix A.

Data from samples collected within a month at a given beach were pooled together, and the statistical techniques described above were applied to the pooled data.

2.2.1.4 Laboratory growth assays (molt increment)

Experiments to assay molt increments in the laboratory were done periodically from the fall of 1976 to the spring of 1978. Data are available for a total of 13 months. Auyong (1981) measured molt increments for crabs collected at her five "experimental" sites arrayed up to 6.5 km to the north and south of the plant and at two "control" sites 16 and 65 km south of SONGS. She collected sand crabs from her field sites, held them in the laboratory for four days, and recorded increases in carapace width at molt for each crab that molted.

Molt increment is defined as carapace width after molting minus carapace width before molting. In our analyses we categorized sand crabs into three size classes based on initial carapace length: less than 7 mm (small), 7-10 mm (medium-small), and 10-13 mm (medium-large); and did separate analyses for small males and females (< 7 mm) and medium-small females (7 - 10 mm). Although molt increments of larger individuals were sometimes measured, this was done too infrequently to warrant quantitative analysis. We did not test for location effects (see below) on molt increment from October 1977 on, because few (or unknown numbers) of crabs were assayed, and/or because few crabs molted after October.

2.2.2 Analytical Methods for Testing for Location Effects

Over the course of the MRC's studies on sand crabs, data that allow the estimation of a variety of biological variables have been collected. In general, these data were collected with the view that characteristics of sand crabs collected near SONGS would be compared with those of sand crabs further from the generating station. Evidence that sand crab biology is somehow related to proximity to SONGS is referred to in this report as a "location effect", to distinguish this type of pattern from ones clearly caused by the operations of SONGS. This distinction is important because "location effects" could arise for reasons unrelated to the operation of SONGS. The types of patterns we look for are indications that the mean of some variable of interest is different at beaches in the vicinity of SONGS in comparison with elsewhere, or that the value of the variable shows a trend in relation to distance from the power plant.

Throughout our report we use the terms "Near beaches", "Far beaches", and "SONGS beaches". The terms "Near beaches" and "Far beaches" refer to the two sets of beaches used in our t-tests described below. (In our primary analyses, Near beaches were those 6.5 km or closer to SONGS and Far beaches were all beaches farther than 6.5 km from SONGS). The term "SONGS beaches" (within 20 km of SONGS) refers to the beaches included in our correlation analyses of biological variables and distance from SONGS.

2.2.2.1 Two types of tests for location effects

A detailed quantitative model of the expected spatial pattern of a potential SONGS effect is not available. Such a mechanistic model is probably beyond the scope of even a massive research program because of the complexities involved in nearshore oceanography, and also because the mechanisms by which SONGS might impact the various biological variables are not known in any detail. Although we lack such a spatial model, we analyze data (on a month by month basis) from beaches at varying distances from SONGS in two basic ways that we feel are useful in making a judgment regarding location effects.

At one extreme we might expect SONGS to have similar effects on crab populations on a set of beaches in the vicinity of SONGS, and no or substantially smaller effects at beaches further from the plant. We test for this possibility by designating Near beaches and Far beaches, and comparing them using Student t-tests. In our primary tests we define the Near zone as 6.5 km or closer to SONGS and the Far zone as more than 6.5 km from SONGS. This choice of a Near zone is partly a consequence of the spatial sampling design of the sand crab studies. In every study a number of beaches within our Near zone were sampled, and in most of the studies no additional beaches were sampled within 12 km of the power plant. In a second set of ancillary analyses we have also defined a Near Zone as including all beaches out to 12.5 km from SONGS. This second set of analyses was done largely in response to a claim that a location effect did extend this far from the plant (Siegel and Wenner 1984). The qualitative conclusions based on these ancillary tests are the same as those reported here and the detailed results are presented in Appendix F. In addition, we also did t-tests on log (or for proportions, angular) transformed data. In general these results were qualitatively in agreement with our primary data treatment, although they produced slightly fewer significant results. The results of these ancillary analyses, using transformed data, are also included in Appendix F. We also repeated our primary Near - Far comparison, excluding Cabrillo Beach from the analyses. This beach had extreme values for sediment metals and several other environmental variables in 1983 and in principle including this beach in the Far group might obscure location effects. The results of those analyses, however, are in qualitative agreement with our primary tests, and the detailed results are presented in Appendix F.

In the second type of test for location effects, we assume SONGS is the source of a disturbance impacting sand crabs, with effects decreasing with increasing distance from the power plant. We test for this kind of spatial pattern by examining the linear correlation between the biological variable of interest and distance from SONGS. Since the patterns need not be linear, we also correlate the ranked values of biological variables with the ranked distance from SONGS. These nonparametric, ancillary analyses lead to the same qualitative conclusions as those reported here. We have also done two additional sets of analyses using transformed data. First, we correlated log (or for proportions, angular) transformed data with distance from SONGS. Second, we assumed that the peak impact would be displaced 2 km downcoast from SONGS, and correlated the transformed data against distance from this "center". This second procedure follows from an oceanographic model of the long-term concentrations of plume water (Final Technical Report L), which predicts that a permanent tracer would have its maximum concentration, on average, approximately this distance downcoast from SONGS. Again, both sets of analyses using transformed data lead to the same conclusions drawn in this report, and they are included in Appendix F. In our correlations we use only data from beaches within 20 km of SONGS, based on our view that it is unreasonable to expect detectable effects at greater distances from the power plant.

Since the procedures differ, and the data set used in our correlations is a subset of that used in our t-tests, the two types of tests for location effects can produce apparently contradictory results. It is entirely possible for the value of a variable to gradually decrease with increasing distance from SONGS among beaches *within 20 km* of the power plant, while the mean value at beaches 6.5 km or closer to SONGS is less than the mean value seen at beaches farther from the plant if, for example, values are high at beaches greater than 20 km from SONGS.

2.2.2.2 Limitations of tests for location effects

If SONGS does affect sand crabs it would probably be manifested in a way that is not completely consistent with either of the statistical models used in our analyses. Actual effects may be displaced or asymmetrical with respect to SONGS, or even expressed bimodally in space (i.e. with maximum effects displaced both upcoast and downcoast from the power plant). One can generate potential spatial patterns of impacts *ad infinitum*. In the absence of strong *a priori* expectations of most of these alternatives in particular, we tested for the two kinds of location effects described above on the grounds that (a) they correspond with what constitutes our basic idea of a location effect; (b) processes arising from SONGS' operations could plausibly produce such location effects; and (c) these types of location effects were used historically as circumstantial evidence for a SONGS effect, and provided the motive for continuing and extending the study on sand crabs (MRC 1977, Auyong 1981, Siegel and Wenner 1984). We do not assume that the absence of a location effect as we have defined it indicates that SONGS did not have an impact on sand crabs. As discussed above, we looked for patterns in the data that would not be detected by our primary statistical methods, but might result from the operation of SONGS, through the use of a number of ancillary analyses.

We also examined plots of the data for patterns that could result from the operation of SONGS. We do not discuss the results of these other approaches because they did not reveal any additional patterns that we thought were indicative of SONGS effects.

2.2.2.3 Details of Statistical Methodology

Student t-tests

Analyses were generally done separately for data collected during each month. The mean value of a variable at Near beaches was compared with the mean at Far beaches using Student t-tests. Tests were only done if data were available from at least four beaches, with at least one observation from both the Near and Far zones.

A preliminary test to determine whether variances were equal at Near and Far beaches was done using the "folded-F" statistic (Freund and Littell 1981). If variances were found to be significantly different at the 0.10 level, Satterthwaite's (1946) approximate t-test was used instead of the standard t-test. Means were compared using a two-sided test, and differences with nominal probabilities less than 0.05 were declared "statistically significant". However, rather than just reporting whether a result is significant or not, we also report the attained significance level (i.e., the actual p value). T-tests are generally robust against most other violations of assumptions (for example the assumption of normality, see Stewart-Oaten *et al.* 1986). An important exception is the assumption of independence, and because our observations are ordered in space, it seems plausible that this assumption is sometimes violated. We did not attempt to correct for this type of violation for two main reasons. First, with the relatively small sample sizes, and unequal spacing of sampling locations, our ability to detect serial correlation in space is severely limited. Second, we use the t-test as an objective way to classify the data, and not because we believe that the underlying statistical model is an entirely accurate portrayal of any spatial effects caused by SONGS. What we might detect as "serial correlation" could actually represent SONGS effects not in perfect accord with our model. Because beaches were generally closely spaced in the Near zone, but not in the Far zone, this possibility cannot be discounted. If spatial serial correlation does exist, we will tend to declare significant results more frequently than our declared significance level, even when there are no real differences. Since our procedure is environmentally conservative (i.e. we tend to declare too many rather than not enough effects), and because a clearly better alternative could not be identified, we feel that the t-test is a reasonable, objective, and useful method for identifying location effects.

Correlation analyses

In these analyses, we correlated the value of the biological variable of interest with distance from SONGS (i.e. the absolute value of longshore distance upcoast or downcoast from SONGS). Only data from beaches within 20 km of SONGS were used, and analyses were done only when the variable of interest could be estimated for at least three of these beaches. In all cases the variables were plotted against distance from SONGS, and carefully examined as an aid in interpreting the correlation results.

We used only beaches within 20 km of SONGS for most of the correlations because we thought it was unreasonable to expect detectable effects at distances further from SONGS. In our correlations using CPUE as the biological variable for 1976-1978, however, we used only data from beaches 6.5 km or closer to SONGS. Except for the exclusion of beaches further than this distance from SONGS, the methods used in the analysis were the same as those described above. This more restricted set of beaches was used to evaluate the possibility that there is a "gradient" out to 6.5 km. More distant sites were thought to be inappropriate sites for this variable and were eliminated from the analyses since they might obscure any relationship (see Auyong 1981).

Tests for general patterns

In many cases our tests for location effects during a given month have low power, but we have appropriate data from a number of months. Standard multivariate methods, or analysis of covariance using all the data, are not appropriate due to the inconsistency of the sampling regime, and time varying spatial patterns. Rather than attempting to develop such statistical techniques specific for the sand crab data, we instead look for overall patterns in the direction of the individual location effects, ignoring the statistical significance of each test alone. We do this overall analysis whenever we have five or more tests of the same type for a variable. For example, if we are evaluating the results of ten Near - Far comparisons, and in nine out ten cases the Near mean is greater than the Far mean, this would be declared a significant general pattern because it deviates significantly from binomial expectations, under the null hypothesis that it is as likely that the Near mean will exceed the Far mean, as it is that the Far mean will exceed the Near mean. In order to allow a significant result even when only five analyses were done, a critical value of 0.10 is used, rather than the value of 0.05 that is used in our t-tests and correlations.

2.2.3 Correlations with Flow Volume

It is possible that effects of SONGS vary through time, with their intensity correlated with the operating status of SONGS. If we could generally detect larger differences between the values of biological variables near SONGS and those at a more distant site when SONGS was operating at a higher level, this would be strong circumstantial evidence that the location effects were, at least partially, due to SONGS' operations rather than to other causes.

We therefore tested for correlations between Impact-Control differences ("deltas") and SONGS' flow volume for each of the six types of variables that were also analyzed for "location effects" (Table 4).

2.2.3.1 Selection of Control and Impact sites

Only two beaches were used in our primary set of analyses. These were the sites at 6.5 km north (Control), and 1.5 km south (Impact). Our Control and Impact sites were selected from among the five sites located 6.5 km or closer to SONGS and the site near La Jolla, since these were the only sites sampled consistently across the studies. We chose not to use the site at La Jolla as a primary control on the grounds that it was too distant from SONGS, and known to differ from the nearer sites in a number of environmental characteristics (Appendix C). Among the remaining sites we chose the beach at 6.5 km North as our primary Control because it was the site furthest from SONGS in the upcoast direction. Analyses of current patterns indicate that when currents flow in the upcoast direction they rarely have a strong enough inshore component to reach the beach (Final Technical Report L).

We therefore chose the site at 1.5 km South as our primary Impact site because it is the site nearest to the power plant in the downcoast direction.

If, however, SONGS' effects were to extend *undiminished* more than 6.5 km upcoast, our primary analyses would not detect temporal variation due to SONGS. Therefore, in an ancillary set of analyses we use the beach near La Jolla (65 km south) as an alternate Control station. The results we obtained for our primary Control and Impact stations are qualitatively the same as those obtained with the alternative Control station, and we present the detailed results of these ancillary analysis in Appendix F.

2.2.3.2 Sources of biological data

Analyses of molt increment and catch per unit effort (CPUE) of sand crabs were done for 1976-1978. Only Unit 1 was operating at this time, so correlations with the flow volume of Units 2 and 3 were not calculated. Comparable data were not collected in other years, and the data on CPUE from 1983 and 1986 were not extensive enough to warrant separate analysis.

We had data allowing calculation of the correlation of deltas (Impact-Control differences) with flow volume of Unit 1, and Units 2 and 3, for the "fraction reproductive", "fraction spent", "mean maximum sizes" for males and females, and "minimum size of reproduction" variables (Table 4). Data from the 1976 - 1978 study were used in the analysis of the fraction reproductive and for mean maximum size and mean minimum size of reproduction. In addition, we used data from 1980, 1981 and 1983 in our analyses of the size variables and data from these same years plus 1984 and 1986 in our analysis of the fraction reproductive. Our data on the fraction spent came from studies done from 1981 through 1986.

2.2.3.3 Selection of transformations

Dependent (biological) variables used in correlation analyses were transformed, when necessary, in an attempt to induce additivity. Lack of additivity would occur if the difference between Control and Impact values tended to change in relation to the mean or sum of the Control and Impact values. This would occur, for example, if the value at the Control site tended to be a constant fraction of the value at the Impact site. For a detailed discussion of this issue see Interim Technical Report 2. To decide upon the most appropriate transformation, we applied a modification of the Tukey "one degree of freedom for non-additivity test" (Stewart-Oaten 1986). For this test we did a number of regressions of deltas (differences between Impact and Control values) against sums (sums of Impact and Control values) using a different transformation for each regression. The data were transformed before calculating the differences and sums of the variables used in this preliminary analysis. We chose the transformation that tended to yield the largest p-values since significant regressions here are regarded as evidence for lack of additivity. For a particular variable (e.g. catch per unit effort (CPUE)) we applied the same type of transformation to all categories of crabs and for all pairs of Impact - Control stations. We thus used some subjective judgment in deciding which transformation was best, but we did not base our choice of transformations on the outcome of our correlations against flow volume.

For CPUE and molt increments we considered untransformed, logarithms, and inverse transforms as possible treatments for the data. For data that were proportions (i.e. fraction reproductive and fraction spent) we considered untransformed, arcsine square-root, and the log of arcsine square-root as possibilities. For size variables (i.e. mean maximum size, and mean minimum size of reproduction), we considered untransformed and log transformed data. In the case of log and inverse transformations we needed to add a constant when zeros occurred because these transformations are undefined for arguments of zero. As possible constants we considered: (1) 10% and 20% of the mean value (calculated over all observations for the Control and Impact sites of interest), and (2) the minimum non-zero value observed.

The arcsine square root (angular) transformation was chosen for the "fraction reproductive" and "fraction spent"; the CPUE, molt increment, and size variables were all log transformed.

2.2.3.4 Calculation of flow volume

Daily values of the flow volume were recorded separately for Units 1, 2 and 3 and are available from January 1, 1976 through the end of the last sand crab study. We calculated a 45 day moving average for the flow volume of Unit 1, and Units 2 and 3 combined over this entire period. In our analyses we used the moving average value of the 15th day of each month for which corresponding biological data were collected. The main reason for our choice of a 45 day averaging period was to ensure that for analyses of reproductive variables, the entire period of egg development (approximately 30 days; see Introduction) would be covered in the moving average. Furthermore, 45 days seemed a reasonable, averaging period for other variables. Our use of the average on the mid-point of a month ensured that a minimum of 30 days of flow volumes prior to the date any sand crab samples were taken are included in the average. We acknowledge that choosing a 45 day time period in the past to average over is somewhat arbitrary, however, we know of no objective way (i.e. one that does not rely on the strength of the resulting correlation) through which a more appropriate averaging period can be chosen. Because there is no "correct" averaging period, we also plot our averaged flow volume, through time, along with the biological variables of interest, which allows examination of the graphs for patterns suggesting that flow volume might impact sand crabs on longer time scales than our 45 day average. We saw no obvious patterns in our own examination of these and other plots.

2.2.3.5 Correlations with flow volume

Correlations were only done if Impact-Control differences were available from at least three months. In addition to our primary test of correlations on the transformed data, correlations between "deltas" and flow volume were also calculated after ranking both deltas and flow volume (i.e. nonparametric Spearman correlations). The deltas used in this analysis were calculated in the same way as above (i.e. the data were transformed, if necessary, and then differences between Impact and Control calculated). Plots were produced to check for potentially important nonlinear relationships, and to facilitate interpretation of the simple correlations.

2.2.4 Calculation of Statistical Power

For most of the analyses presented here, statistical power is presented along with an evaluation of statistical significance. Power is an evaluation of the statistical procedure's sensitivity to departures from the null hypothesis. To calculate power we need to propose an alternative hypothesis. Power is then our estimate of the probability of rejecting the null hypothesis when it is false and the alternative is true. Perhaps the most difficult and subjective aspect of calculating statistical power is deciding on an appropriate alternative hypothesis (e.g. see the debate between Toft and Shea (1983), and Rotenberry and Wiens (1985)). We state the alternative hypotheses we have used in the tables where our estimates of power are presented. In general, the alternative is equivalent to a 50 percent change in magnitude either between Near and Far sites (t-tests) or over a ten km distance (correlations), but their exact form depends on the analyses for technical reasons. We stress that our choice of alternative hypotheses neither implies that these are the only violations from the null hypothesis that we are interested in, nor that we think that the alternative is likely to actually occur. They are simply reasonable choices used to evaluate the sensitivity of our statistical methods in a standard way.

For both Near-Far comparisons and tests for trends, power is the probability of obtaining a result in the rejection region when the alternative hypothesis is correct. In both cases, we use a noncentral t-distribution to evaluate this probability. The noncentrality parameter for the t-distribution is equal to the Near-Far difference assumed by our alternative, divided by the standard error for the Near-Far difference. For tests of trends, the noncentrality parameter is equal to our assumed rate of change in the Y variable as a function of the X variable divided by the standard error for the slope of a regression of Y against X. Our Y variable is assumed to be the biological variable of interest, and X is either distance from SONGS, or SONGS' flow volume.

We also present power for "overall" tests. In these overall tests we ask whether the results from a set of tests tend to be in the same direction (say positive rather than negative correlations) more often than would be expected by chance, ignoring the statistical significance of individual tests (see above). We calculate power of these overall tests as follows. First, using the noncentral t distribution, the probability of getting a result (either Near-Far difference or correlation coefficient) larger than zero was calculated, under the alternative hypothesis, for each individual test. Thus we were assuming as our alternative hypothesis that there was a real difference, in the same direction, on all surveys. These probabilities were then used in a simulation (with 10,000 runs) to determine how often enough results would be in the same direction (when our alternative was true) to declare the overall pattern significant. The proportion of the 10,000 simulation runs for each overall test in which there was a significant departure from equal numbers of positive and negative results is our estimate of power.

3. RESULTS

3.1. Location Effects

3.1.1. Catch per Unit Effort (CPUE)

In interpreting the catch per unit effort (CPUE) results it is important to recognize the limitations of the data that are consequences of the methods used to collect the samples. Data on sand crab CPUE collected during the MRC's studies are of three distinct types, and are never analyzed together. During the 1976 to 1978 period, cores were taken within a recognized band or patch of sand crabs, and the resulting data do not necessarily indicate the density of sand crabs on the beach as a whole. For example, even if the average numbers of sand crabs per unit total area was actually the same on two beaches, the mean number per core could be higher at one beach if crabs there were aggregated into a smaller proportion of the beach. In 1986, sand crabs were collected using a commercial sand crab catcher. The number of crabs collected and the amount of time required to collect them was recorded. The ratio of numbers caught to number of sampling hours is used as a measure of catch per unit effort for this study. A different, and better, sampling method was used to collect data in three surveys during 1983. These surveys were designed specifically to assess the density of sand crabs on the study beaches and a stratified-randomized sampling design was employed.

3.1.2. CPUE during 1976-1978

All data used in these analyses come from beaches 6.5 km or closer to SONGS, collected for a total of 13 months during the September 1976 - March 1978

3.1.2. CPUE during 1976-1978

All data used in these analyses come from beaches 6.5 km or closer to SONGS, collected for a total of 13 months during the September 1976 - March 1978 period. Among SONGS beaches, the *total* number of sand crabs per core (CPUE) did not follow a general pattern of either increases or decreases with increasing distance from SONGS (Table 5). Correlations of CPUE with distance from SONGS indicated that relationships with distance from the plant were generally weak, and the number of months with positive correlations (7) was about equal to the number of months with negative correlations (6). This proportion of negative to positive slopes are not significantly different from equality (Table 5). The power for the overall test was only 0.36, and the power during each individual month was generally much lower (Appendix E, Table E-1).

The pattern for total catch per unit effort described above is for the sum of spatial patterns in CPUE for different sizes and categories of crabs. We also analyzed the data separately for the numbers of megalopae, males, and five size classes of female sand crabs. The results are striking: there is an obvious general tendency for CPUE to increase with increasing distance from SONGS in the three largest size classes of female sand crabs, but this trend is not evident for the other categories of crabs (Table 5). In the three largest size classes of female crabs, 35 of 36 correlation coefficients were positive, and the departure from equal numbers of positive and negative relationships was significant for each of these size classes (Table 5). The difference between the pattern seen for total CPUE and that seen for the larger sizes of females is presumably a consequence of the fact that the sand crab populations were generally dominated by smaller crabs.

The power of our tests varied among categories of crabs, but was always somewhat less than that for total abundance (Table 5), but again tests for each month had even lower power than the overall tests (Appendix E, Table E-1).

3.1.2.1. CPUE During 1983

In this year, data come from a total of 16 beaches, with samples collected on three surveys, taken during June, July, and August. Since data are available for only three surveys during 1983, no overall tests are done on the pattern of the results. Instead, we consider the results survey by survey. The power of the individual tests, however, is low (Tables 6 and 7).

Total CPUE showed no general indication of an increasing or decreasing trend with distance from SONGS, among SONGS beaches (within 20 km of the station) during 1983. Only one of the three correlation coefficients between CPUE and distance from SONGS was positive, and none of the relationships were significant (Table 6). Relationships between CPUE and distance for specific categories of sand crabs also showed no indications of trends with distance from SONGS (Table 6).

Although there were no significant trends among SONGS beaches (above), the total CPUE of sand crabs at beaches 6.5 km or closer to SONGS (Near beaches) was significantly lower than at Far beaches during June 1983 (Table 7). This difference was not evident later that summer (Table 7). During June 1983, mean CPUE was lower at Near Beaches than at Far beaches for all six categories (males and five size classes of females) of sand crabs that were enumerated, and this difference was significant (3) or nearly significant (1) in four cases (Table 7). By July 1983, the only significant difference was that CPUE at Near beaches was lower than CPUE at Far beaches in the large size class of female sand crabs (13-16 mm carapace length). For the three largest categories of female crabs, the actual mean value was still (nonsignificantly in two cases) lower at Near than at Far Beaches, although CPUE was about equal at Near and Far beaches for males (Table 7). No differences were significant for individual categories during August, with the mean value being (nonsignificantly) lower at Near beaches than at Far beaches for the two larger size classes of female sand crabs, and (nonsignificantly) higher for males and the three smallest size categories of females (Table 7).

3.1.2.2. CPUE during 1986

Data are available from a total of 29 beaches for a single survey collected during August. Most of these beaches were within 20 km of SONGS. No obvious trends with distance, or significant differences in sand crab catch per unit effort between Near and Far beaches, were evident during 1986 for either size class (Tables 8 & 9). The power of these tests, however, was very low (Tables 8 & 9).

3.1.3. Mean maximum sand crab size

Data are available from a total of 23 months of studies during the 1976-1983 period. The number and location of beaches varied among the various studies (Appendix A).

The mean of the maximum mode of the sand crab size distribution was estimated for females and males (see Analytical Methods). These estimates are referred to as the mean maximum female and male sizes. Small values for these variables are taken to indicate either a relative scarcity or absence of larger crabs.

We begin with an evaluation of overall patterns in the data, considering all studies together.

For both females and males, the mean maximum size tended to increase with distance from the station, among SONGS beaches. There were 34 positive correlations of size with distance from SONGS and only nine negative ones, and the departure from equal numbers of positive and negative correlations was significant for both sexes (Table 10). The average of mean maximum size was not, however, generally smaller at Near beaches than at Far Beaches (Table 11).

We now consider the results for mean maximum size on a study by study basis but do not do summary analyses for each study due to the limited number of tests for most studies. In general, these month-by-month tests had quite high power (Appendix E, Tables E-2 - E-5).

During the 1976-1978 study there were no significant trends among SONGS beaches. However, it is obvious that there was a general tendency for mean maximum size to be positively correlated with distance from SONGS. In 19 out of 23 cases (considering both sexes together), mean maximum size was positively correlated with distance from SONGS (Appendix E, Tables E-2 & E-3). Fewer Near-Far comparisons are available, and the results were mixed, with 6 of the 10 comparisons indicating larger values at Near beaches and 4 indicating larger values at Far beaches (Appendix E, Tables E-4 & E-5). The only significant result was for females in June of 1977, and this result indicated *larger* values at Near beaches than at Far beaches (Appendix E, Table E-4).

During 1980, mean maximum size could be correlated with distance from SONGS on only one survey for males and females. T-tests comparing values at Near and Far beaches were done for each sex during two surveys. There were no statistically significant results or obvious general patterns (Appendix E, Tables E-2 - E-5).

In 1981 there is a general pattern for maximum sizes to be smaller near SONGS among SONGS beaches, with 11 positive and one negative correlation against distance when both sexes are considered together (Appendix E, Tables E-2 & E-3). In contrast, the pattern is not clear for the Near-Far comparisons. These comparisons indicate, if anything, larger crabs occur near SONGS, with the mean value being larger at the Near than at the Far beaches in six out of eight cases (Appendix E, Tables E-4 & E-5). None of these correlations or differences were statistically significant.

During 1983 there were no significant results, or obviously general patterns (Appendix E, Tables E-2 - E-5), even though the power was quite high (greater than 0.9 in most cases, Appendix E, Tables E-2 - E-5).

3.1.4. Short-term Laboratory Growth Assays

Short-term laboratory growth assays were done only during the 1976-1978 period. Here we assess the mean molt increment (i.e. the mean of carapace width after molting minus carapace width prior to molting). We do not calculate growth rate by taking the product of molt increment and the fraction molting because the estimates of fraction molting are relatively inaccurate due to small sample sizes and because differences in the fraction molting between beaches vary greatly through time (see Appendix D).

3.1.4.1. Molt increment of females

There is some indication that molt increments of medium-small females tended to be smaller in the vicinity of SONGS, but there are too few months of data to test for an overall pattern. For this size class, three of four correlations with distance from SONGS were positive, and four of four Near-Far comparisons indicated smaller molt increments at Near beaches. Of these, one correlation and one t-test indicated significantly smaller molt increments in the vicinity of SONGS (Appendix E, Table E-6). The results for the small size class showed no general pattern for molt increments to be smaller in the vicinity of SONGS (Tables 12 & 13), but there was one significant positive correlation with distance from SONGS (May 1977), and in one case the Near mean was significantly less than the Far mean (July 1977) (Appendix E, Table E-6). There was also one significant negative correlation (October 1976), but this was based on data from only three beaches (Appendix E, Table E-6).

3.1.4.2. Molt increment of males

There was a general pattern for molt increments of males to be smaller in the vicinity of SONGS than elsewhere. Six of seven correlations between mean molt increment and distance from SONGS were positive (Table 12), and in four out of five cases the mean molt increment at Near beaches was less than that at Far beaches (Table 13). The positive relationship with distance from SONGS was significant during two months, and these were the months for which we had highest power (July and August 1977; Appendix E, Table E-7).

3.1.5. Reproductive variables

3.1.5.1. Fraction of females carrying eggs (fraction reproductive)

The fraction reproductive is calculated by dividing the number of crabs carrying clutches of eggs by the total number of female crabs. Crabs carrying clutches including some viable eggs (i.e. "partially spent" crabs were included, "spent crabs" were excluded; see Methods) were classified as carrying clutches of eggs. Data are available from all studies conducted during the 1976 - 1986 period. There was no general pattern, extending over all studies, for the fraction of female sand crabs carrying eggs to increase or decrease with distance from SONGS among SONGS beaches. Although there were more negative correlations than positive ones for each size class, only one of the departures from equal numbers of positive and negative correlations was significant (Table 14).

The fraction carrying eggs did tend to be lower at Near beaches than at Far beaches for large females, but not for other sizes. This was indicated by eight of 11, three of 11, and one of 10 cases where the mean fraction reproductive was higher at Near than at Far beaches for the medium-small, medium-large, and large size classes, respectively (Table 15). The deviation from equal numbers of positive and negative coefficients was significant for large females (Table 15).

We now turn to a consideration of the results on a study by study basis. During the 1976 - 1978 study, there was a general tendency for the proportion of females carrying eggs to *decline* with increasing distance from SONGS. Ten of 12 correlations against distance from the plant were negative, and in two cases the results were significant (Appendix E, Table E-8). Although there were fewer Near-Far comparisons, these results also seem to indicate a higher fraction of females reproducing near SONGS, with the Near mean exceeding the Far mean in five of six cases, including one significant and one nearly significant difference (Appendix E, Table E-9).

For 1980, because of the small amount of appropriate data, trends could be evaluated in only one month, and Near-Far differences in two months. No overall pattern is obvious, but the fraction carrying eggs was significantly lower at Near than at Far beaches in one case (July for large crabs, Appendix E, Table E-9).

During 1981 the fraction with eggs was negatively correlated with distance from SONGS, among SONGS beaches, in every case, although none of the 12 correlations was statistically significant (Appendix E, Table E-8). In contrast with this indication of greater reproduction near SONGS, Near - Far comparisons indicate, if anything, lower reproduction at Near than at Far beaches in the larger size classes (Appendix E, Table E-9).

During 1983, in contrast with results from earlier studies, the fraction of reproductive females was positively correlated with increasing distance from SONGS in seven of eight cases, with two significant correlation coefficients (Appendix E, Table E-8). Near-Far comparisons also indicated lower reproduction near SONGS, with the mean proportion with eggs lower at Near than at Far beaches in all eight cases, and with two of the differences statistically significant (Appendix E, Table E-9).

Only one survey was done during 1986; correlations of the fraction reproductive with distance were weak, and Near - Far differences were small (Appendix E, Tables E-8 & E-9).

3.1.5.2. The completely spent condition (fraction spent)

The completely spent condition was first assayed in July 1981. The fraction of females completely spent was positively correlated and negatively correlated with distance from SONGS about an equal number of times for large and medium-large females. The fraction spent *declined* with increasing distance from SONGS in five out of five months for the medium-small size class, however, and this is a significant departure from the hypothesis that increases and decreases were equally likely (Table 16).

In contrast with the pattern among SONGS beaches, the mean fraction completely spent was higher at Near beaches than at Far beaches, for all surveys for each size class, with only one exception (18 comparisons in all) (Table 17). Although most of the monthly comparisons of Near and Far beaches are not significant (Appendix E, Table E-10), the overall pattern in the direction of the differences departs significantly from equal numbers of increases and decreases in two of the three size classes (Table 17).

We now turn to the results on a study by study basis. The fraction with spent clutches was higher at Near than at Far beaches in all cases during both 1981 and 1983 (Appendix E, Table E-10). Fractions spent were low during the 1986 survey, with little difference between Near and Far beaches (Appendix E, Table E-10).

During 1981, all correlations of fraction spent with distance from SONGS were positive for medium-large and large female crabs, and were negative for the medium-small size class. No individual correlation was significant. Thus, there does not appear to be a strong general trend among SONGS beaches during this year. In contrast with the results from 1981, correlations for all months and size classes were negative during 1983, and two of the correlation coefficients were statistically significant (Appendix E, Table E-11). The correlations between the fraction spent and distance from SONGS were very weak for the one survey during 1986 (Appendix E, Table E-11).

3.1.5.3. The partially spent condition (fraction partially spent)

Data on the partially spent condition are available for two time periods: July and August 1983 combined, with all size classes pooled, and August 1986 for two size classes. Because of the scarcity of data, no attempt is made to evaluate an overall pattern statistically, and the results are presented on a case by case basis. In 1983, the fraction partially spent was significantly higher at Near than at Far beaches (Table 18). In addition, the tendency for the fraction partially spent to decline with increasing distance, among SONGS beaches, was nearly significant in 1983 (Table 18).

During 1986 the results for the fraction partially spent differed between the two size classes of crabs that were evaluated. For the medium-large size class, the fraction partially spent was significantly higher at Near beaches than at Far beaches, and also declined significantly with increasing distance from SONGS (Table 18). For the large size class, there was no evidence that the fraction partially spent was higher in the vicinity of SONGS than elsewhere. This was true for both the comparison of Near and Far beaches, and for spatial patterns among SONGS beaches (Table 18).

3.1.6. Minimum size of reproduction

There is no evidence that female sand crabs generally tended to begin reproducing at smaller sizes at Near beaches than at Far beaches (Table 19), and the only significant result for an individual month (June 1983; Appendix E, Table E-13) showed reproduction at smaller sizes on Far beaches.

In contrast, there is some evidence for trends among SONGS beaches. Eight of 11 correlation coefficients indicated that the mean minimum size of reproduction increased with increasing distance from SONGS (Table 19). Although this pattern is not a statistically significant deviation from expectations, it suggests that sand crabs might have been reproducing at smaller sizes at the beaches closest to SONGS.

The only obvious pattern, when considering the results on a study by study basis, is that the correlation of mean minimum size of reproduction and distance from SONGS was negative (nonsignificantly) in each month during 1983 and positive in all cases during the earlier studies, with two cases of statistical significance (Appendix E, Table E-12).

3.2 Correlations with SONGS' Flow Volume

Table 4 provides a list of the variables correlated with the volume of water flowing through SONGS' cooling system. The results of these analyses can be summarized succinctly: they provide no evidence that SONGS is the cause of observed location effects. There were only two significant correlations out of 31 tests (Tables 20-23). The fraction with spent eggs for the medium-small size class *decreased* significantly (relative to a Control beach) with increasing flow volume of SONGS' Unit 1, and the mean maximum female size *increased* significantly with increasing flow volume of Units 2 and 3. These two results are counter to expectations if SONGS were causing the location effects seen for them.

3.3. Supplementary Studies

The results of supplementary studies are presented in Appendices B through D. Appendix B examines the MRC's data on metals and radionuclide activity levels in sand crabs and beach sediments. Appendix C uses data collected in 1983 and 1986 to address potential relationships between sand crab biology and physical-chemical properties of the environment. Appendix D presents the results of abbreviated surveys done at the end of the 1983 study, and a study from 1984 evaluating the temporal phenology of reproduction in sand crab populations, with a special emphasis on gaining a better understanding of the "spent condition". Below, the results of these supplementary studies are summarized. Additional detail on methods, analytical approach, and results can be found in the appendices.

3.3.1. Metals and Radionuclides in Sand Crab Tissues and Beach Sediments

Concentrations of eight metals were measured in beach sediments and sand crab tissues on two surveys (July and August) during 1983. Initial analyses suggested that three metals (iron, manganese and chromium) might be at higher concentrations in sand crab tissues at beaches near SONGS, at least at times, and that the spent condition was correlated with chromium concentration in tissues during August for crabs greater than 13 mm in carapace length. (These preliminary analyses were based on metal concentrations pooled over reproductive categories, but later analyses indicated that metal concentrations may be related to sand crab reproductive category (Appendix B).) The three metals (chromium, iron and manganese) were again assayed in sand crab tissues during August 1986.

Additional analyses and study have uncovered no evidence that releases of metals or radionuclides by SONGS had adverse impacts on sand crabs. Generally, metal concentrations were not substantially higher in either sediments or sand crab tissues from beaches near SONGS in comparison with beaches further from the plant. There were a few exceptions to this generality for sand crab tissues, but these patterns were consistent neither across categories of crabs nor through time. During August 1983, the concentration of manganese in female sand crabs without eggs was, on average, higher at beaches 6.5 km or closer to SONGS in comparison with beaches further away, but there is no evidence that SONGS is a significant source of this metal and a variety of studies suggest that the local peak manganese concentrations occur near San Mateo Creek, approximately 5 km upcoast of SONGS (Final Technical Report E). Iron and chromium concentrations in one of two categories of crabs (10-14 mm carapace length with eggs) during the August 1983 survey were both highest in the same sample from a beach (0.4 km North) near SONGS. For sand crabs without eggs during the same survey, a similarly high value for chromium was seen at a site 12 km north of the plant, but not at other sites, including the site 0.4 km from the plant.

There were some significant correlations between biological variables and chromium concentrations in sand crabs without eggs during August 1983, but the concentration of chromium in this class of crabs was not elevated near SONGS, and the results were not consistent with the results based on concentration of metals in crabs with eggs (Appendix B). For example, although the fraction of large crabs with spent eggs was significantly and positively correlated with the tissue chromium level in sand crabs without eggs in August 1983, at that time this same variable was significantly, but negatively correlated with the tissue chromium level in sand crabs with eggs. It is worth noting that it is only the latter category of crabs for which there is any evidence that the tissue levels of chromium were higher near SONGS than elsewhere at that time.

Chromium tissue concentrations were, on average, higher at beaches 6.5 km or closer to SONGS during August 1986. This results from the fact that there were no low values in this zone, rather than from especially high values in the area. There were no significant correlations between biological variables and chromium concentration during 1986, and levels of chromium in sand crab tissues were of approximately the same magnitude as in the 1983 collections.

Wenner (1988) reports metal concentrations in tissues of sand crabs from beaches in the SONGS area during 1982 and 1983. Higher levels (near SONGS relative to other locations) of nickel, zinc, manganese, and iron, but not of chromium or other metals, were reported for 1982. In 1983, metal concentrations in sand crabs at the beach closest to SONGS (6.5 km north) were about the same as at other beaches sampled. Thus, the location effects on the fraction of females in the spent condition during 1982 (Siegel and Wenner 1984) and 1983 (this report) occurred when Wenner did not find elevated chromium concentrations in the tissues of sand crabs near SONGS. The metal data reported by Wenner (1988) are discussed in greater detail in Final Technical Report E.

Results presented elsewhere (Final Technical Report E) indicate that San Mateo Creek may be a source of chromium, iron and manganese. Thus, the observed "location effects" discussed above may indeed be real, but unrelated to SONGS. However, these tissue concentrations of metals are neither high enough nor pervasive enough to explain observed location effects on biological variables (Final Technical Report E, Appendix B).

SONGS releases two radionuclides (^{60}Co and ^{54}Mn) at rates high enough to be detected in sand crabs as far as 10 km from the plant. All observed activity levels, however, indicate that the internal dose rate experienced by sand crabs from this source is far below (several orders of magnitude) the minimum dose rate that has ever been shown to have a sublethal effect on a marine invertebrate. These results are also in agreement with data collected and reported to the NRC (see Final Technical Report E).

3.3.2. Relationships between Sand Crab Biology and the Physical Environment

Results from 1983 indicate that attributes of sand crab populations, such as the proportion of the population in the partially spent condition, or the abundance of crabs on a beach, could be explained by physical/chemical properties of the environment (Appendix C). Sand crab populations were less "robust" (i.e. lower abundances, and lower or atypical reproduction) on beaches with steep slopes, coarse grain sizes and high prevalence of cobble.

For the 1986 survey, relationships between attributes of sand crab populations and the physical/chemical environment were generally weaker than in 1983. However, the prevalence of cobble on the beach could again account for the location effect in the partially spent condition seen in medium large females living at beaches near SONGS. This location effect was the only one detected in 1986.

Thus, "location effects" can be adequately explained by the physical environment near SONGS, for both 1983 and 1986.

Examination of information on the prevalence of cobble both in the intertidal and subtidal shows that the physical characteristics of the substrate at beaches most proximate to SONGS differ from other beaches, with cobble generally being most abundant at beaches closest to SONGS. Differences in the physical environment provide viable alternative explanations for location effects, as opposed to arguments based on the operation of the power plant and better explain the observed spatial patterns in sand crab biology (Appendix C).

3.3.3. Abbreviated Surveys and Reproductive Synchrony in Sand Crabs

Two studies, done during 1983 and 1984, were designed to provide biological background on the spent condition, which has been put forth as evidence of abnormal reproduction near SONGS. The results of these studies show that the spent and partially spent conditions can reach quite high levels at beaches far from SONGS (Appendix D).

The 1983 study concentrated on the prevalence of the spent condition over a broad geographic range during the end of the reproductive season. The results show that the spent condition did reach substantial levels among females at beaches far removed from SONGS, and that the spent condition became increasingly prevalent towards the end of the reproductive season.

The 1984 study examined the reproductive characteristics of sand crab populations at weekly intervals starting at the height of the reproductive season.

There were three main study beaches, one very close to SONGS (0.4 km North), one 6.5 km to the north, and La Jolla (65 km south).

The results of the 1984 study supported the conclusions from the 1983 study: the spent condition became more prevalent towards the end of the reproductive season. This study also provided evidence that females within a beach may be in reproductive synchrony, so that the proportions of the population bearing intact or spent egg cases may fluctuate, depending on the timing of sampling relative to the egg production cycle (Appendix D).

4. DISCUSSION

There is no compelling evidence that SONGS has had large and chronic effects on populations of sand crabs. Many attributes of sand crab populations were not generally different in the vicinity of the power plant than elsewhere. For example, the fraction of the population carrying eggs was higher near SONGS in 1977, lower near SONGS in 1983, and not consistently different than elsewhere during other study years (1980, 1981, and 1986). There were some attributes of sand crabs populations in the area near the San Onofre Generating Station (SONGS) that did tend to differ from other populations that were sampled. Both catch per unit effort of larger crabs and maximum crab size were generally lower near SONGS, although the spatial scales of these "location effects" were not all the same. There is also evidence that the fraction spent and partially spent were higher in sand crab populations near SONGS. It seems reasonable, and even likely, however, that these location effects are the product of natural environmental differences unassociated with SONGS' operations. These (and other) biological characteristics did not show clear relationships with the volume of water passing through SONGS' cooling system. We looked for strong and consistent correlations between the biological attributes of sand crab populations near SONGS (relative to elsewhere) and the amount of water pumped by the power plant because the primary mechanism by which the power plant is thought to affect the marine environment is through the pumping of water through the cooling system of the generating station (Interim Technical Report 1; see also Siegel and Wenner 1984, and Wenner 1988).

We have presented analyses showing that the location effects that were detected were not clearly linked to the operating status of SONGS. In contrast with the conclusions of this report, Wenner (1982, 1988) notes what appears to be a close the conclusions of this report, Wenner (1982, 1988) notes what appears to be a close correspondence between the operating status of SONGS (both Unit 1 and Units 2 and 3) and the appearance or disappearance of location effects. Although no explicit and mechanistic link is made between the biology of sand crabs and SONGS' operating status, it seems likely that at least some readers will infer from these documents that the regular operations of SONGS are responsible for location effects, since they seem to indicate that location effects are not evident when SONGS ceases operations. We do not believe that such a pattern exists, and we therefore think that the presentations by Wenner (1982, 1988) could mislead some readers.

The patterns presented by Wenner (1982, 1988) could be misleading for two major reasons: (1) comparisons confound year and spatial effects, and (2) there does not appear to be a consistent definition for categorizing SONGS as "operational" or "nonoperational." One set of comparisons contrasts sand crab populations near SONGS in 1977 (Auyong's study) with data collected at that same site in 1980, and at other sites (such as Goleta, La Jolla and Monterey) in 1980, or yet other years. It was noted by Wenner (1982, 1988) that SONGS (Unit 1) was operating in 1977 and had been shutdown in 1980. The point of these presentations appears to be that sand crabs were different (e.g., shorter reproductive season, smaller minimum size of reproduction) near SONGS when Unit 1 was operating in comparison with a time when it was not, and in comparison with sites far removed from the power plant. Because no data for a control (a site more distant from SONGS) sampled during 1977 are presented, we can not dismiss the possibility that the differences between the 1977 data near SONGS and the data from other years (at SONGS and elsewhere) simply reflect year effects common to all sites. Auyong did collect data at La Jolla, as well as several other sites more than 10 km from

SONGS during 1977, but these were not included in Wenner's analyses. In our analyses for 1977 we did not detect a striking difference between these sites, and those nearer SONGS. Problems with comparisons that confound time and location effects are discussed at length elsewhere (Interim Technical Report 2), along with examples of how widespread changes through time could be mistaken for plant effects.

As mentioned above, the requirements for SONGS to be "operational" do not appear to be defined in a consistent fashion in the Wenner (1982, 1988) documents. For example, Unit 1 pumped approximately one million cubic meters of water per day during the spring and summer of 1980 (in comparison with approximately 1.6 million cubic meters per day in 1977), but is described as "shut down" for this period (Wenner 1982, Wenner 1988, Auyong 1981: *personal communication* from Wenner). It is noted that the spent condition was first seen four months after initial operation of Unit 2 pumps (Wenner 1988), but the rate at which water was pumped by Unit 2 over this time period was about the same as that pumped by Unit 1 when it was classified as being nonoperational. In addition, it is claimed that SONGS (presumably all Units) had been inoperative most of the time during a 1.5 month period during the summer of 1984 (Wenner 1988), when in fact Units 2 and 3 had been pumping in excess of five million cubic meters a day during that period. We feel that this lack of a clear and consistent definition by Wenner of what constitutes an operational status for SONGS explains why there appears to be a tight relation between the occurrence of location effects and the operating status of SONGS in his reports. In contrast, we found virtually no evidence for effects of SONGS' operations when we correlated attributes of sand crab populations near SONGS with the volume of water pumped by the power plant.

A second initially plausible mechanism through which the operation of SONGS could affect sand crabs is via the release of toxic metals or radionuclides. Metal concentrations were generally low, however, in both sediments and tissues of sand crabs near SONGS. Higher metal concentrations (in particular, chromium) were occasionally documented in sand crab tissues at some beaches nearer to SONGS, than at other beaches sampled at the same time. But, even these concentrations were low in comparison with the levels observed to have sublethal effects on invertebrates. Additionally, no single metal was at higher concentrations in sand crab tissues near SONGS during all times when location effects were seen. Close examination of the spatial pattern of metal concentrations in sand crabs and mussels suggests that San Mateo creek may be responsible for a *modest*, and ecologically unimportant elevation in bioavailable chromium, iron and manganese in the local area (Final Technical Report E). Radiation activity levels in sand crab tissues also appear to be at physiologically insignificant levels.

We excluded the tissue levels of all metals as independent variables from our multiple regressions in this report. The primary reason for this exclusion is that we felt that the tissue levels of metals in sand crabs may not be very indicative of environmental levels of metals. We found very little correspondence between metal levels in tissues and metal levels in sediments. Although metal levels in sediments may not indicate bioavailability in general, it seems likely that environmental availability of metals was higher at Cabrillo beach, where sediment concentrations were an order of magnitude higher than elsewhere. It is curious, then, that tissue metal concentrations were not especially high at that site. In addition, within beaches, tissue metal levels varied in sand crabs among categories of crabs, suggesting that tissue metal levels were responding to factors other than merely environmental availability. For these reasons we treated tissue concentrations as biological (dependent) variables in our multiple regressions. We did include sediment metal concentrations as independent variables in our multiple regressions.

Although we did not use tissue metal levels from our multiple regressions, we did test separately for correlations between biological variables and tissue chromium concentration. This metal was one of the three (chromium, iron and manganese) that were sometimes at relatively high levels near SONGS in the MRC studies, and it is the only one of the three for which there is any evidence that significant releases can occur as a consequence of SONGS' operations. There were some significant correlations in 1983, but they were not consistent in time or across categories of crabs. No significant relationships with tissue chromium were seen in the 1986 study, which was specifically designed to test for such relationships.

Although there is no good evidence that SONGS sometimes releases toxic quantities of some metals, we can not exclude this possibility. The evidence does strongly suggest, however, that any such releases do not lead to consistent increases in metal concentrations in sediments or sand crab tissues near SONGS. Thus, the release of metals by SONGS does not appear to be the cause of those location effects that are relatively persistent (and which have been the ones of most concern).

We believe that the few persistent location effects can be adequately explained by attributes of the physical environment near SONGS. Beaches near SONGS, particularly those directly upcoast of the plant, differ from other beaches that were sampled, in that cobble is more prevalent in the substrate. This appears to be a natural difference unassociated with either the construction or operation of SONGS. It is very plausible that this natural difference in substrate composition is responsible for the observed "location effects", since sand crabs live interstitially, just below the sand's surface, and could be adversely affected in their movement and feeding due to the presence of cobble. When location effects were observed, they were most marked at those beaches where cobble was also prevalent.

It has been suggested that sand crab reproduction (Siegel and Wenner 1984) and population size distributions (Wenner 1982, 1988) are abnormal near SONGS. We reject these assertions on several grounds. The observed characteristics of sand crab populations near SONGS are not outside of the range observed elsewhere. Other populations have been observed to lack larger crabs (Efford 1970, Diaz 1980). These differences have been variously attributed to the prevalence of cobble and shortages of food. The MRC's studies documented high levels of both the spent and partially spent reproductive conditions near and far from SONGS. This result indicates that the occurrence of these reproductive conditions should not be regarded as evidence of abnormal reproduction, *per se*, for SONGS beaches only appear to differ (at times) in the *degree* to which these conditions are present. The detection of these conditions at sites far removed from SONGS suggests that the failure to see these characteristics in studies prior to 1980 may be because they were not looked for, rather than because of their absence. Nevertheless, we do feel that the repeated detection of location effects for the spent condition suggests that sand crab reproduction was generally poorer near SONGS than at other beaches sampled.

Although we feel that the weight of evidence is against SONGS being the primary cause of the observed "large scale" location effects, extending 10 km and further from SONGS (e.g. Siegel and Wenner 1984), we are less confident, based on the results of sand crab studies, that SONGS Units 2 and 3 have had insignificant impacts on sand crab populations within distances on the order of one to several kilometers of SONGS. Our reluctance to discount this possibility is not due to strong evidence that Units 2 and 3 have had impacts, but rather because the thrust of the sand crab program was to follow up on the location effects that were observed in the early studies, rather than to measure the effects of Units 2 and 3 in the immediate vicinity of its outfalls. Thus, for example, we cannot confidently state that SONGS Units 2 and 3 has not caused a decline of 50 percent in sand crab abundance in the vicinity very near to SONGS, as we are able to for other programs, such as the MRC's studies of ichthyoplankton (Interim Technical Report 5). To potentially make this assertion, it would be necessary to collect quantitative samples using standardized techniques many times at Control and Impact locations, both Before and After the new units began operating. In a sense, the sand crab program demonstrates by counter-example, many of the virtues of the Before-After-Control-Impact-Pairs Design (BACIP). However, since the first observations of differences between sand crab populations near SONGS and those elsewhere came before Units 2 and 3 became operational, the emphasis on location effects rather than on the effects of these new units, seems appropriate. Even with this emphasis, the study could have benefitted from greater standardization in sampling design and methods across years. An additional complication making it still more difficult to determine whether sand crabs are affected by SONGS' operations is that activities associated with the construction of SONGS have undoubtedly had significant effects on the beach environment near the plant, whereas construction probably had less severe effects on many of the subtidal organisms that were studied. Large quantities of sediments were placed on the beach during 1977-1979, and the construction laydown pad impeded normal longshore transport of sand from 1974 through 1984. These could both contribute to, or obscure location effects.

Studies of the subtidal soft bottom invertebrate community, using a variant of the BACIP approach, suggest that negative location effects on intertidal sand crabs are unlikely to be due to the operations of SONGS Units 2 and 3. Observed changes near SONGS were generally increases, or trending up through time (Final Technical Report I). At the 18 m depth, changes in the abundance of these subtidal invertebrates, were sometimes observed as far as 3350 m and for a few taxa perhaps as far as 6700 m downcoast from SONGS. These impacts of SONGS are less common at the 8 m depth, and few extend as far as 3350 m downcoast. No relative declines were observed beyond 1 km from SONGS at either depth. If negative impacts of SONGS cannot even be detected among crustaceans living in the shallow subtidal, beyond a kilometer of SONGS' outfalls, it seems unlikely that crabs in the intertidal would be substantially and adversely affected by SONGS at distances as far as 12 km upcoast from the plant.

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6. TABLES

Table 1

Summary of location effects, for each study, and overall. The summary conclusions are based upon a subjective interpretation of the detailed results presented in Appendix E. ⇩ indicates lower values near SONGS, ⇧ indicates *higher* values near SONGS, NDP indicates no distinct pattern, and -- indicates no data were available. Larger, solid symbols indicate more clear cut results. Patterns are evaluated for trends among SONGS beaches (i.e. within 20 km of SONGS) and for differences between Near (within 6.5 km) and Far beaches.

		1976-1978	1980	1981	1983	1986	OVERALL
Catch per unit effort of larger crabs	Among SONGS Beaches	↓	--	--	NDP	NDP	⇩
	Near vs. Far	--	--	--	↓ (June only)	NDP	⇩
Mean maximum size of crabs	Among SONGS Beaches	↓	NDP	↓	NDP	--	↓
	Near vs. Far	NDP	NDP	NDP	NDP	--	NDP
Molt Increment	Among SONGS Beaches	↓	--	--	--	--	↓
	Near vs. Far	↓	--	--	--	--	↓
Fraction with eggs	Among SONGS Beaches	↑	NDP	↑	↓	NDP	NDP
	Near vs. Far	↑	NDP	⇩	↓	NDP	NDP
Fraction[1] spent	Among SONGS Beaches	--	--	NDP	↑ [1]	NDP	NDP
	Near vs. Far	--	--	↑ [1]	↑ [1]	NDP	↑ [1]
Fraction[1] partially spent	Among SONGS Beaches	--	--	--	↑ [1]	NDP	⇧ [1]
	Near vs. Far	--	--	--	↑ [1]	NDP	⇧ [1]
Minimum size of reproduction	Among SONGS Beaches	↓	NDP	↓	↑	--	↓
	Near vs. Far	NDP	NDP	NDP	NDP	--	NDP

[1] Note that for these variables it has been argued that high values rather than low values indicate an adverse affect.

Table 2

Timing of major events at San Onofre.

EVENT	DATE OR PERIOD
Unit 1 became commercially operational	1968
San Onofre State Beach opened to public	1971
Laydown construction pad for Units 2 and 3 built	May 1974
Excavation of sea cliffs and deposition of about 1.6×10^6 m^3 of sand on beach	May-October 1974
Major period of dredging for Units 2 and 3 diffusers and intakes and 0.3×10^6 m^3 of spoils deposited on beach	March 1977-End of 1978
Unit 2 first pumped water	January 1980
Unit 3 first pumped water	January 1982
Unit 2 first produced power	October 1982
Units 2 and 3 first reached "normal" operational levels of water flow	June 1983
Unit 3 first produced power	September 1983
Construction laydown pad for Units 2 and 3 removed	December 1984

Table 3

List of variables tested for location effects during each study. √ indicates that appropriate data were available. Note that in 1984 data could not be tested for location effects.

VARIABLE	DESCRIPTION	STUDY				
		1976-1978	1980	1981	1983	1986
Catch per unit effort	numbers of male, female, megalopal and total crabs. Females are categorized into 5 size classes	√			√	√
Mean maximum size	upper size modes for male and female crabs	√	√	√	√	
Molt increment	mean daily increase in carapace width for males, and 2 sizes of female crabs	√				
Fraction Reproductive	proportion of female crabs carrying a clutch of eggs. Females are classified into 3 size categories	√	√	√	√	√
Fraction Spent	proportion of female crabs with only spent eggs in a clutch. Females are classified into 3 size categories			√	√	√
Fraction Partially Spent	proportion of ovigerous crabs with more than 15% of eggs spent				√	√
Mean Minimum Size of Reproduction	estimates of size at which 50% of female crabs are reproductive	√	√	√	√	

Table 4

List of variables tested for correlations with flow volume of SONGS, for Unit 1 and Units 2 & 3. √ indicates that appropriate data were available, and the correlation was done.

VARIABLE	DESCRIPTION	UNIT 1	UNITS 2 & 3
Catch per unit effort	Numbers of male, female, megalopal and total crabs. Females are categorized into 5 size classes	√	
Mean Maximum Size	Upper size modes for male and female crabs	√	√
Molt Increment	Mean daily increase in carapace width for males, and 2 sizes classes of female crabs	√	
Fraction Reproductive	Proportion of female crabs carrying a clutch of eggs. Females are classified into 3 size categories	√	√
Fraction Spent	Proportion of female crabs with only spent eggs in a clutch. Females are classified into 3 size categories	√	√
Mean Minimum Size of Reproduction	Estimates of size at which 50% of female crabs are reproductive	√	√

Table 5

Summary of Pearson product-moment correlations for sand crab catch per unit effort (CPUE) and distance from SONGS using the 1976-1978 data. Given are the numbers of positive and negative correlations and power for detecting a significant deviation from equal numbers of positive and negative correlations. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant results is that during every survey sand crab CPUE increased linearly with distance by 50% of the mean CPUE (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	# POSITIVE CORRELATIONS	# NEGATIVE CORRELATIONS	POWER
Total CPUE	7	6	0.36
Very Large Females*	11	0	0.16
Large Females*	11	1	0.12
Medium-large Females*	13	0	0.31
Medium-small Females	7	6	0.27
Small Females	5	8	0.23
Males	7	6	0.29
Megalopa	8	4	0.16

Table 6

Pearson product-moment correlation coefficients of sand crab catch per unit effort versus distance from SONGS during 1983. Very large: carapace length (c.l.) > 16 mm; Large: 13 mm < c.l. < 16 mm; Medium-large: 10 mm < c.l. < 13 mm: Medium-small: 7 mm < c.l. < 10 mm; Small: c.l. < 7 mm. Data from sites 20 km or closer to SONGS were used. Power is the probability of detecting a change (linearly with distance) of 50% of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	CLASS	r	N	P	POWER
JUN 83	Total	0.49	9	0.22	0.10
	Very large females	-0.12	9	0.76	0.06
	Large females	0.52	9	0.15	0.07
	Medium-large females	0.56	9	0.11	0.06
	Medium-small females	0.51	9	0.16	0.08
	Small females	-0.1	9	0.79	0.09
	Males	0.13	9	0.75	0.11
JUL 83	Total	-0.04	9	0.93	0.10
	Very large females	0.39	9	0.30	0.10
	Large females	0.55	9	0.12	0.08
	Medium-large females	-0.18	9	0.65	0.11
	Medium-small females	-0.08	9	0.84	0.10
	Small females	-0.05	9	0.89	0.08
	Males	-0.01	9	0.98	0.09
AUG 83	Total	-0.58	9	0.10	0.13
	Very large females	-0.14	9	0.71	0.06
	Large females	-0.26	9	0.496	0.07
	Medium-large females	-0.57	9	0.11	0.15
	Medium-small females	-0.5	9	0.17	0.07
	Small females	-0.46	9	0.21	0.06
	Males	-0.51	9	0.16	0.12

Table 7

T-tests comparing mean catch per unit effort of sand crabs between Near (impact) versus Far (control) beaches during 1983. Tests were done including beaches 6.5 km or closer in the Near group. Very large: carapace length c.l. > 16 mm; Large: 13 mm < c.l. < 16 mm; Medium-large: 10 mm < c.l. < 13 mm; Medium-small: 7 mm < c.l. < 10 mm; Small: c.l. < 7 mm. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a difference between Near and Far beaches of 50% of the mean (of beaches within 20 km of SONGS) at the 0.05 level.

Date (Mo. Yr.)	Class	Near Beaches Mean	Near Beaches SE	Near Beaches N	Far Beaches Mean	Far Beaches SE	Far Beaches N	DF	T	P	Power
JUN 83	Total	42.17	17.01	5	300.83	100.18	10	9.5	-2.54	0.03*	0.06
	Very large females	2.76	2.15	5	5.76	4.42	10	12.2	-0.61	0.55	0.05
	Large females	0.46	0.24	5	4.52	1.58	10	9.4	-2.54	0.03*	0.06
	Medium-large females	1.02	0.37	5	46.32	18.98	10	9.0	-2.39	0.04*	0.06
	Medium-small females	7.93	3.77	5	101.4	38.89	10	9.2	-2.39	0.04*	0.05
	Small females	5.71	3.98	5	34.78	16.5	10	10.0	-1.71	0.12	0.05
	Males	24.30	11.18	5	108.06	40.69	10	10.3	-1.98	0.07	0.06
JUL 83	Total	224.71	106.08	5	260.86	83.5	10	13.0	-0.26	0.8	0.09
	Very large females	0.74	0.34	5	1.88	0.91	10	11.2	-1.18	0.26	0.07
	Large females	1.32	0.63	5	20.94	7.76	10	9.1	-2.52	0.03*	0.05
	Medium-large females	23.66	9.69	5	66.84	26.28	10	11.1	-1.54	0.15	0.06
	Medium-small females	65.63	30.9	5	36.87	11.51	10	13.0	1.08	0.3	0.14
	Small females	19.78	11.54	5	7.92	3.34	10	4.7	0.99	0.37	0.07
	Males	113.57	61.58	5	126.40	43.48	10	13.0	-0.17	0.87	0.08
AUG 83	Total	228.04	72.93	5	180.73	83.22	11	14.0	0.35	0.73	0.08
	Very large females	3.4	2.35	5	19.34	15.5	11	10.5	-1.02	0.33	0.05
	Large females	12.16	7.12	5	21.02	13.72	11	13.6	-0.57	0.58	0.06
	Medium-large females	45.75	12.06	5	43.65	18.69	11	14.0	0.07	0.94	0.07
	Medium-small females	44.94	29.66	5	17.85	10.47	11	5.0	0.86	0.43	0.07
	Small females	3.03	2.71	5	0.72	0.34	11	4.1	0.85	0.44	0.06
	Males	118.76	41.16	5	78.15	37.95	11	14.0	0.64	0.53	0.09

Table 8

Pearson product-moment correlation coefficients of female sand crab catch per unit effort versus distance from SONGS during 1986. Large: > 13 mm carapace length (c.l.); Medium-large: 10 mm < c.l. < 13 mm. Data from sites 20 km or closer to SONGS were used. Power is the probability of detecting a change (linearly with distance) of 50% of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
AUG 86	Large	0.16	27	0.44	0.16
	Medium-large	-0.1	27	0.61	0.15

Table 9

T-tests comparing mean catch per unit effort of female sand crabs between Near (impact) versus Far (control) beaches during 1986. Tests were done including beaches 6.5 km or closer in the Near group. Large: > 13 mm carapace length (c.l.); Medium-large: 10 mm < c.l. < 13 mm. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a difference between Near and Far beaches of 50% of the mean (of beaches within 20 km of SONGS) at the 0.05 level.

DATE	SIZE	NEAR BEACHES			FAR BEACHES						
(MO. YR.)	CLASS	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
AUG 86	Large	47.42	16.74	15	64.87	17.26	14	27	-0.73	0.47	0.20
	Medium large	129.06	43.68	15	116.37	29.88	14	27	0.24	0.81	0.20

Table 10

Summary of Pearson product-moment correlations of mean maximum size and distance from SONGS. Given are the numbers of positive and negative correlations and power for detecting a significant deviation from equal numbers of positive and negative correlations. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant results is that during every survey the size variables increased linearly with distance by 50% of the mean (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	# POSITIVE CORRELATIONS	# NEGATIVE CORRELATIONS	POWER
mean maximum size* of females	16	6	1.0
mean maximum size* of males	18	3	1.0

Table 11

Summary of t-tests comparing the mean maximum size between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. Given are the numbers of positive and negative differences (Near - Far) and power for detecting a significant deviation from equal numbers of positive and negative differences. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the size variable was 50% higher (of the mean from beaches within 20 km of SONGS) at Far beaches than at Near beaches.

	# POSITIVE DIFFERENCES	# NEGATIVE DIFFERENCES	POWER
mean maximum size of females	9	5	1.0
mean maximum size of males	8	6	1.0

Table 12

Summary of Pearson product-moment correlations of molt increment of female and male sand crabs and distance from SONGS. Given are the numbers of positive and negative correlations and power for detecting a significant deviation from equal numbers of positive and negative correlations. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey molt increment increased linearly with distance by 50% of the mean (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	CLASS	# POSITIVE CORRELATIONS	# NEGATIVE CORRELATIONS	POWER
Molt	Small Females	4	3	0.94
Increment	Small Males	6	1	0.87

Table 13

Summary of t-tests comparing the molt increment of female and male sand crabs sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. Given are the numbers of positive and negative differences (Near - Far) and power for detecting a significant deviation from equal numbers of positive and negative differences. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey molt increment was 50% higher (of the mean of beaches within 20 km of SONGS) at Far beaches than at Near beaches.

	CLASS	# POSITIVE DIFFERENCES	# NEGATIVE DIFFERENCES	POWER
Molt	Small Females	2	3	1.0
Increment	Small Males	1	4	0.83

Table 14

Summary of Pearson product-moment correlations of the fraction of reproductive female sand crabs and distance from SONGS. Given are the numbers of positive and negative correlations and power for detecting a significant deviation from equal numbers of positive and negative correlations. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the fraction of reproductive female sand crabs increased linearly with distance by 50% of the mean (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	SIZE CLASS	# POSITIVE CORRELATIONS	# NEGATIVE CORRELATIONS	POWER
Fraction Reproductive	Large	5	7	0.34
	Medium-large	4	9	0.62
	Medium-small*	2	9	0.24

Table 15

Summary of t-tests comparing the fraction of reproductive female sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. Given are the numbers of positive and negative differences (Near - Far) and power for detecting a significant deviation from equal numbers of positive and negative differences. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the fraction of reproductive female sand crabs was 50% higher (of the mean from beaches within 20 km of SONGS) at Far beaches than at Near beaches.

	Size Class	# Positive Differences	# Negative Differences	Power
Fraction Reproductive	Large*	1	9	0.48
	Medium-large	3	8	0.61
	Medium-small	8	3	0.48

Table 16

Summary of Pearson product-moment correlations of female sand crabs that had spent clutches (fraction spent) and distance from SONGS. Given are the numbers of positive and negative correlations and power for detecting a significant deviation from equal numbers of positive and negative correlations. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the fraction of female sand crabs that had spent clutches decreased linearly with distance by 50% of the mean (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	Size Class	# Positive Correlations	# Negative Correlations	Power
Fraction Spent	Large	4	3	0.19
	Medium-large	3	3	0.42
	Medium-small*	0	5	0.19

Table 17

Summary of t-tests comparing the fraction of female sand crabs that had spent clutches between Near (impact) versus Far (control) beaches. Given are the numbers of positive and negative differences (Near - Far) and power for detecting a significant deviation from equal numbers of positive and negative differences. Significant (α = 0.10) results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the fraction of female sand crabs with spent clutches was 50% lower (of the mean from beaches within 20 km of SONGS) at Far beaches than at Near beaches.

	SIZE CLASS	# POSITIVE DIFFERENCES	# NEGATIVE DIFFERENCES	POWER
Fraction Spent	Large	6	1	0.57
	Medium-large*	6	0	0.69
	Medium-small*	5	0	0.43

Table 18

Test for location effects on the fraction partially spent during 1983 and 1986

Pearson product-moment correlation coefficients of fraction of ovigerous sand crabs that had partially spent clutches versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50% of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
JUL & AUG 83	–	-0.8	6	0.054	0.26
AUG 86	Large	0.15	16	0.57	0.12
	Medium-large	-0.46	22	0.03*	0.78

T-tests comparing the fraction of ovigerous sand crabs with partially spent clutches between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a difference between Near and Far beaches of 50% of the mean (of beaches within 20 km of SONGS) at the 0.05 level.

DATE	SIZE	NEAR BEACHES			FAR BEACHES						
(MO. YR.)	CLASS	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
JUL & AUG 83	–	0.497	0.081	3	0.137	0.058	9	10	3.22	0.009*	0.33
AUG 86	Large	0.096	0.03	7	0.157	0.031	10	15	-1.34	0.2	0.25
	Medium-large	0.428	0.051	13	0.29	0.025	11	22	2.28	0.03*	0.85

Table 19

Summary of tests for location effects on mean mimimum size of reproduction.

Summary of Pearson product-moment correlations of mean minimum size of reproduction and distance from SONGS. Given are the numbers of positive and negative correlations and power for a detecting significant deviation from equal numbers of positive and negative correlations. Significant results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the variable increased linearly with distance by 50% of the mean (for all beaches used in the analysis) over a 10 km distance starting at SONGS.

	# POSITIVE CORRELATIONS	# NEGATIVE CORRELATIONS	POWER
mean minimum size of reproduction by females	8	3	1.0

Summary of t-tests comparing the mean minimum size of reproduction between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. Given are the numbers of positive and negative differences (Near - Far) and power for detecting a significant deviation from equal numbers of positive and negative differences (α = 0.10). Significant results are marked by an *. The alternative hypothesis used in power calculations for detecting such significant effects is that during every survey the variable was 50% higher (of the mean from beaches within 20 km of SONGS) at Far beaches than at Near beaches.

	# POSITIVE DIFFERENCES	# NEGATIVE DIFFERENCES	POWER
mean minimum size of reproduction by females	6	3	1.0

Table 20

Pearson product-moment correlation coefficients of sand crab catch per unit effort (CPUE) versus flow volume from SONGS. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a halving of the untransformed mean as flow volume increases from 0 to 100% at the 0.05 level.

DEPENDENT VARIABLE	SONGS UNITS	TRANSFORMATION	N	R	P	POWER
Female CPUE Very Large	1	Log(x + MIN)	9	-0.21	0.59	0.06
Female CPUE Large	1	Log(x + MIN)	11	0.16	0.64	0.05
Female CPUE Medium-Large	1	Log(x + MIN)	12	-0.26	0.42	0.05
Female CPUE Medium-Small	1	Log(x + MIN)	12	-0.31	0.33	0.06
Female CPUE Small	1	Log(x + MIN)	11	-0.28	0.41	0.05
Total Female CPUE	1	Log(x + MIN)	12	-0.28	0.38	0.06
Megalopal CPUE	1	Log(x + MIN)	9	0.04	0.93	0.05
Male CPUE	1	Log(x + MIN)	12	-0.57	0.06	0.07
Total CPUE	1	Log(x + MIN)	12	-0.32	0.31	0.07

Table 21

Pearson product-moment correlation coefficient of sand crab reproductive variables versus flow volume from SONGS. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50% from an untransformed value of 0.5, as flow volume increases from 0 to 100%, at the 0.05 level.

DEPENDENT VARIABLE	SONGS UNITS	TRANSFOR-MATION	N	R	P	POWER
Fraction Reproductive Large	1	Angular	9	-0.20	0.60	0.08
Fraction Reproductive Medium-Large	1	Angular	10	-0.37	0.29	0.14
Fraction Reproductive Medium-Small	1	Angular	7	0.07	0.88	0.12
Fraction Reproductive Large	2 & 3	Angular	9	-0.5	0.17	0.09
Fraction Reproductive Medium-Large	2 & 3	Angular	9	0.11	0.77	0.17
Fraction Reproductive Medium-Small	2 & 3	Angular	7	0.0000	0.998	0.11
Fraction with Spent Eggs Large	1	Angular	5	-0.04	0.95	0.06
Fraction with Spent Eggs Medium-Large	1	Angular	6	0.17	0.75	0.12
Fraction with Spent Eggs Medium-Small	1	Angular	5	-0.94	0.02*	1.0
Fraction with Spent Eggs Large	2 & 3	Angular	5	0.53	0.35	0.08
Fraction with Spent Eggs Medium-Large	2 & 3	Angular	6	0.63	0.18	0.32
Fraction with Spent Eggs Medium-Small	2 & 3	Angular	5	0.64	0.25	0.86

Table 22

Perason product-moment correlation coefficients of sand crab size variables versus flow volume from SONGS. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a halving of the untransformed mean as flow volume increases from 0 to 100% at the 0.05 level.

DEPENDENT VARIABLE	SONGS UNITS	TRANSFORMATION	N	R	P	POWER
Mean Maximum Female Size	1	Log(x + MIN)	19	-0.39	0.10	1.0
Mean Maximum Female Size	2&3	Log(x + MIN)	17	0.64	0.006*	1.0
Mean Maximum Male Size	1	Log(x + MIN)	19	0.34	0.15	1.0
Mean Maximum Male Size	2 & 3	Log(x + MIN)	17	0.00000	0.99	1.0
Mean Minimum Size at Reproduction	1	Log(x + MIN)	9	0.29	0.45	0.99
Mean Minimum Size at Reproduction	2&3	Log(x + MIN)	9	0.26	0.5	0.99

Table 23

Pearson product-moment correlation of sand crab molt increment versus flow volume from SONGS. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a halving of the untransformed mean as flow volume increases from 0 to 100%, at the 0.05 level.

DEPENDENT VARIABLE	SONGS UNITS	TRANSFOR-MATION	N	R	P	POWER
Female Molt increment Medium-Small	1	Log(x + .1MN)	7	0.30	0.51	0.06
Female Molt increment Small	1	Log(x + .1MN)	6	-0.75	0.09	0.07
Male Molt increment Medium-small	1	Log(x + .1MN)	4	-0.35	0.65	0.06
Male Molt increment Small	1	Log(x + .1MN)	8	0.38	0.36	0.12

7. FIGURES

Figure 1: Locations of the main study beaches during the 1976-1978 study. The sites 6.5 km or closer to SONGS were generally also sampled in subsequent studies.

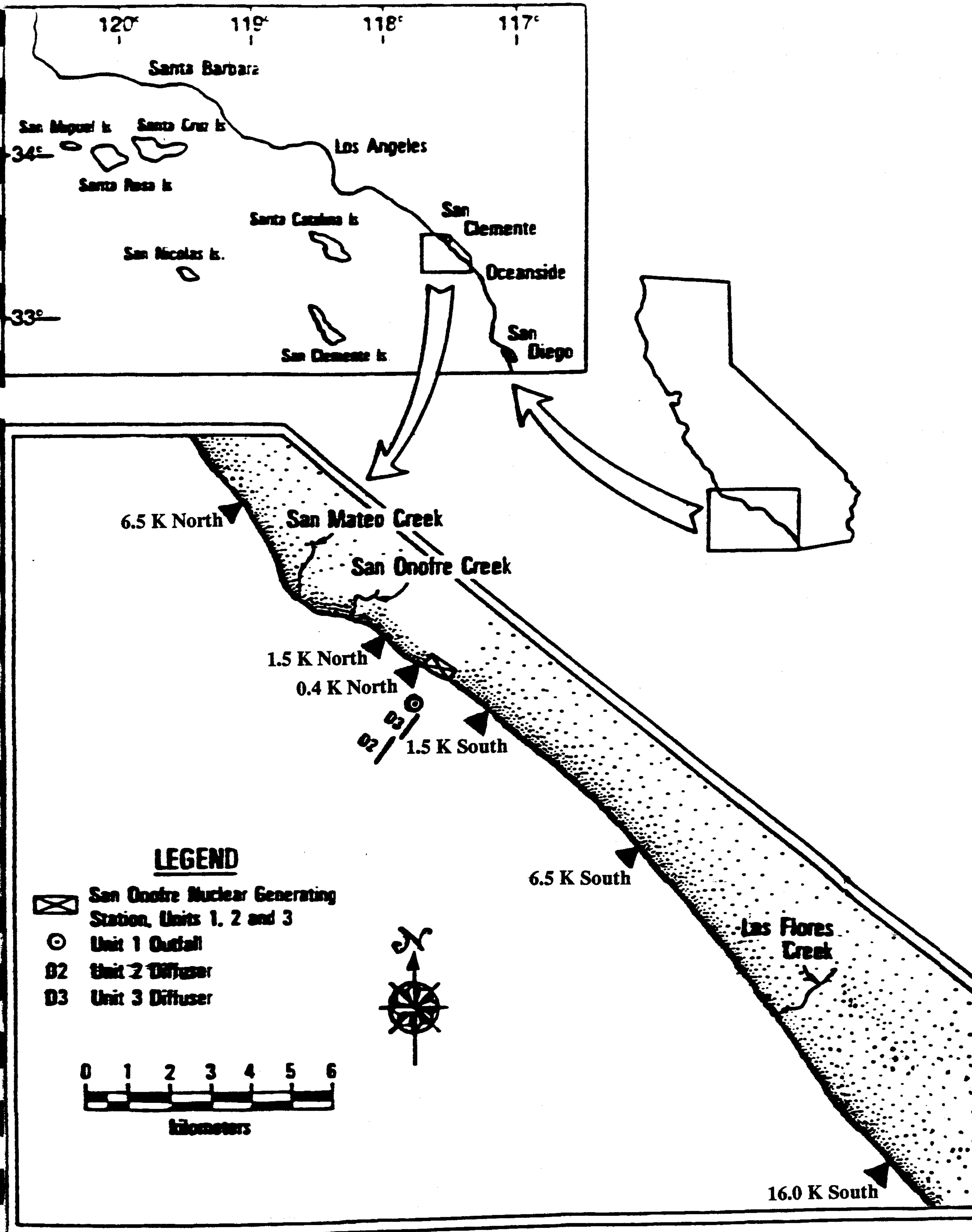

120°
119°
118°
117°
34°
33°
Santa Barbara
San Miguel Is
Santa Cruz Is
Santa Rosa Is
Los Angeles
San Clemente
Santa Catalina Is
San Nicolas Is.
Oceanside
San Diego
San Clemente Is
6.5 K North
San Mateo Creek
San Onofre Creek
1.5 K North
0.4 K North
D3
D2
1.5 K South
6.5 K South
Las Flores Creek
16.0 K South
LEGEND
San Onofre Nuclear Generating Station, Units 1, 2 and 3
Unit 1 Outfall
D2 Unit 2 Diffuser
D3 Unit 3 Diffuser
N
0 1 2 3 4 5 6
kilometers

Figure 2: Three main study areas of beach site locations used in the 1980 study. Sampling near San Onofre was predominantly at the 0.4 K North location.

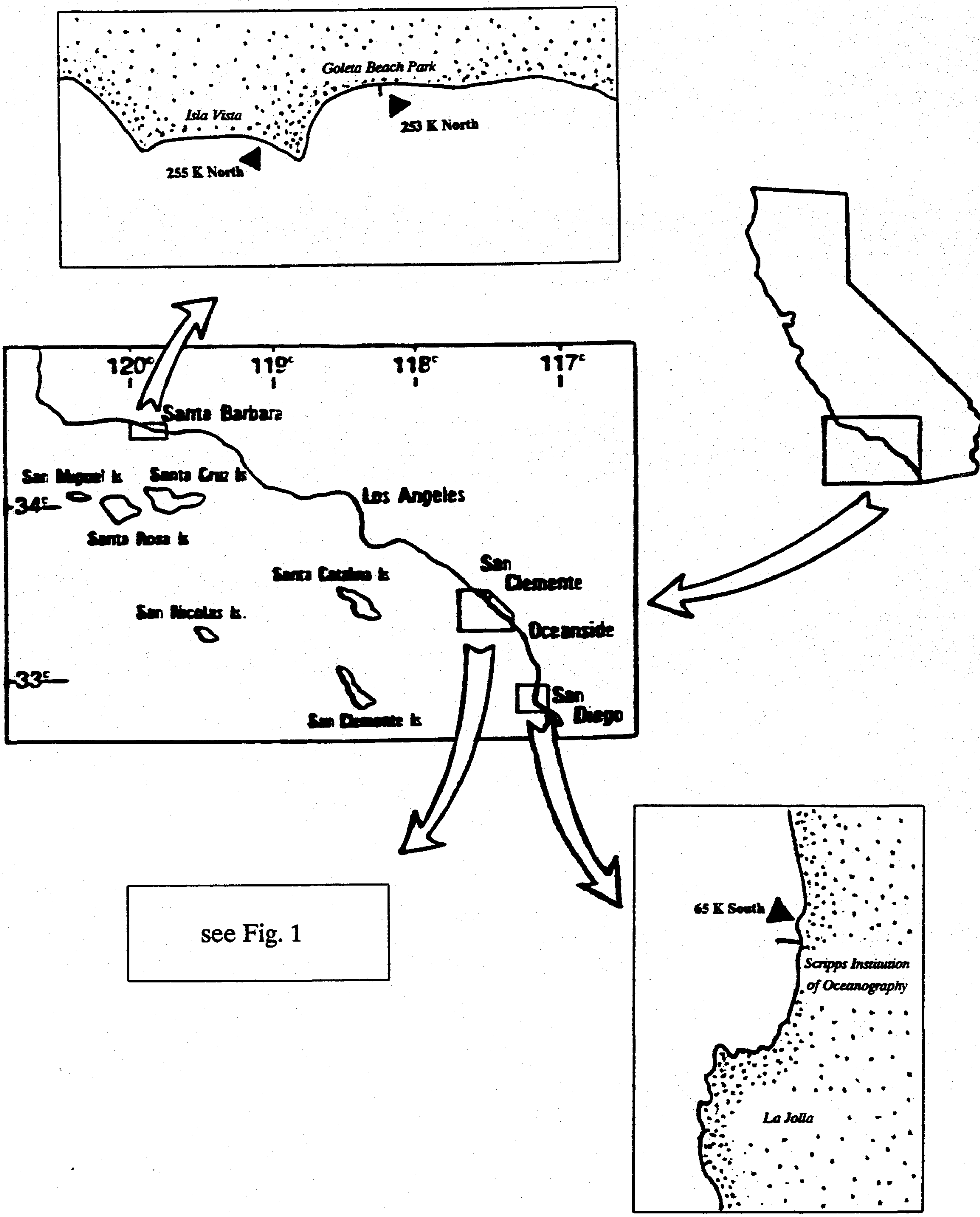
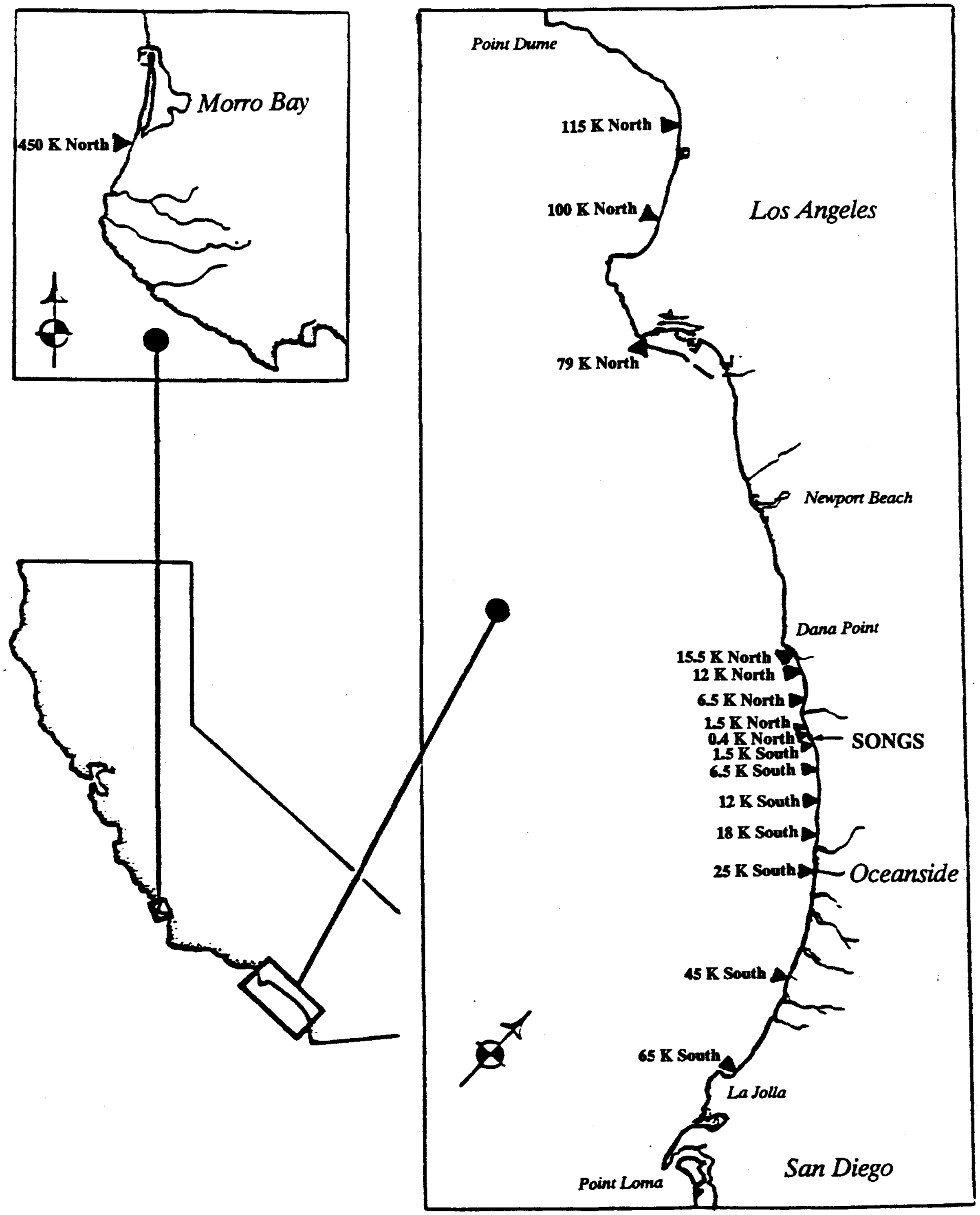

Goleta Beach Park
Isla Vista
253 K North
255 K North
120°
119°
118°
117°
Santa Barbara
Santa Cruz Is
34°
Santa Rosa Is
Los Angeles
Santa Catalina Is
San Nicolas Is.
San Clemente
Oceanside
33°
San Clemente Is
San Diego
see Fig. 1
65 K South
Scripps Institution of Oceanography
La Jolla

Figure 3: **Location of study beaches during the 1983 study.**


Morro Bay
450 K North
Point Dume
115 K North
100 K North
Los Angeles
79 K North
Newport Beach
Dana Point
15.5 K North
12 K North
6.5 K North
1.5 K North
0.4 K North
SONGS
1.5 K South
6.5 K South
12 K South
18 K South
25 K South
Oceanside
45 K South
65 K South
La Jolla
Point Loma
San Diego

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APPENDIX A. ADDITIONAL INFORMATION ON STATISTICAL ESTIMATION OF VARIABLES AND DATA AVAILABILITY.

A.1. Estimation of mean maximum sizes of male and female sand crabs, and mean minimum size of female sand crabs at reproduction.

A.1.1 Mean Maximum Size

Our task is to determine the mean maximum male or female size, without knowing which individuals are part of the maximum mode, and which individuals are not. In order to do this, we assume that our observations on male or female size come from a statistical population composed from a mixture of two distributions. The first describes the distribution of maximum male or female sizes, and is assumed normal with unknown mean or variance. The second describes the distribution of males or females that have not yet reached their maximum size, and is given a distribution of arbitrary continuous type, with the proviso that it only contaminates the lower tail of the normal distribution. Our statistical model is given by the mixture of CDF's (cumulative distribution functions):

$$F(x) = p\,A(x) + (1-p)\,G(x)$$

where

(1) $0 < p < 1$,

(2) $G(x)$ is a normal CDF, with unknown mean and variance,

(3) $A(x)$ is a continuous CDF with density $a(x)$, and

(4) there is some unknown c such that c < the mean for G, and $A(x) = 1$ for $x > c$.

Brownie *et al.* (1983) describe how to estimate p, and the mean and variance of G. Our SAS programs implementing their procedures have been permanently stored using the MRC's Disk Inventory Control System. Sample sizes less than 30, or failure to converge, result in mean maximum male sizes being set to missing values. Convergence of p to negative values is assumed to indicate that G was uncontaminated.

The statistical model may not be strictly valid. For example, we know that if maximum male size is normally distributed then half the individuals are, at some time, above the mean maximum size. We still chose this procedure because:

(a) The procedure gives close to the same answer as procedures that assume that contaminants (immature males or females) come from normal distributions when the underlying distributions are normal (These procedures are the antecedents of methods based on the use of probability paper [Harding 1949, Cassie 1954]). When the underlying distributions are not normal the procedure used here often out performs the procedures based on mixtures of normal distributions (Brownie *et al.* 1983).

(b) With most mixtures of distribution methods the user needs to decide on subjective grounds how many distributions are involved in the mixture (Everitt and Hand 1981). The technique used here lumps all contaminants into a single distribution of arbitrary shape, and thus there is no need to define the number of distributions contributing to the contamination of the normal distribution of interest.

(c) The proportion of time that individuals are greater than the mean maximum, but not part of the (assumed normally distributed) maximum mode may be small, so the statistical model may be approximately correct.

A.1.2 Estimation of Mean Minimum Size of Females at Reproduction.

The probability that a female sand crab is reproductive increases with its size (Wenner *et al.* 1974). We define the mean minimum size of females at reproduction as that minimum size at which the probability that a female is carrying eggs reaches 0.5. If we assume that for small sizes the probability is near zero, and for large enough sizes the probability approaches one, then the proportion carrying eggs can be considered an empirical depiction of the CDF for size at maturity. The data from the MRC's studies supports these assumptions (note that we are also assuming that carrying eggs is equivalent to being mature). We now make the further assumption that the CDF is for a normal distribution. This allows us to use Probit analysis. This statistical method is designed for dichotomous variables (usually for "alive" vs "dead" as a function of the concentration of a toxic substance, but "with eggs" vs "without eggs" as a function of size works just as well). The statistical details of maximum likelihood estimation can be found in Cox (1970) and Finney (1971). These procedures have been incorporated into Proc Probit in SAS (SAS 1985). For each population analyzed, a probit regression model was fit, and the size at which the probability of carrying eggs reached 0.5 was calculated for that model. This was used as the estimate of mean minimum size of females at reproduction. If sample sizes were less than 30, or the procedure failed to converge on an estimate, the mean minimum size of females at reproduction was set to a missing value.

A.2. Data Availability

Listings by month, for each variable, of the beaches for which data were available for use in our analyses follow. In these listings the variable "XLOCBCH" refers to distance from SONGS in meters, with values to the north being negative and values to the south being positive. With the exception of La Jolla during the 1976-1978 study, these values are equal to the variable "XLOCBCH" in the MRC data bases. For consistency we have used a value of 65,000 to refer to La Jolla, although a value of 64,000 is stored in the data bases for the 1976-1978 data. On some data sheets from the 1980-1981 studies data were recorded as at 0.0 north (or some similar designation). These are stored in the data bases with values of XLOCBCH of -400 since the difference in distance is so small between these locations very near SONGS. We have used the values of XLOCBCH stored in the data bases for 1986, although a different measurement system was used for some of these beaches than in past years. In 1986 distance from SONGS was measured by distance along the beach rather than by straight line distance, for the beaches near SONGS. This leads to some differences in distance for beaches more than 6.5 km from SONGS in comparison with past measurements. We use the new measurements in our tests of location effects in 1986 because the differences do not change the rank order of distances from SONGS, or whether a beach should be in the Near vs. Far category.

A. Data availability for catch per unit effort variables.

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15SEP76	15OCT76	15NOV76	15DEC76	15JAN77	15FEB77	15MAR77	15APR77	15MAY77	TOTAL
-6500	1	1	1	1	1	1	1	1	1	17
-1500	1	1	1	1	1	1	1	1	1	17
-400	1	1	1	1	1	1	1	1	1	17
1500	1	1	1	1	1	1	1	1	1	17
6500	1	1	1	1	1	1	1	1	1	17
16000	1	1	1	1	1	1	1	1	1	17
48000	0	0	0	0	0	0	0	0	0	4
65000	0	0	0	0	0	0	0	0	0	5
TOTAL	6	6	6	6	6	6	6	6	6	111

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15JUN77	15JUL77	15OCT77	15NOV77	15DEC77	15JAN78	15FEB78	15MAR78	TOTAL
-6500	1	1	1	1	1	1	1	1	17
-1500	1	1	1	1	1	1	1	1	17
-400	1	1	1	1	1	1	1	1	17
1500	1	1	1	1	1	1	1	1	17
6500	1	1	1	1	1	1	1	1	17
16000	1	1	1	1	1	1	1	1	17
48000	0	0	0	0	1	1	1	1	4
65000	0	0	0	1	1	1	1	1	5
TOTAL	6	6	6	7	8	8	8	8	111

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION OF BEACH)   DATE(DATE SAMPLING BEGAN)

FREQUENCY	14JUN83	01JUL83	03AUG83	15AUG86	TOTAL
-450000	0	0	1	0	1
-115000	1	1	1	0	3
-100000	1	1	1	0	3
-79000	1	1	1	0	3
-17500	0	0	0	1	1
-15500	1	1	1	0	3
-14000	0	0	0	1	1
-12500	0	0	0	1	1
-12000	1	1	1	0	3
-11500	0	0	0	1	1
-10500	0	0	0	1	1
-8500	0	0	0	1	1
-7500	0	0	0	1	1
-6500	1	1	1	1	4
-5500	0	0	0	1	1
-4500	0	0	0	1	1
-3500	0	0	0	1	1
-2500	0	0	0	1	1
-1500	1	1	1	1	4
TOTAL	15	15	16	29	75

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION OF BEACH)   DATE(DATE SAMPLING BEGAN)

FREQUENCY	14JUN83	01JUL83	03AUG83	15AUG86	TOTAL
-400	1	1	1	1	4
0	0	0	0	1	1
500	0	0	0	1	1
1500	1	1	1	1	4
2500	0	0	0	1	1
3500	0	0	0	1	1
4500	0	0	0	1	1
5500	0	0	0	1	1
6500	1	1	1	1	4
7500	0	0	0	1	1
8500	0	0	0	1	1
9500	0	0	0	1	1
10500	0	0	0	1	1
12000	1	1	1	1	4
18000	1	1	1	0	3
25000	1	1	1	0	3
45000	1	1	1	1	4
65000	1	1	1	1	4
TOTAL	15	15	16	29	75

B. Data availability for "fraction reproductive"..

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15SEP76	15OCT76	15NOV76	15APR77	15MAY77	15JUN77
-450000	0	0	0	0	0	0
-255000	0	0	0	0	0	0
-253000	0	0	0	0	0	0
-115000	0	0	0	0	0	0
-100000	0	0	0	0	0	0
-79000	0	0	0	0	0	0
-17500	0	0	0	0	0	0
-15500	0	0	0	0	0	0
-14000	0	0	0	0	0	0
-12500	0	0	0	0	0	0
-12000	0	0	0	0	0	0
-11500	0	0	0	0	0	0
-10500	0	0	0	0	0	0
-8500	0	0	0	0	0	0
-7500	0	0	0	0	0	0
-6500	1	1	0	1	1	1
-5500	0	0	0	0	0	0
-4500	0	0	0	0	0	0
-1500	1	1	0	1	1	1
-400	1	1	0	1	1	1
TOTAL	6	6	1	6	6	7

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15JUL77	15AUG77	15OCT77	15NOV77	15DEC77	15JAN78	TOTAL
-450000	0	0	0	0	0	0	1
-255000	0	0	0	0	0	0	6
-253000	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	3
-100000	0	0	0	0	0	0	4
-79000	0	0	0	0	0	0	3
-17500	0	0	0	0	0	0	1
-15500	0	0	0	0	0	0	3
-14000	0	0	0	0	0	0	1
-12500	0	0	0	0	0	0	1
-12000	0	0	0	0	0	0	4
-11500	0	0	0	0	0	0	1
-10500	0	0	0	0	0	0	1
-8500	0	0	0	0	0	0	1
-7500	0	0	0	0	0	0	1
-6500	1	1	1	1	0	1	24
-5500	0	0	0	0	0	0	1
-4500	0	0	0	0	0	0	1
-1500	1	1	1	1	1	1	22
-400	1	1	1	1	1	1	28
TOTAL	7	7	5	5	4	5	210

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15SEP76	15OCT76	15NOV76	15APR77	15MAY77	15JUN77
0	0	0	0	0	0	0
500	0	0	0	0	0	0
1500	1	1	0	1	1	1
2500	0	0	0	0	0	0
3500	0	0	0	0	0	0
4500	0	0	0	0	0	0
5500	0	0	0	0	0	0
6500	1	1	1	1	1	1
7500	0	0	0	0	0	0
8500	0	0	0	0	0	0
9500	0	0	0	0	0	0
10500	0	0	0	0	0	0
12000	0	0	0	0	0	0
16000	1	1	0	1	1	1
18000	0	0	0	0	0	0
25000	0	0	0	0	0	0
45000	0	0	0	0	0	0
51000	0	0	0	0	0	0
65000	0	0	0	0	0	1
TOTAL	6	6	1	6	6	7

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY]	15JUL77]	15AUG77]	15OCT77]	15NOV77]	15DEC77]	15JAN78]	TOTAL
0]	0]	0]	0]	0]	0]	0]	1
500]	0]	0]	0]	0]	0]	0]	1
1500]	1]	1]	1]	1]	1]	0]	22
2500]	0]	0]	0]	0]	0]	0]	1
3500]	0]	0]	0]	0]	0]	0]	1
4500]	0]	0]	0]	0]	0]	0]	1
5500]	0]	0]	0]	0]	0]	0]	1
6500]	1]	1]	1]	1]	1]	1]	25
7500]	0]	0]	0]	0]	0]	0]	1
8500]	0]	0]	0]	0]	0]	0]	1
9500]	0]	0]	0]	0]	0]	0]	1
10500]	0]	0]	0]	0]	0]	0]	1
12000]	0]	0]	0]	0]	0]	0]	3
16000]	1]	1]	0]	0]	0]	0]	7
18000]	0]	0]	0]	0]	0]	0]	3
25000]	0]	0]	0]	0]	0]	0]	4
45000]	0]	0]	0]	0]	0]	0]	4
51000]	0]	0]	0]	0]	0]	0]	1
65000]	1]	1]	0]	0]	0]	1]	23
TOTAL	7	7	5	5	4	5	210

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15FEB78	15MAR78	15APR80	15MAY80	15JUN80	15JUL80
-450000	0	0	0	0	0	0
-255000	0	0	0	1	1	1
-253000	0	0	0	0	0	0
-115000	0	0	0	0	0	0
-100000	0	0	0	0	0	1
-79000	0	0	0	0	0	0
-17500	0	0	0	0	0	0
-15500	0	0	0	0	0	0
-14000	0	0	0	0	0	0
-12500	0	0	0	0	0	0
-12000	0	0	0	0	0	1
-11500	0	0	0	0	0	0
-10500	0	0	0	0	0	0
-8500	0	0	0	0	0	0
-7500	0	0	0	0	0	0
-6500	1	1	0	0	0	1
-5500	0	0	0	0	0	0
-4500	0	0	0	0	0	0
-1500	1	0	0	0	1	0
-400	0	1	0	1	0	1
TOTAL	4	4	1	3	3	9

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15AUG80	15SEP80	15OCT80	15NOV80	15APR81	15MAY81	TOTAL
-450000	0	0	0	0	0	0	1
-255000	1	0	1	1	0	0	6
-253000	1	0	0	0	0	0	1
-115000	0	0	0	0	0	0	3
-100000	0	0	0	0	0	0	4
-73000	0	0	0	0	0	0	3
-17500	0	0	0	0	0	0	1
-15500	0	0	0	0	0	0	3
-14000	0	0	0	0	0	0	1
-12500	0	0	0	0	0	0	1
-12000	0	0	0	0	0	0	4
-11500	0	0	0	0	0	0	1
-10500	0	0	0	0	0	0	1
-8500	0	0	0	0	0	0	1
-7500	0	0	0	0	0	0	1
-6500	0	0	0	0	1	1	24
-5500	0	0	0	0	0	0	1
-4500	0	0	0	0	0	0	1
-1500	0	0	0	0	1	1	23
-400	1	1	1	0	0	1	28
TOTAL	4	2	3	1	4	6	210

(CONTINUED)

;ABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY]	15FEB78]	15MAR78]	15APR80]	15MAY80]	15JUN80]	15JUL80]
0]	0]	0]	0]	0]	0]	0]
500]	0]	0]	0]	0]	0]	0]
1500]	1]	1]	0]	0]	0]	0]
2500]	0]	0]	0]	0]	0]	0]
3500]	0]	0]	0]	0]	0]	0]
4500]	0]	0]	0]	0]	0]	0]
5500]	0]	0]	0]	0]	0]	0]
6500]	1]	1]	0]	0]	0]	1]
7500]	0]	0]	0]	0]	0]	0]
8500]	0]	0]	0]	0]	0]	0]
9500]	0]	0]	0]	0]	0]	0]
10500]	0]	0]	0]	0]	0]	0]
12000]	0]	0]	0]	0]	0]	0]
16000]	0]	0]	0]	0]	0]	0]
18000]	0]	0]	0]	0]	0]	0]
25000]	0]	0]	0]	0]	0]	1]
45000]	0]	0]	0]	0]	0]	0]
51000]	0]	0]	0]	0]	0]	1]
65000]	0]	0]	1]	1]	1]	1]
TOTAL	4	4	1	3	3	9

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15AUG80	15SEP80	15OCT80	15NOV80	15APR81	15MAY81	TOTAL
0	0	0	0	0	0	0	1
500	0	0	0	0	0	0	1
1500	0	0	0	0	1	1	22
2500	0	0	0	0	0	0	1
3500	0	0	0	0	0	0	1
4500	0	0	0	0	0	0	1
5500	0	0	0	0	0	0	1
6500	0	0	0	0	1	1	25
7500	0	0	0	0	0	0	1
8500	0	0	0	0	0	0	1
9500	0	0	0	0	0	0	1
10500	0	0	0	0	0	0	1
12000	0	0	0	0	0	0	3
16000	0	0	0	0	0	0	7
18000	0	0	0	0	0	0	3
25000	0	0	0	0	0	0	4
45000	0	0	0	0	0	0	4
51000	0	0	0	0	0	0	1
65000	1	1	1	0	0	1	23
TOTAL	4	2	3	1	4	6	210

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY]	15JUL81]	15AUG81]	15SEP81]	15OCT81]	14JUN83]	01JUL83]
-450000]	0]	0]	0]	0]	0]	0]
-255000]	0]	0]	0]	0]	0]	0]
-253000]	0]	0]	0]	0]	0]	0]
-115000]	0]	0]	0]	0]	1]	1]
-100000]	0]	0]	0]	0]	1]	1]
-79000]	0]	0]	0]	0]	1]	1]
-17500]	0]	0]	0]	0]	0]	0]
-15500]	0]	0]	0]	0]	1]	1]
-14000]	0]	0]	0]	0]	0]	0]
-12500]	0]	0]	0]	0]	0]	0]
-12000]	0]	0]	0]	0]	1]	1]
-11500]	0]	0]	0]	0]	0]	0]
-10500]	0]	0]	0]	0]	0]	0]
-8500]	0]	0]	0]	0]	0]	0]
-7500]	0]	0]	0]	0]	0]	0]
-6500]	1]	1]	1]	0]	1]	1]
-5500]	0]	0]	0]	0]	0]	0]
-4500]	0]	0]	0]	0]	0]	0]
-1500]	1]	1]	0]	0]	1]	1]
-400]	1]	1]	1]	1]	1]	1]
TOTAL	6	6	5	3	15	15

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY]	03AUG83]	15JUL84]	15AUG84]	15SEP84]	15OCT84]	15AUG86]	TOTAL
-450000]	1]	0]	0]	0]	0]	0]	1
-255000]	0]	0]	0]	0]	0]	0]	6
-253000]	0]	0]	0]	0]	0]	0]	1
-115000]	1]	0]	0]	0]	0]	0]	3
-100000]	1]	0]	0]	0]	0]	0]	4
-79000]	1]	0]	0]	0]	0]	0]	3
-17500]	0]	0]	0]	0]	0]	1]	1
-15500]	1]	0]	0]	0]	0]	0]	3
-14000]	0]	0]	0]	0]	0]	1]	1
-12500]	0]	0]	0]	0]	0]	1]	1
-12000]	1]	0]	0]	0]	0]	0]	4
-11500]	0]	0]	0]	0]	0]	1]	1
-10500]	0]	0]	0]	0]	0]	1]	1
-8500]	0]	0]	0]	0]	0]	1]	1
-7500]	0]	0]	0]	0]	0]	1]	1
-6500]	1]	1]	1]	0]	0]	1]	24
-5500]	0]	0]	0]	0]	0]	1]	1
-4500]	0]	0]	0]	0]	0]	1]	1
-1500]	1]	1]	0]	0]	0]	1]	23
-400]	1]	1]	1]	0]	0]	1]	28
TOTAL	16	4	3	1	1	26	210

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE(SAMPLING DATE)

FREQUENCY	15JUL81	15AUG81	15SEP81	15OCT81	14JUN83	01JUL83
0	0	0	0	0	0	0
500	0	0	0	0	0	0
1500	1	1	1	1	1	1
2500	0	0	0	0	0	0
3500	0	0	0	0	0	0
4500	0	0	0	0	0	0
5500	0	0	0	0	0	0
6500	1	1	1	1	1	1
7500	0	0	0	0	0	0
8500	0	0	0	0	0	0
9500	0	0	0	0	0	0
10500	0	0	0	0	0	0
12000	0	0	0	0	1	1
16000	0	0	0	0	0	0
18000	0	0	0	0	1	1
25000	0	0	0	0	1	1
45000	0	0	0	0	1	1
51000	0	0	0	0	0	0
65000	1	1	1	0	1	1
TOTAL	6	6	5	3	15	15

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE(SAMPLING DATE)

FREQUENCY	03AUG83	15JUL84	15AUG84	15SEP84	15OCT84	15AUG86	TOTAL
0	0	0	0	0	0	1	1
500	0	0	0	0	0	1	1
1500	1	0	0	0	0	1	22
2500	0	0	0	0	0	1	1
3500	0	0	0	0	0	1	1
4500	0	0	0	0	0	1	1
5500	0	0	0	0	0	1	1
6500	1	0	0	0	0	1	25
7500	0	0	0	0	0	1	1
8500	0	0	0	0	0	1	1
9500	0	0	0	0	0	1	1
10500	0	0	0	0	0	1	1
12000	1	0	0	0	0	0	3
16000	0	0	0	0	0	0	7
18000	1	0	0	0	0	0	3
25000	1	0	0	0	0	0	4
45000	1	0	0	0	0	1	4
51000	0	0	0	0	0	0	1
65000	1	1	1	1	1	1	23
TOTAL	16	4	3	1	1	25	210

C. Data availability for "fraction spent".

TABLE OF XLOCBCH BY DATE

XLOCBCH(DISTANCE SOUTH OF SONGS (METERS))   DATE(DATE OF SAMPLE (DDMONYY))

FREQUENCY	15JUL81	15AUG81	15SEP81	15OCT81	14JUN83	01JUL83	03AUG83	15JUL84
-450000	0	0	0	0	0	0	1	0
-255000	0	1	1	0	0	0	0	0
-253000	0	1	0	0	0	0	0	0
-248000	0	1	1	0	0	0	0	0
-115000	0	0	0	0	1	1	1	0
-100000	0	0	0	0	1	1	1	0
-79000	0	0	0	0	1	1	1	0
-17500	0	0	0	0	0	0	0	0
-15500	0	0	0	0	1	1	1	0
-14000	0	0	0	0	0	0	0	0
-12500	0	0	0	0	0	0	0	0
-12000	0	0	0	0	1	1	1	0
-11500	0	0	0	0	0	0	0	0
-10500	0	0	0	0	0	0	0	0
-8500	0	0	0	0	0	0	0	0
-7500	0	0	0	0	0	0	0	0
-6500	1	1	1	0	1	1	1	1
-5500	0	0	0	0	0	0	0	0
-4500	0	0	0	0	0	0	0	0
TOTAL	6	9	7	3	15	15	16	4

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(DISTANCE SOUTH OF SONGS (METERS))   DATE(DATE OF SAMPLE (DDMONYY))

FREQUENCY	15AUG84	15SEP84	15OCT84	15AUG86	TOTAL
-450000	0	0	0	0	1
-255000	0	0	0	0	2
-253000	0	0	0	0	1
-248000	0	0	0	0	2
-115000	0	0	0	0	3
-100000	0	0	0	0	3
-79000	0	0	0	0	3
-17500	0	0	0	1	1
-15500	0	0	0	0	3
-14000	0	0	0	1	1
-12500	0	0	0	1	1
-12000	0	0	0	0	3
-11500	0	0	0	1	1
-10500	0	0	0	1	1
-8500	0	0	0	1	1
-7500	0	0	0	1	1
-6500	1	0	0	1	3
-5500	0	0	0	1	1
-4500	0	0	0	1	1
TOTAL (CONTINUED)	3	1	1	22	10[illegible]

TABLE OF XLOCBCH BY DATE

XLOCBCH(DISTANCE SOUTH OF SONGS (METERS))   DATE(DATE OF SAMPLE (DDMONYY))

FREQUENCY	15JUL81	15AUG81	15SEP81	15OCT81	14JUN83	01JUL83	03AUG83	15JUL84
-1500	1	1	0	0	1	1	1	1
-400	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0
1500	1	1	1	1	1	1	1	0
2500	0	0	0	0	0	0	0	0
3500	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0
5500	0	0	0	0	0	0	0	0
6500	1	1	1	1	1	1	1	0
7500	0	0	0	0	0	0	0	0
8500	0	0	0	0	0	0	0	0
9500	0	0	0	0	0	0	0	0
10500	0	0	0	0	0	0	0	0
12000	0	0	0	0	1	1	1	0
18000	0	0	0	0	1	1	1	0
25000	0	0	0	0	1	1	1	0
45000	0	0	0	0	1	1	1	0
65000	1	1	1	0	1	1	1	1
TOTAL	6	9	7	3	15	15	16	4

TABLE OF XLOCBCH BY DATE

XLOCBCH(DISTANCE SOUTH OF SONGS (METERS))   DATE(DATE OF SAMPLE (DDMONYY))

FREQUENCY	15AUG84	15SEP84	15OCT84	15AUG86	TOTAL
-1500	0	0	0	1	7
-400	1	0	0	1	10
0	0	0	0	1	1
500	0	0	0	1	1
1500	0	0	0	1	8
2500	0	0	0	1	1
3500	0	0	0	1	1
4500	0	0	0	1	1
5500	0	0	0	1	1
6500	0	0	0	1	6
7500	0	0	0	1	1
8500	0	0	0	1	1
9500	0	0	0	1	1
10500	0	0	0	1	1
12000	0	0	0	0	3
18000	0	0	0	0	2
25000	0	0	0	0	2
45000	0	0	0	1	4
65000	1	1	1	1	11
TOTAL	3	1	1	28	10[illegible]

D. Data availability for "mean maximum female size".

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE

FREQUENCY	15SEP76	15OCT76	15NOV76	15APR77	15MAY77	15JUN77	15JUL77	15AUG77	15OCT77	15NOV77	15DEC77	TOTAL
-450000	0	0	0	0	0	0	0	0	0	0	0	1
-255000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-253000	0	0	0	0	0	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-100000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-79000	0	0	0	0	0	0	0	0	0	0	0	3
-15500	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-12000	0	0	0	0	0	0	0	0	0	0	0	4
-6500	1	1	0	1	1	1	1	1	1	1	0	[illegible]
-1500	1	1	0	1	1	1	1	1	1	1	1	[illegible]
-400	1	1	0	1	1	1	1	1	1	1	1	[illegible]
1500	1	1	0	1	1	1	1	1	1	1	1	[illegible]
6500	1	1	1	1	1	1	1	1	1	1	1	24
12000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
16000	1	1	0	1	1	1	1	1	0	0	0	[illegible]
18000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
25000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
45000	0	0	0	0	0	0	0	0	0	0	0	3
51000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
64000	0	0	0	0	0	1	1	1	0	0	0	4
65000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
TOTAL	6	6	1	6	6	7	7	7	5	5	4	[illegible]

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE

FREQUENCY	15JAN78	15FEB78	15MAR78	15APR80	15MAY80	15JUN80	15JUL80	15AUG80	15SEP80	15OCT80	15NOV80	TOTAL
-450000	0	0	0	0	0	0	0	0	0	0	0	1
-255000	0	0	0	0	1	1	1	1	0	1	1	6
-253000	0	0	0	0	0	0	0	1	0	0	0	1
-115000	0	0	0	0	0	0	0	0	0	0	0	3
-100000	0	0	0	0	0	0	1	0	0	0	0	4
-79000	0	0	0	0	0	0	0	0	0	0	0	3
-15500	0	0	0	0	0	0	0	0	0	0	0	3
-12000	0	0	0	0	0	0	1	0	0	0	0	4
-6500	1	1	1	0	0	0	1	0	0	0	0	21
-1500	1	1	0	0	0	1	0	0	0	0	0	20
-400	1	0	1	0	1	0	1	1	1	1	0	25
1500	0	1	1	0	0	0	0	0	0	0	0	21
6500	1	1	1	0	0	0	1	0	0	0	0	24
12000	0	0	0	0	0	0	0	0	0	0	0	3
16000	0	0	0	0	0	0	0	0	0	0	0	7
18000	0	0	0	0	0	0	0	0	0	0	0	3
25000	0	0	0	0	0	0	1	0	0	0	0	4
45000	0	0	0	0	0	0	0	0	0	0	0	3
51000	0	0	0	0	0	0	1	0	0	0	0	1
64000	1	0	0	0	0	0	0	0	0	0	0	4
65000	0	0	0	1	1	1	1	1	1	1	0	14
TOTAL	5	4	4	1	3	3	9	4	2	3	1	175

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE

FREQUENCY	15APR81	15MAY81	15JUL81	15AUG81	15SEP81	15OCT81	15JUN83	15JUL83	15AUG83	TOTAL
-450000	0	0	0	0	0	0	0	0	1	1
-255000	0	0	0	0	0	0	0	0	0	6
-253000	0	0	0	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	1	1	1	3
-100000	0	0	0	0	0	0	1	1	1	4
-79000	0	0	0	0	0	0	1	1	1	3
-15500	0	0	0	0	0	0	1	1	1	3
-12000	0	0	0	0	0	0	1	1	1	4
-6500	1	1	1	1	1	0	1	1	1	21
-1500	1	1	1	1	0	0	1	1	1	20
-400	0	1	1	1	1	1	1	1	1	25
1500	1	1	1	1	1	1	1	1	1	21
6500	1	1	1	1	1	1	1	1	1	24
12000	0	0	0	0	0	0	1	1	1	3
16000	0	0	0	0	0	0	0	0	0	7
18000	0	0	0	0	0	0	1	1	1	3
25000	0	0	0	0	0	0	1	1	1	4
45000	0	0	0	0	0	0	1	1	1	3
51000	0	0	0	0	0	0	0	0	0	1
64000	0	0	0	0	0	0	0	0	0	4
65000	0	1	1	1	1	0	1	1	1	14
TOTAL	4	6	6	6	5	3	15	15	16	175

E. Data availability for "mean maximum male size".

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE

FREQUENCY	15SEP76	15OCT76	15NOV76	15APR77	15MAY77	15JUN77	15JUL77	15AUG77	15OCT77	15NOV77	15DEC77	TOTA
-450000	0	0	0	0	0	0	0	0	0	0	0	1
-255000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-253000	0	0	0	0	0	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-100000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-79000	0	0	0	0	0	0	0	0	0	0	0	3
-15500	0	0	0	0	0	0	0	0	0	0	0	[illegible]
-12000	0	0	0	0	0	0	0	0	0	0	0	4
-6500	1	1	0	1	1	1	1	1	1	1	0	2
-1500	1	1	0	1	1	1	1	1	1	1	1	2
-400	1	1	0	1	1	1	1	1	1	1	1	25
1500	1	1	0	1	1	1	1	1	1	1	1	2
6500	1	1	1	1	1	1	1	1	1	1	1	24
12000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
16000	1	1	0	1	1	1	1	1	0	0	0	[illegible]
18000	0	0	0	0	0	0	0	0	0	0	0	2
25000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
45000	0	0	0	0	0	0	0	0	0	0	0	3
51000	0	0	0	0	0	0	0	0	0	0	0	[illegible]
64000	0	0	0	0	0	1	1	1	0	0	0	4
65000	0	0	0	0	0	0	0	0	0	0	0	14
TOTAL	6	6	1	6	6	7	7	7	5	5	4	17

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS)) DATE

FREQUENCY	15JAN78	15FEB78	15MAR78	15APR80	15MAY80	15JUN80	15JUL80	15AUG80	15SEP80	15OCT80	15NOV80	TOTAL
-450000	0	0	0	0	0	0	0	0	0	0	0	1
-255000	0	0	0	0	1	1	1	1	0	1	1	6
-253000	0	0	0	0	0	0	0	1	0	0	0	1
-115000	0	0	0	0	0	0	0	0	0	0	0	3
-100000	0	0	0	0	0	0	1	0	0	0	0	4
-79000	0	0	0	0	0	0	0	0	0	0	0	3
-15500	0	0	0	0	0	0	0	0	0	0	0	3
-12000	0	0	0	0	0	0	1	0	0	0	0	4
-6500	1	1	1	0	0	0	1	0	0	0	0	21
-1500	1	1	0	0	0	1	0	0	0	0	0	20
-400	1	0	1	0	1	0	1	1	1	1	0	25
1500	0	1	1	0	0	0	0	0	0	0	0	21
6500	1	1	1	0	0	0	1	0	0	0	0	24
12000	0	0	0	0	0	0	0	0	0	0	0	3
16000	0	0	0	0	0	0	0	0	0	0	0	7
16000	0	0	0	0	0	0	0	0	0	0	0	2
25000	0	0	0	0	0	0	1	0	0	0	0	4
45000	0	0	0	0	0	0	0	0	0	0	0	3
51000	0	0	0	0	0	0	1	0	0	0	0	1
64000	1	0	0	0	0	0	0	0	0	0	0	4
65000	0	0	0	1	1	1	1	1	1	1	0	14
TOTAL (CONTINUED)	5	4	4	1	3	3	9	4	2	3	1	174

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE

FREQUENCY	15APR81	15MAY81	15JUL81	15AUG81	15SEP81	15OCT81	15JUN83	15JUL83	15AUG83	TOTAL
-450000	0	0	0	0	0	0	0	0	1	1
-255000	0	0	0	0	0	0	0	0	0	6
-253000	0	0	0	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	1	1	1	3
-100000	0	0	0	0	0	0	1	1	1	4
-79000	0	0	0	0	0	0	1	1	1	3
-15500	0	0	0	0	0	0	1	1	1	3
-12000	0	0	0	0	0	0	1	1	1	4
-6500	1	1	1	1	1	0	1	1	1	21
-1500	1	1	1	1	0	0	1	1	1	20
-400	0	1	1	1	1	1	1	1	1	25
1500	1	1	1	1	1	1	1	1	1	21
6500	1	1	1	1	1	1	1	1	1	24
12000	0	0	0	0	0	0	1	1	1	3
16000	0	0	0	0	0	0	0	0	0	7
18000	0	0	0	0	0	0	1	1	0	2
25000	0	0	0	0	0	0	1	1	1	4
45000	0	0	0	0	0	0	1	1	1	3
51000	0	0	0	0	0	0	0	0	0	1
64000	0	0	0	0	0	0	0	0	0	4
65000	0	1	1	1	1	0	1	1	1	14
TOTAL	4	6	6	6	5	3	15	15	15	174

F. Data availability for "mean minimum size at reproduction".

TABLE OF XLOCBCH BY DATE

XLOCBCH DATE

FREQUENCY	15SEP76	15APR77	15JUN77	15JUL77	15AUG77	15MAY80	15JUN80	15JUL80	15AUG80	15SEP80	TOTAL
-450000	0	0	0	0	0	0	0	0	0	0	1
-255000	0	0	0	0	0	1	1	1	1	0	5
-253000	0	0	0	0	0	0	0	0	1	0	1
-115000	0	0	0	0	0	0	0	0	0	0	2
-100000	0	0	0	0	0	0	0	1	0	0	4
-79000	0	0	0	0	0	0	0	0	0	0	1
-15500	0	0	0	0	0	0	0	0	0	0	1
-12000	0	0	0	0	0	0	0	1	0	0	3
-6500	0	0	1	1	1	0	0	1	0	0	11
-1500	0	0	1	1	1	0	1	0	0	0	8
-400	1	0	1	1	1	0	0	1	1	1	13
1500	1	0	1	1	1	0	0	0	0	0	11
6500	0	1	1	1	1	0	0	0	0	0	11
12000	0	0	0	0	0	0	0	0	0	0	2
16000	0	0	0	0	0	0	0	0	0	0	2
25000	0	0	0	0	0	0	0	1	0	0	4
45000	0	0	0	0	0	0	0	0	0	0	3
51000	0	0	0	0	0	0	0	1	0	0	1
65000	0	0	0	1	1	1	1	1	1	1	14
TOTAL	2	1	5	6	6	2	3	8	4	2	96

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH DATE

FREQUENCY	15OCT80	15APR81	15MAY81	15JUL81	15AUG81	15SEP81	15JUN83	15JUL83	15AUG83	TOTAL
-450000	0	0	0	0	0	0	0	0	1	1
-255000	1	0	0	0	0	0	0	0	0	5
-253000	0	0	0	0	0	0	0	0	0	1
-115000	0	0	0	0	0	0	1	1	0	2
-100000	0	0	0	0	0	0	1	1	1	4
-79000	0	0	0	0	0	0	0	1	0	1
-15500	0	0	0	0	0	0	0	0	1	1
-12000	0	0	0	0	0	0	0	1	1	3
-6500	0	0	1	1	1	1	1	1	1	11
-1500	0	0	0	1	1	0	0	1	1	8
-400	0	0	1	1	1	1	0	1	1	13
1500	0	1	1	1	1	1	0	1	1	11
6500	0	0	1	1	1	1	1	1	1	11
12000	0	0	0	0	0	0	0	1	1	2
18000	0	0	0	0	0	0	1	1	0	2
25000	0	0	0	0	0	0	1	1	1	4
45000	0	0	0	0	0	0	1	1	1	3
51000	0	0	0	0	0	0	0	0	0	1
65000	1	0	1	1	1	0	1	1	1	14
TOTAL	2	1	5	6	6	4	8	14	13	98

G. Data availability for molt increments of females.

FEMALE MOLT INCREMENTS

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE

FREQUENCY	15SEP76	15OCT76	15APR77	15MAY77	15JUN77	15JUL77	15AUG77	TOTAL
-6500	1	1	0	1	1	1	1	10
-1500	1	0	1	1	1	1	1	10
-400	1	1	1	1	1	1	1	9
1500	1	0	1	1	1	1	1	10
6500	1	1	1	1	1	1	1	12
16000	0	0	1	1	1	1	1	5
65000	0	0	0	0	1	1	1	3
TOTAL	5	3	5	6	7	7	7	59

(CONTINUED)

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE

FREQUENCY	15OCT77	15NOV77	15DEC77	15JAN78	15FEB78	15MAR78	TOTAL
-6500	1	1	0	1	0	1	10
-1500	1	1	1	1	0	0	10
-400	1	0	0	1	0	0	9
1500	1	1	0	0	1	1	10
6500	1	1	1	0	1	1	12
16000	0	0	0	0	0	0	5
65000	0	0	0	0	0	0	3
TOTAL	5	4	2	3	2	3	59

H. Data availability for molt increments of males.

MALE MOLT INCREMENTS

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION (METERS))   DATE

FREQUENCY	15SEP76	15OCT76	15APR77	15MAY77	15JUN77	15JUL77	15AUG77	15OCT77	15NOV77	15DEC77	15FEB78	15MAR78	TOTAL
-6500	1	1	0	1	1	1	1	1	1	0	0	0	8
-1500	1	0	0	1	0	1	1	1	1	1	0	0	7
-400	1	1	1	1	1	1	1	1	0	0	0	1	9
1500	1	1	1	1	1	1	1	1	1	0	0	0	9
6500	1	1	1	1	1	1	1	0	1	1	1	0	10
16000	0	0	1	1	1	1	1	0	0	0	0	0	5
65000	0	0	0	0	1	1	1	0	0	0	0	0	3
TOTAL	5	4	4	6	6	7	7	4	4	2	1	1	51

I. Data availability for "fraction partially spent".

FRACTION PARTIALLY SPENT

TABLE OF XLOCBCH BY DATE

XLOCBCH(LONGSHORE LOCATION OF BEACH)
DATE(DATE SAMPLING BEGAN)

FREQUENCY	15AUG83	15AUG86	TOTAL
500	0	1	1
1500	0	1	1
2500	0	1	1
3500	0	1	1
4500	0	1	1
5500	0	1	1
6500	1	1	2
7500	0	1	1
8500	0	1	1
9500	0	1	1
10500	0	1	1
12000	1	0	1
18000	1	0	1
25000	1	0	1
45000	1	1	2
65000	1	1	2

FREQUENCY	15AUG83	15AUG86	TOTAL
-450000	1	0	1
-115000	1	0	1
-100000	1	0	1
-17500	0	1	1
-14000	0	1	1
-12500	0	1	1
-12000	1	0	1
-11500	0	1	1
-10500	0	1	1
-8500	0	1	1
-7500	0	1	1
-6500	1	1	2
-5500	0	1	1
-4500	0	1	1
-1500	0	1	1
-400	1	1	2
0	0	1	1
TOTAL	12	26	38

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APPENDIX B: METALS AND RADIONUCLIDES IN SAND CRAB TISSUE AND BEACH SEDIMENTS

B.1. Introduction

The possibility that SONGS might be releasing toxic metals or radionuclides in sufficient quantities to affect sand crabs was raised by Dr. Adrian Wenner, the MRC's contractor for sand crab studies during 1980 and 1981 (see Siegel and Wenner 1984). In this appendix we examine data on metals collected as part of MRC-funded sand crab programs during 1983 and data on metals and radionuclides collected during 1986. Our objectives are to determine (1) whether metal or radionuclide levels in sand crab tissues or beach sediments are higher in the vicinity of SONGS, (2) whether SONGS is responsible for any higher concentrations, and (3) whether elevated levels are sufficient to cause substantial and adverse effects on sand crabs.

Beach sediments and sand crab tissue from the beaches sampled during the 1983 study were analyzed for the concentrations of eight metals. Sand crab tissue collected during the 1986 study was only analyzed for concentrations of chromium, manganese, and iron, since preliminary analyses prior to the 1986 study provided some evidence for higher concentrations of these metals in sand crab tissues near SONGS during 1983. Sand crab tissue collected in 1986 was also analyzed for radionuclide activity.

B.2. Methods

Detailed field and laboratory protocols are described in a number of documents, including reports by contractors, work statements, and memos. Copies of the most important sections of these documents are included in Appendix H. This detailed material is not included here. Instead a general description of how samples were collected and processed is given. The purpose of this section is to provide the reader with a basic understanding of the structure of the data. In addition, details of the statistical and quantitative methods applied to the data are provided in this section.

B.2.1 Laboratory and field methods

Sediment metal concentrations during 1983

During 1983, sand crabs were collected at 15 or 16 beaches by Marine Ecological Consultants (MEC) during June, July and August. Sediment samples were collected during the last two surveys, and kept frozen for later analysis of metal concentrations. Sediment samples from each beach were collected by taking three cores with plastic specimen cups. Concentrations from the three samples are averaged prior to statistical analysis. Thus, our data consist of the average concentrations of each metal at each beach for the July and August surveys.

The stored samples were coded and sent by MEC to Science Applications International Corporation (SAIC) for a "blind" analysis of metal concentrations, and results are reported here on a dry weight (following dissection) basis. Analysis was done for the following eight metals: cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn).

Tissue metal concentrations during 1983

In addition to sediment samples, female sand crabs were collected, frozen, and later analyzed for metal concentrations for the July and August surveys (no metal analyses were done for crabs collected on the June survey). For both surveys the sand crabs used in the metal analyses were collected in an opportunistic fashion by shoveling, rather than as part of the quantitative sampling. For July, the sand crabs were sieved through the full set of sieves used to categorize sand crabs by size in the quantitative samples (see Barnett and Green 1984). For August, only a subset of the sieves was used, and thus the size categories were broader. This causes some problems because the crabs comprising some of these August samples analyzed for metals overlap two size categories used in July. To permit greater comparability between months, we defined three size classes broad enough so that overlapping categories were rare (8-10 mm, 10-14 mm, and >14 mm). Samples that still overlapped two of these broader size classes were excluded from analyses. Sand crabs were also categorized as "with eggs" or "without eggs". As described below, preliminary analyses were used to further reduce the number of size categories used in the analyses.

When sufficient material was available, replicate samples (containing a minimum of about 1.5 g wet weight after dissection) were analyzed for metal content. Some replicates are collections from single sand crab patches at a given beach, while others are combinations of collections from more than one patch when sufficient material was not available from a single patch. We averaged the concentrations over any replicate samples at a beach prior to our statistical analyses. Thus, for each category of crab and survey, our data consist of the mean concentration of each metal for each beach.

Stored samples were again delivered to SAIC, and a blind analysis was done for the same eight metals as analyzed for the sediments.

Tissue metal concentrations during 1986

During 1986, a single sand crab survey was done during August. Some sand crabs collected during this survey were frozen for metal analysis and delivered to SAIC.

Only reproductive female sand crabs in the 10-13 mm size class were analyzed for metals. Samples were composed of ten individuals, five from the "normal" category, and five from the "abnormal" category. Crabs with clutches of eggs that appeared, when examined by eye, to have more than 25% ruptured (spent) egg cases were classified as "abnormal".

SAIC provided analyses for Cr, Mn and Fe, and the results are reported on a dry weight basis. The data set from the original analysis had anomalously low values for two beaches (11.5 K North and 6.5 K South), and these values were replaced with values from subsequent assays of metal concentrations as described below. All these assays used sand crabs from the same set of samples and collected during the same survey. In order to check the reliability of the two anomalous samples, a second sample from these two beaches was analyzed, and compared with the first set of results. Then a third set of samples from these two beaches as well as second samples from three other beaches were subsequently analyzed. Data from the second and third analyses for the two originally anomalous beaches matched well, but differed from the original values, while data for the first and second analyses for the other beaches also matched up well. Consequently, the average of the second and third analyses replaces the original results for the two anomalous beaches, with the original values kept in all other cases.

Radionuclide activity in tissue during 1986

Sand crabs collected during August (see Methods) that were not used in the metal analyses, were stored in 10% formalin, and available for radionuclide analyses. A large amount of biomass was required for these analyses (a minimum of 100 g wet weight, or approximately 200 10-13 mm sand crabs). Thus, bulk samples were analyzed for each beach, with no breakdown by reproductive category within the two size classes (10-13 mm and >13 mm). Even with this pooling, there was insufficient biomass of the larger size class for analyses at a number of beaches.

A second set of samples was analyzed to examine potential relationships between reproductive status and radionuclide activity levels. Sand crabs were pooled from two (>13 mm: 7.5 K South and 6.5 K South) or three (10-13 mm: 7.5 K South, 5.5 K South, and 4.5 K South) sites, and then separated into four reproductive categories for each of the two size classes (normal = masses of intact orange or burnt orange eggs; abnormal = masses of orange or burnt orange eggs with greater than 15% of the egg cases ruptured; spent = virtually all egg cases on the pleopods ruptured; and clean = no eggs or ruptured egg cases on the pleopods). The crabs used were from beaches relatively close to SONGS (and therefore likely to show some activity). The particular beaches used were chosen from among the candidate beaches because sufficient biomass in each reproductive category was available in the samples from these beaches. These samples were analyzed by Thermo Analytical Inc., under contract to SCE, using the same standard methods as in SCE's analyses, contained in reports to the NRC. The MRC coded the samples prior to sending them for analysis, so the analyses were done blind.

B.2.2 Statistical and quantitative methods

Calculation of mean metal concentrations on each beach

In some cases, more than a single sample was analyzed for metal content for a given category of crabs from a given beach on an individual survey. We then averaged these values before doing the statistical analyses. This straightforward averaging procedure was complicated by several aspects of the data. In some cases, metal concentrations for a sample were reported as below detection limits, rather than equal to a particular value. Before averaging, these values were set equal to zero. This procedure tends to exaggerate differences between beaches with high and low concentrations. An alternative, setting these values equal to the detection limits, would tend to minimize differences among beaches. Preliminary analyses indicated that these two alternative procedures lead to similar conclusions.

The data available for statistical analysis of tissue metal concentrations from 1983 consisted of only three sets: sand crabs with no eggs for both July and August (all size classes pooled together), and sand crabs with eggs in the 10-14 mm category for August only. We began with six categories of crabs (three sizes x two reproductive categories) for each month, but generally several of these categories were missing from a given beach. As a result, sample sizes for many of the categories were small, and analyses were impossible or of very low power. Two solutions present themselves. First, we might use all the data in a single analysis. However, standard (univariate) ANCOVA and ANOVA procedures (with size and reproductive class as effects) are inappropriate given the multivariate structure of the data. Unfortunately, available multivariate, repeated-measures methods can only accommodate data for which no categories are missing. Alternatively, we could pool over categories, and analyze the new categories separately. This is the pool over categories, and analyze the new categories separately. This is the approach we adopted. To choose categories to pool over, we compared metal concentrations in adjacent size classes within a reproductive category and reproductive categories within a size class using paired t-tests. Our intention here was to decide on categories based upon overall patterns in the results, and we are less concerned with whether an individual test is statistically significant; we therefore do not adjust significance levels to take into account that some data are used in more than one test. Metal concentrations between size classes within the reproductive category "No eggs" did not differ significantly in almost all comparisons, while size classes within the category "With eggs" did differ in a number of cases; the two reproductive categories also sometimes differed from one another within a size class (Attachment 2). Therefore, we pooled all sizes to obtain the "No eggs" category. An examination of the comparisons of the means for all metals suggested that concentrations tended to be higher in crabs with eggs than in crabs without eggs, and that within the "With eggs" category, larger crabs tended to have higher concentrations of metals. We only had data from a sufficient number of beaches (more than three) to analyze the 10-14 mm size class during August, for the "With eggs" reproductive class.

Location effects

An indication that levels of metals or radionuclide activity are higher at beaches nearer SONGS is considered a "location effect". We use two statistical tests for such location effects. First, we compare the mean value at beaches 6.5 km or closer to SONGS (Near beaches) with that at beaches farther than 6.5 km from SONGS (Far beaches) using a t-test. Second, we regress concentration or activity level against distance from SONGS for those beaches within 20 km of SONGS (SONGS beaches). In all these analyses, concentrations and activity levels are log transformed. Prior to transformation, a constant equal to 1/6 the minimum nonzero value recorded for the data used in the analysis, is added. We excluded data from Cabrillo beach (at L. A. Harbor) in our tests for location effects on the grounds that this site was likely to have high metals levels (Final Technical Report E) and might obscure spatial patterns near SONGS. Additional detail on our general procedures for tests of location effects, can be found in the main text of this report. The data used in these analyses are presented in Attachment 1.

We use log transformations here because, if SONGS is the most significant source of metals in the local area, we expect that metal concentrations will decline approximately as an exponential function of distance from SONGS. This corresponds roughly with the predictions of an oceanographic model (incorporating diffusion and current processes) regarding the concentration of SONGS' effluents (Final Technical Report L). It is worth noting that the oceanographic model is for a hypothetical marker that remains in solution forever, and we feel that use of the less formalized and more flexible, exponential assumption is more appropriate for evaluating metal concentrations in sand crabs. Given the prevailing currents, the oceanographic model predicts a maximum concentration of effluents approximately 2 km downcoast from SONGS. (Because the model makes long-term predictions, we do not believe that it is appropriate to use this model to make quantitative predictions regarding how spatial patterns should change through time.) Consequently, as an ancillary analysis, we also regressed log transformed concentrations against distance from a point located 2 km downcoast from SONGS. These ancillary analyses do not change any of the qualitative conclusions reported here, and are included in Appendix F to the main text of this report.

Metal concentrations are also plotted versus their longshore location. Only Cr, Fe, and Mn, are presented graphically, because they were of special interest, and were the only metals assayed in both 1983 and 1986.

Other regressions

In several places we regress concentration or activity level of one substance against that of another, or against its own concentration in a different set of samples. In these regressions the data were log transformed as described above.

In general, we consider the tissue concentration of metals to be a biological, or dependent variable. Thus, we attempt to explain variation in these concentrations through multiple regression against physical chemical variables (including metal concentrations in sediments) in Appendix C. Because early analyses indicated a strong correlation between the "fraction spent" (see main text) and the tissue concentration of chromium, correlations between biological variables (see main text) and chromium concentration in tissues are also examined in detail here. (For completeness we also include similar analyses using tissue manganese and iron in the tables.) We caution, however, that although the tissue concentrations of metals in mussels are reliable indicators of the environmental concentrations of many metals (Goldberg *et al.* 1978), several of our results (below) indicate that this may not be true for sand crabs.

B.3. Results

B.3.1. Sediment metal concentrations during 1983

Concentrations in beach sediments were estimated for eight metals during July and August. There was no indication that metal concentrations were higher near SONGS than at beaches farther away. (This is also true if we "normalize" metal concentrations by dividing them by either iron concentration or the fraction of the sediment sample that was fine grained (i.e. silt or clay), but only the unnormalized results are presented.) The only significant difference between beaches 6.5 km or closer to SONGS and beaches farther away was for chromium during August, and in this case chromium had a *lower* concentration at Near beaches (Table B-1). In no case was there a significant relationship between metal concentration and distance from SONGS among beaches within 20 km of the plant; if anything there was a tendency for metal concentrations to increase away from the plant, as indicated by a preponderance of positive (but nonsignificant) correlations (Table B-2). Although power to detect effects varied among the tests, there were several cases where power was quite high yet no location effect was detected (Tables B-1 and B-2). In no case was there evidence for a "spike" in concentrations at beaches most proximate to SONGS that might escape detection by the statistical procedures (Figs. B-1, B-2, and B-3; Attachment 1: Tables BA1-1, and BA1-2).

The most obvious patterns in the data were unrelated to proximity to SONGS. For every metal, during both months, the concentration in sediments from Cabrillo Beach (L.A. Harbor, 79 km North of SONGS) was much higher than at any other beach (Attachment 1: Tables BA1-1, and BA1-2). In both months and for every metal there was a negative correlation between metal concentration and distance downcoast (south) from Cabrillo Beach (Table B-3). For five metals, these correlations were statistically significant in both months, while for the other three metals (Cr, Ni, and Pb) the correlations were not significant in either month (Table B-3). In some cases the negative correlations appear to be entirely the product of high values at Cabrillo Beach. For example, it is clear that the negative correlation for chromium is due, in both months, to the very high values at Cabrillo Beach (Fig. B-1). In other cases, such as iron and manganese, the trend for metal concentrations to decline from north to south appears evident among other beaches as well (Figs. B-2 & B-3).

B.3.2. Tissue metal concentrations during 1983

Sand crab tissues were analyzed for concentrations of the same eight metals as in the sediments. Sufficient samples (see Methods) were collected to allow tests for location effects on female sand crabs without eggs during both July and August, and for 10-14 mm sand crabs with eggs during August. Out of the 24 comparisons of Near and Far beaches, only the "August No eggs" comparison indicated a significantly higher concentration at the Near beaches, this occurring for Mn (Table B-4). Although power varied substantially among the individual tests, reasonably high power (0.7 to 1.0) was obtained in 10 of 24 cases (Table B-4). Among beaches within 20 km of SONGS, there was no general tendency for metal concentration to be negatively correlated with distance from SONGS, and none of the 22 cases tested produced a significant relationship between metal concentrations and proximity to SONGS (Table B-5; Figs. B-4 through B-7). Although power varied substantially among the individual tests, reasonably high power (0.7 to 1.0) was obtained in 9 of 22 cases (Table B-5).

For the "10-14 mm With eggs" category during August there were only four observations within 20 km of SONGS and power to detect significant relationships was sometimes low (Table B-5). Particularly high chromium and iron concentrations occurred at 0.4 K North (Fig. B-7) in these data. Note that the chromium concentration at this beach was over three fold higher than at any other beach for this category of crabs (Attachment 1, Table BA1-5). A higher mean value occurred one other time in the chromium data. This was during the same survey, in the crabs without eggs, at a beach 12 km north of the plant (Attachment 1, Table BA1-4).

Sand crabs from north of Los Angeles to within 20 km of SONGS were not analyzed for metal concentrations except for sand crabs without eggs during August. Consequently, an analysis of a north - south gradient starting at Cabrillo beach and extending to La Jolla in tissue metals was only done for this category. There was a significant trend for copper concentration to decline with increasing distance to the south of Cabrillo beach for the "no eggs" category during August (Table B-6). Five of seven correlations for other metals also had negative values, but none of these were close to significant (Table B-6). The metal concentrations seen at Cabrillo beach were generally in the middle of the range seen at other beaches, and the concentration of chromium was on the low side (Attachment 1, Table BA1-4). The contrast between the strong north - south trends in sediments (Table B-3) and weak or no trends for most metals in the tissues (Table B-6) suggests that tissue metal concentrations in sand crabs might not be tightly related to metal concentrations in the sediments (see below).

B.3.3. Tissue metal vs. sediment metal concentrations during 1983

One might generally expect a positive relationship between metal concentration in tissues and metal concentrations in the sediments. These relationships were weak, however, with only 15 of the 24 analyses indicating a positive association (Table B-7). Only two relationships were significant and positive (copper for "August, With eggs 10-14 mm" and manganese for "July, No eggs"). There was one significant negative relationship (cadmium for "July, No eggs"). The positive relationships for the log-log regressions generally had slopes less than one, indicating that metal concentrations in tissues changed less than in a directly proportionate response (direct proportionality would yield a slope of unity in a log-log regression) to changes in sediment metal concentrations (Table B-7). This suggests that the sediments are not the principal source of metals accumulated in sand crab tissues, or that variation among beaches in the current concentrations of metals in the tissues depends primarily upon other factors (e.g. physiological condition) besides current ambient metal concentrations in the environment. Further possible explanations for the lack of a tight relationship include longshore migration of sand crabs, or that tissue concentrations reflect environmental concentrations averaged over some time period in the past.

We examined residuals from the tissue - sediment relationships to determine whether metal concentrations in tissues were unexpectedly high, given the sediment concentrations, at the beaches adjacent to SONGS. In general, there were few large residuals (defined as studentized residuals [a residual divided by the standard deviation of the residuals] with absolute values greater than 2). Information on large residuals at beaches 6.5 km or closer to SONGS is included in Table B-7. In most cases there were no large residuals, and there was never more than one from beaches in the Near zone. Large residuals did not cluster at the beaches most adjacent to SONGS, and were more common 6.5 km from the plant than at 0.4 K North. The large positive residual at 0.4 K North for chromium during August for the "10-14 mm With eggs" category is worth noting, since this shows that the especially high chromium concentration seen at that beach cannot be explained merely by a high sediment concentration.

B.3.4. Tissue metal concentrations during 1986

During 1986, metal concentrations (Cr, Fe, and Mn) were evaluated in tissues of 10 - 13 mm females consisting of a mixture of reproductive states (Methods) during a single survey in August. For this survey, the mean chromium concentration at Near beaches was significantly higher than at Far beaches (Table B-8). In addition, chromium concentration declined significantly with increasing distance from SONGS among 24 beaches within 20 km of SONGS (Table B-8). Although metal concentrations were as high at some Far beaches as at the Near beaches (Attachment 1, Table BA1-6), the lack of "low concentration beaches" within a few kilometers of SONGS apparently causes the statistical significance (Fig. B-8).

Concentrations of the other two metals did not appear to be related to proximity to SONGS (Table B-8, Fig. B-8).

B.3.5. Radionuclide activity levels during 1986

Radioactivity was evaluated in tissues for only one survey (August), for two size classes (10-13 mm and >13 mm) composed of a mixture of reproductive categories of females collected at each beach (see Methods). In addition to analyzing samples from each beach separately, samples classified by reproductive category, but pooled over two or three beaches (in order to obtain sufficient material for analysis) were also analyzed (see Methods).

Of the isotopes that were assessed (Attachment 3), only three (^{40}K, ^{54}Mn, and ^{60}Co) had non-zero activity values at more than a single isolated beach. Activity levels of the non-naturally occurring isotopes (^{54}Mn and ^{60}Co) were generally very low (often zero) in the tissues of the larger size class of crabs (> 13 mm), and there was no evidence for a location effect on this size class (Table B-9, Figs. B-10 - B-11; Attachment 1: Table BA1-6).

Activity levels of ^{54}Mn and ^{60}Co were significantly higher in the 10-13 mm size class in comparison with the "greater than 13 mm" class at the same beaches (paired t-tests, $p < 0.001$). For the smaller size class (10-13 mm), the mean activities of both ^{60}Co and ^{54}Mn was higher at Near than at Far beaches. The difference was significant for ^{60}Co and not significant ($p = .14$) for ^{54}Mn (Table B-9). As power was quite low in both comparisons (Table B-9), it is encouraging that a location effect could be detected, since SONGS is the only known source for these radionuclides in the local area. For the 10-13 mm size class, activity also declined significantly (^{60}Co) and nearly significantly (^{54}Mn) with distance from the generating station (Figs. B-10 - B-11; Table B-9).

We now turn to the samples sorted by reproductive type. As stated above, these samples consisted of crabs pooled from several beaches (see Methods). For small crabs, the "abnormal" class (composed of females carrying clutches with some ruptured eggs) and the clean pleopods category (crabs with no egg cases) showed activity for both ^{54}Mn and ^{60}Co (Table B-10). The normal (carrying apparently intact clutches of eggs) and spent (carrying clutches where all eggs had either hatched or been ruptured) categories of crabs did not show any activity for either radionuclide (Table B-10).

In contrast, larger crabs (> 13 mm) showed no activity for the abnormal or spent categories for either radionuclide, and activity for the clean pleopod category was found only for ^{54}Mn (Table B-10). The "normal" category, however, which showed no activity for the smaller crabs, showed activity for both ^{54}Mn and ^{60}Co in these larger crabs (Table B-10).

These differences in the reproductive categories showing activity, between the two size categories of crabs, as well as the generally lower activity levels for the larger size class in the unsorted samples from each beach (above), are puzzling.

The generally lower activities seen in the larger crabs in the samples analyzed for each beach could be a consequence of activity levels specific to each reproductive category of crabs, in conjunction with the representation of each category at the beach. In principle, for example, low activity levels in the larger size of crabs could result if most large crabs fell into one of the categories that had low activity levels. This does not, however, appear to be the case. To test this idea we calculated an index of expected activity in the samples taken at each beach. Our index was calculated as the sum, over all reproductive categories (cross classified by size), of the expected activity level for that category times the proportion of the sample made up of that category. Thus, we would obtain a high value for a given isotope if a large fraction of the population were in a category that also tended to have high activity levels for that isotope. We use as our expected activity levels for each reproductive category x size category, the levels that were actually measured in the samples where analyses of activity were done separately by reproductive category (and by size). Our index is thus a weighted average, over reproductive classes, of the values seen in those sorted samples. We did separate calculations for each size class. In each case we calculated the proportion of the population in each of our four (normal, clean pleopods, spent, and abnormal) reproductive categories in the samples from each beach. In each case this was taken as the number of crabs in that category divided by the total number of crabs in all four categories for the sample taken at that beach.

Based on this procedure, our "expected activity" for ^{60}Co is significantly lower for small crabs in comparison with large crabs (paired t-test, $p<.001$), which is opposite of the actual observed activity difference. Also, for ^{54}Mn, our expected values were not significantly different between size classes (paired t-test, $p>.10$), which also differs from the significantly higher activity actually seen for the 10-13 mm crabs (above).

A second potential explanation for the higher activity levels seen in smaller crabs is that larger crabs might actively eliminate ^{54}Mn and ^{60}Co. A decline in the concentration of metals with increasing size of individuals is known to occur in other organisms, such as mussels (Boyden 1974 and 1977), and perhaps results from active elimination. This tendency should apply, however, to stable as well as unstable manganese, yet concentrations of stable manganese appear to be at as high, or higher concentrations in larger crabs as opposed to smaller ones (see Methods).

Another possible explanation is that larger crabs near SONGS have immigrated from elsewhere. Since large crabs are scarce near SONGS, it is clear that most crabs that survive the summer do not successfully overwinter in the local area. Perhaps the large crabs that are found, also did not overwinter near SONGS, and being new immigrants are newly exposed to the power plant generated isotopes.

B.3.6. Relationships among tissue metal and tissue radionuclide activity during 1986.

Because ^{54}Mn and ^{60}Co are released by SONGS and are unlikely to be present in the local environment from other sources, their levels in sand crab tissues can be regarded as an index of exposure to material that has passed through SONGS. Because we found a significant location effect for tissue levels of ^{60}Co, we consider this to be our primary "tracer". In this section we evaluate whether metal levels (Mn, Cr, and Fe) or ^{54}Mn activity are related to the activity observed for ^{60}Co. (We also examine the correlation between the concentration of Mn and the activity of the unstable isotope of that metal.) This is done only for the 10-13 mm size class because this is the only size of crabs for which metals were assayed in 1986. We examine these relationships because if ^{60}Co is a good index of exposure to water that has passed through SONGS, and if a substantial amount of the body burden of metals comes about because of chronic exposure to the same water, positive correlations should occur.

We expect, *a priori*, a strong positive correlation between the concentration of ^{54}Mn and the concentration of ^{60}Co, since they are released from the same source (SONGS). This is the case, with the activity of ^{60}Co explaining 63% of the variation in the activity of ^{54}Mn (Table B-11). The slope of almost exactly one for the log-log regression, indicates that the activity of ^{54}Mn changes proportionately with changes in the activity of ^{60}Co (Table B-11). In contrast, there is no significant relationship between the concentrations of Mn or Fe and ^{60}Co activity, or between Mn concentration and ^{54}Mn activity. There was a statistically significant and positive relationship between the concentration of Cr and ^{60}Co. The relationship is weak, however: the activity of ^{60}Co explained 20% of the variation in the concentration of Cr, and the slope of the log-log relationship was .12 (Table B-11). This low slope, substantially less than one, indicates that Cr concentration changed a disproportionately smaller amount in response to a change in activity of ^{60}Co.

B.3.7. Sand Crab Biology vs. Chromium Concentration in tissues

Correlations between the biological variables (the same ones as those analyzed in the main text of this report) and tissue concentrations of chromium are in Table B-12. Out of 11 analyses for July 1983, the only significant correlations were negative ones for the catch per unit effort of male sand crabs and the total catch per unit effort, both versus the concentration of chromium in female crabs without eggs (Table B-12a). There were 22 analyses for August 1983 because sufficient data on tissue chromium concentration in tissues were available for two categories of crabs. There were five significant correlations during August, but the results differed strongly depending upon whether the concentration of chromium was measured in crabs without eggs, or crabs with eggs (10-14 mm carapace length). The fraction of large females that were in the spent condition was *negatively* correlated with the chromium concentration in sand crabs with eggs (10-14 mm carapace length) while the fraction with eggs (fraction reproductive) was *positively* correlated with the concentration of chromium in this same category of crabs. These same biological variables were also significantly correlated with the concentration of chromium in sand crabs without eggs, but in this case the correlations both were in the opposite direction (Table B-12a).

In 1986, chromium concentration was assayed in a standard sample consisting of equal numbers of reproductive and "partially spent" female crabs from each beach. There were no significant correlations between the biological variables and tissue concentrations of chromium in this study (Table B-12b). It is worth noting that although all the correlations are positive, this fact has no general interpretation since positive correlations for different biological variables have qualitatively different biological interpretations (e.g. for catch per unit effort, more crabs are caught when chromium concentration is high, a "positive effect"; while for fraction spent this condition is more prevalent when chromium concentration is high, a "negative effect").

In tables B-12c, d, e, and f we present similar correlations for Mn, and Fe of biological variables against Mn, and Fe, the other two metals assayed in both 1986. As with Cr, the results are inconclusive. There are a number of significant correlations of biological variables and tissue concentration of Mn in crabs without eggs during 1983. Similar results are not seen for crabs with eggs, or in 1986.

B.4. Discussion

The data and analyses presented in this appendix have addressed whether metal or radionuclide levels in sand crab tissues or beach sediments are higher in the vicinity of SONGS. As a larger goal we also would like to know whether SONGS is responsible for any higher concentrations, and whether elevated levels are sufficient to cause substantial and adverse impacts.

There was no indication that metal concentrations were elevated in beach sediments near SONGS during 1983, and metal concentrations in beach sediments also did not explain much of the variation in metal concentrations in sand crab tissues. This indicates that sand crabs might be picking up metals from other sources, such as their food or water (e.g. Jenne and Luoma 1977, Bretelen *et al.* 1981, Willis and Sunda 1984), or perhaps the current tissue metal concentration is only weakly dependent on the current environmental metal concentration, and depends more upon other factors such as physiological condition (e.g. Frazier 1975, Harrison 1979), or conditions that crabs were exposed to elsewhere or at other times. We cannot distinguish among these possibilities.

There was some evidence that manganese, chromium, and iron occurred in higher concentrations, at least at some times, in sand crabs at beaches near SONGS. Evidence for higher chromium and iron levels in 1983 does not come from our statistical analyses, but instead from our examination of data on a beach by beach basis. The fact that higher levels were seen in only one of the two categories of crabs during the August 1983 survey (at 0.4 km north of SONGS) seems to argue against simply higher environmental availability explaining the patterns. In addition, there is no evidence that SONGS is a source of significant quantities of Mn (Final Technical Report E). It also seems unlikely that SONGS could be releasing sufficient iron into the ocean to elevate concentrations substantially in sand crab tissues. Iron rapidly becomes insoluble when released into the ocean, and ambient concentrations of insoluble iron are quite high (e.g. Bryan 1984). We therefore concentrate our attention on chromium, as the metal most likely to be released in quantities that could adversely affect sand crabs, and for which there is some evidence of higher levels near SONGS.

Outside of the occasionally higher values of chromium in the tissue data for beaches near SONGS, evidence supporting the hypothesis that SONGS is affecting sand crabs through the release of this metal, is not strong. Higher chromium concentrations could arise from sources other than SONGS, and chromium might be higher in some populations for reasons other than environmental availability. In addition, the empirical basis for concluding that tissue concentrations near SONGS are elevated over the background is not very strong. For these reasons we now consider the likelihood that SONGS could be releasing sufficient quantities of chromium to cause a substantial "elevation" in sand crab tissues near SONGS.

We first address the possibility that releases of chromium through SONGS' discharge could lead to a substantial and chronic increase in chromium concentration in sand crabs on the beaches. In principle, a record of plant releases of chromium could resolve the question, and SCE is required by their NPDES permit to measure the concentration of stable chromium in the major waste streams at SONGS. Unfortunately the available data on chromium concentrations in SONGS' effluents permits a wide range of possible release rates. Chromium concentrations are determined semi-annually by taking grab samples in the combined effluents of Units 2 and 3, the in-plant waste stream of Units 2 and 3, and the in-plant waste stream of Unit 1. The concentrations found in each of these samples are reported to the Water Quality Control Board as both the daily maximum and the six month median. The sensitivity of concentration measurements for chromium is generally reliable only to 0.01 mg/l, and this level often constitutes the lower detection limit for chromium. Since many measurements submitted by SCE are reported as at or below this detection limit, one "worst case" of mass emissions can be calculated based on a continuous release rate of 0.01 mg/l of chromium, assuming the flow volume of Units 1, 2 and 3 is 87% of their maximum. At this rate, 39.8 metric tons of chromium would be released by the plant per year. Since Dr. John Palmer (advisor to MRC member Dr. Mechalas) had previously estimated a release rate of only 0.28 MT per year, the MRC contracted with MHB Technical Associates (MHB), an engineering consulting company, to determine best estimates of chromium release based on engineering considerations.

MHB estimated based on the concentration in chromated systems, and leakage rates that chromium releases from SONGS would fall in the range of 2 - 8.5 metric tons per year (Final Technical Report E). Their minimum estimate is about eight times Dr. Palmer's estimate, and their maximum estimate is approximately one fifth the above "worst case".

MHB based their analysis on a number of stated assumptions, and presented their results with the caveat that their estimates would be altered if operating practices at SONGS deviated from these assumptions. Newly available information has shown that several of these assumptions were incorrect. Of importance was their erroneous assumption that the Turbine Plant Cooling Systems and Component Cooling Water Systems of Units 2 and 3 were chromated. Taking the new information into account, the lower and upper bounds on chromium release (based on MHB's analyses) become 0.3 to 1.1 MT per year (See Final Technical Report E). The results of the MHB study indicate that the "worst case" of almost 40 MT of chromium releases per year is unlikely to occur given the known operating procedures and characteristics of SONGS and similar nuclear generating stations. We accept MHB's estimates in the following discussion.

In our calculations below, we assume direct proportionality between metal concentrations in sand crabs and metal concentrations in the environment. Although body burdens of metals in marine invertebrates are usually higher than those seen in the environment (e.g. Watling and Watling 1983, Oshida and Word

1982, Capuzzo and Sasner 1977, Krenkel 1975, Vernberg *et al.* 1979), we have no reason to expect that increases in body burdens of chromium would appreciably exceed the *percentage* elevation of concentrations in the environment. Data on this topic are limited, but two laboratory studies found that body burden of hexavalent chromium in *Neanthes* (a marine polychaete) increased linearly with environmental concentration (Oshida 1976), and Bryan (1984) noted that body burdens of metals in mussels tend to increase, at most, linearly with environmental concentrations of metals. Thus for example, we assume that a doubling of metal concentrations (say from 0.001 to 0.002 mg per liter) in the environment (food or water) would lead to a doubling (say from 0.5 to 1 μg per g) in the tissues. Sand crabs might take up metals during filter-feeding on plankton, through contact of antennae with sediments, or through direct adsorption. Accumulation through contact with the sediments probably does not explain any of the "elevations" of tissue levels near SONGS, however, since we found no evidence that sediment concentrations were higher near SONGS.

We now consider whether the estimates of metal releases from SONGS could reasonably lead to substantially elevated concentrations of chromium in sand crabs near SONGS. Since sediment concentrations were not elevated near SONGS, we ask whether the release of chromium from the plant could increase the concentration of chromium in sea water impinging upon beaches sufficiently to produce significant increases in observed body burdens in sand crabs living near SONGS.

The best available evidence suggests that elevations in environmental concentrations of chromium are unlikely to be sufficient to explain the "elevations" seen in the tissues. Ambient concentrations of chromium in clean coastal waters are on the order of 0.2 μg/l (e.g. Bascom 1982, Moore and Ramamoorthy 1984). Based on the MHB's adjusted worst case, with an annual release of 1.1 MT of chromium by Unit 1 (and none from Units 2 and 3), maximum elevations in concentrations impinging on the most heavily impacted beaches would be on the order of 0.005 μg/l. This is based on estimates of the dilution of the SONGS plume, and the concentration of chromium in Unit 1's effluents. It is assumed that 0.3 percent of the water impinging on beaches near SONGS has passed through the cooling system of Unit 1, and that the concentration of chromium in effluents is approximately 1.6 μg/l. This latter concentration is calculated based on the assumption that 1.1 MT tons of chromium are released per year and that Unit 1 will pump approximately 6.8 x 10^{11} l of water per year when operating at maximum capacity. The dilution estimate is based on an approximation of 1.5% of the effluent waters from Units 2 and 3 reaching the beach when operating at full capacity (Final Technical Report L), taking into account the fact that Unit 1 only pumps one fifth the flow volume of Units 2 and 3 combined. The estimated increase in chromium concentration at nearby beaches represents a 2.5 percent increase over ambient concentrations in clean seawater. Since the assumed release rate is an upper bound based on the adjusted MHB estimate, this 2.5% figure might be a substantial *overestimate* of the actual elevation of chromium attributable to SONGS, at even the closest beaches. In order to produce a four-fold increase in concentrations (as was seen in one category of crabs on one survey at one beach), as a chronic condition, release rates would have to be about 160 times higher than our estimate (assuming direct proportionality between ambient and tissue concentrations). We can not completely exclude this possibility since chromium might enter SONGS' discharge through other pathways, such as the dumping of chromated paint residues in SONGS' waste streams. There is however, no evidence that this type of massive dumping activity occurs (see Final Technical Report E).

Releases of metals by SONGS probably occur episodically, such as when systems are flushed following shutdowns. Such episodic releases could lead to occasional high chromium values, but seem unlikely to explain the more persistent location effects in biological variables that we have seen. We cannot accurately estimate what quantity of chromium, released over what time period, would be required to produce a substantial increase in sand crab tissue chromium concentrations. The answer depends, in part, on the biological turnover rate of chromium in sand crab tissues and on short-term oceanographic events. However, for an episodic release to substantially increase chromium concentrations in sand crabs, very rapid uptake is required, and such releases, because they would be episodic, would likely have occasional (and hard to detect) biological effects.

Even if releases by SONGS were responsible for the observed "elevations" in chromium concentrations in sand crabs, there is no direct evidence that the observed concentrations are sufficient to produce adverse effects. Chromium has been observed to reduce hatching rate of eggs in a different species of crab (MacDonald *et al.* 1988), although the concentrations used in this study were higher than could reasonably occur at beaches near SONGS, and the concentration of chromium within the developing eggs was not measured in that laboratory study. One of the few studies evaluating both sublethal effects and tissue burden of chromium is Oshida and Word's (1982) study of the polychaete *Neanthes arenaceodentata*. Since sand crabs are virtually unrelated taxonomically to polychaetes, we would not expect results for one species to necessarily carry over to the other. Nevertheless, such comparisons can provide some insight, and are appropriate, when data for more closely related species are unavailable. At least in this case, both species are marine invertebrates.

The maximum chromium concentrations in sand crabs were only about one ninth the levels found to produce sublethal effects in this polychaete. (This comparison required a conversion of sand crab data expressed on a dry weight basis to a wet weight basis. The conversion factor was 0.2 based on wet and dry weight determinations for the same sand crab samples.) In addition, while Oshida and Word used the toxic, hexavalent form of chromium, which is water soluble, the filter-feeding sand crab is likely to take up at least some of its chromium in the insoluble, and relatively innocuous, trivalent form through its food (see Bernhard *et al.* 1986). Further evidence that the observed chromium concentrations are not causing substantial effects in sand crabs, is that there is not a clear-cut pattern among correlations between sand crab biology and chromium concentrations in tissues.

Finally, we turn to the question of radiation. In contrast with stable metals, there is little question that SONGS is responsible for ^{60}Co and ^{54}Mn activity in sand crabs. The occurrence of this activity is not especially surprising, since higher activity levels have been reported in lobsters and other invertebrates caught in the vicinity of SONGS, in SCE's Annual Radiological Environmental Monitoring Reports to the NRC (Final Technical Report E).

It is extremely doubtful whether the observed levels of activity could have any measurable effects on sand crabs (Final Technical Report E). Dr. Florence Harrison of the Lawrence Livermore Laboratory engaged Dr. Dennis Woodhead's services to estimate the radiation dose rate attributable to ^{60}Co in sand crab tissues. The calculated dose rate is approximately 1.2×10^{-5} mrad/h. This was deemed to be within the natural range of variation from background radiation. This dose rate is also over one million times less than 21 mrad/h, the minimum dose rate ever shown to produce sublethal effects in marine invertebrates (unpublished data on nereid worms, Harrison *et al.*). In Harrison *et al.*'s study, the dose rate was continuously applied over the entire life history of the worm. It is also worth noting that most of the internal gamma radioactivity in sand crabs is due to ^{40}K, which is not linked to proximity to SONGS, and occurs naturally (Final Technical Report E).

Table B-1

T-tests comparing mean metal concentration (μg/g dry wt.) in sediments between Near (impact) versus Far (control) beaches during 1983. Metal concentrations were transformed using ln(x + 1/6 min). Tests were done including beaches 6.5 km or closer in the Near group (data from 79 km North [Cabrillo beach] was not included in the analyses). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration differs two-fold between Near and Far beaches.

		Near Beaches			Far Beaches						
Metal	Month	Mean	SE	N	Mean	SE	N	DF	T	P	Power
Cd	July	-4.87	0.096	5	-4.73	0.238	9	10.3	0.518	0.62	0.68
	August	-5.12	0.121	5	-4.68	0.132	10	13.0	2.07	0.059	0.87
Cr	July	-1.88	0.132	5	-1.50	0.14	9	12.0	1.76	0.10	0.84
	August	-2.51	0.138	5	-1.69	0.225	10	13.0	2.42	0.03*	0.48
Cu	July	-1.87	0.09	5	-1.69	0.121	9	12.0	1.03	0.32	0.95
	August	-1.92	0.084	5	-1.90	0.124	10	13.0	0.114	0.91	0.92
Fe	July	4.35	0.092	5	4.53	0.108	9	12.0	1.11	0.29	0.97
	August	4.5	0.357	5	4.49	0.119	10	4.9	-0.03	0.98	0.32
Mn	July	1.51	0.141	5	1.36	0.179	9	12.0	-0.587	0.57	0.67
	August	1.18	0.107	5	1.33	0.15	10	13.0	0.665	0.52	0.80
Ni	July	-0.486	0.061	5	-0.418	0.044	9	12.0	0.908	0.38	1.0
	August	-0.591	0.019	5	-0.50	0.062	10	10.5	1.4	0.19	1.0
Pb	July	-1.05	0.338	5	-0.849	0.312	9	12.0	0.423	0.68	0.25
	August	-1.25	0.295	5	-1.06	0.276	10	13.0	0.428	0.68	0.30
Zn	July	0.386	0.059	5	0.60	0.107	9	12.0	1.41	0.18	0.99
	August	0.301	0.059	5	0.61	0.107	10	12.7	2.49	0.03*	1.0

Table B-2

Pearson product-moment correlation coefficients of mean metal concentrations (μg/g dry wt.) in sediment versus distance from SONGS during 1983. Sites within 20 km of SONGS were used. Metal concentrations were transformed using ln(x + 1/6 min). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration changes by two-fold over a distance of 10 km.

METAL	MONTH	R	N	P	POWER
Cd	July	0.158	9	0.68	0.52
	August	0.597	9	0.09	0.69
Cr	July	0.337	9	0.38	0.99
	August	0.4	9	0.29	0.85
Cu	July	0.06	9	0.88	0.93
	August	0.039	9	0.92	0.96
Fe	July	0.313	9	0.41	0.98
	August	-0.298	9	0.44	0.42
Mn	July	0.083	9	0.83	0.72
	August	0.348	9	0.36	0.70
Ni	July	0.421	9	0.26	1.0
	August	0.220	9	0.57	1.0
Pb	July	-0.4	9	0.29	0.40
	August	-0.431	9	0.25	0.59
Zn	July	0.216	9	0.58	1.0
	August	0.331	9	0.39	1.0

Table B-3

Pearson product-moment correlation coefficients of mean metal concentrations (μg/g dry wt.) in sediment versus distance south of Cabrillo beach [L.A. Harbor] during 1983. Sites from 79 km north to 65 km south of SONGS were used. Metal concentrations were transformed using ln(x + 1/6 min). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration changes by two-fold over a distance of 10 km.

METAL	MONTH	R	N	P	POWER
Cd	July	-0.865	13	0.0001*	1.0
	August	-0.776	13	0.002*	1.0
Cr	July	-0.464	13	0.11	1.0
	August	-0.417	13	0.16	1.0
Cu	July	-0.764	13	0.002*	1.0
	August	-0.88	13	0.0001*	1.0
Fe	July	-0.783	13	0.001*	1.0
	August	-0.66	13	0.014*	1.0
Mn	July	-0.894	13	0.0001*	1.0
	August	-0.816	13	0.0007*	1.0
Ni	July	-0.488	13	0.09	1.0
	August	-0.519	13	0.07	1.0
Pb	July	-0.341	13	0.25	1.0
	August	-0.536	13	0.06	1.0
Zn	July	-0.697	13	0.008*	1.0
	August	-0.631	13	0.02*	1.0

Table B-4

T-tests comparing mean metal concentration (μg/g dry wt) in sand crab tissue between Near (impact) versus Far (control) beaches during 1983. Metal concentrations were transformed using ln(x + 1/6 min). Tests were done including beaches 6.5 km or closer in the Near group (79 km North [Cabrillo beach] was not included in the analyses). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration differs two-fold between Near and Far beaches.

			Near Beaches			Far Beaches						
Metal	Month	Type	Mean	SE	N	Mean	SE	N	DF	T	P	Power
Cd	July	no eggs	0.886	0.099	5	0.848	0.149	9	12	-0.175	0.86	0.84
	August	no eggs	0.779	0.190	4	0.729	0.151	7	9	-0.204	0.84	0.71
	August	eggs (10-14 mm)	0.644	0.201	2	1.08	0.276	6	6	0.857	0.42	0.21
Cr	July	no eggs	-0.767	0.174	5	-0.843	0.216	9	12	-0.237	0.82	0.51
	August	no eggs	0.268	0.329	4	-0.301	0.389	7	9	-0.986	0.35	0.19
	August	eggs (10-14mm)	0.319	1.18	2	-0.128	0.185	6	1.1	-0.376	0.77	0.05
Cu	July	no eggs	4.96	0.113	5	4.93	0.197	9	12	-0.109	0.92	0.62
	August	no eggs	5.36	0.06	4	5.20	0.152	7	7.7	-0.992	0.35	0.96
	August	eggs (10-14mm)	5.41	0.013	2	5.57	0.074	6	6	1.01	0.35	0.99
Fe	July	no eggs	5.31	0.181	5	4.92	0.106	9	12	-2.01	0.07	0.90
	August	no eggs	5.89	0.254	4	5.41	0.145	7	9	-1.77	0.11	0.63
	August	eggs (10-14mm)	6.13	0.562	2	5.71	0.239	6	6	-0.825	0.44	0.21
Mn	July	no eggs	3.74	0.13	5	3.58	0.148	9	12	-0.722	0.48	0.82
	August	no eggs	3.8	0.133	4	3.28	0.147	7	9	-2.35	0.04*	0.80
	August	eggs (10-14mm)	3.86	0.207	2	3.34	0.127	6	6	-1.29	0.25	0.30
Ni	July	no eggs	-0.595	0.726	5	-0.72	0.524	9	12	-0.142	0.89	0.11
	August	no eggs	-0.99	0.784	4	-0.487	0.647	7	9	0.482	0.64	0.09
	August	eggs (10-14mm)	-1.16	0	2	0.35	0.49	6	6	1.68	0.14	0.10
Pb	July	no eggs	-2.51	0.82	5	-2.24	0.627	9	12	0.266	0.80	0.09
	August	no eggs	-1.36	0.928	4	-1.76	0.747	7	9	-0.331	0.75	0.07
	August	eggs (10-14mm)	-3.04	0	2	-1.17	0.64	6	6	1.6	0.16	0.07
Zn	July	no eggs	4.66	0.076	5	4.58	0.031	9	12	-1.24	0.24	1.0
	August	no eggs	4.77	0.028	4	4.7	0.042	7	9	-1.18	0.27	1.0
	August	eggs (10-14mm)	4.84	0.012	2	4.79	0.045	6	6	-0.626	0.55	1.0

Table B-5

Pearson product-momnet correlation coefficients of metal concentration (μg/g dry wt.) in sand crab tissue versus distance from SONGS during 1983. Only beaches within 20 km of SONGS were used. -- indicates the metal was below detection limit at all sites. Metal concentrations were transformed using ln(x + 1/6 min). Power is calculated (α = 0.05) for the alternative hypothesis: concentration changes by two-fold over a distance of 10 km.

METAL	MONTH	CRAB TYPE	R	N	P	POWER
Cr	July	no eggs	0.19	9	0.62	0.55
	August	no eggs	0.19	6	0.71	0.11
	August	eggs(10-14mm)	-0.72	4	0.28	0.08
Mn	July	no eggs	0.13	9	0.74	0.92
	August	no eggs	-0.34	6	0.50	0.64
	August	eggs(10-14mm)	-0.21	4	0.79	0.15
Fe	July	no eggs	-0.42	9	0.26	0.78
	August	no eggs	-0.35	6	0.49	0.27
	August	eggs(10-14mm)	-0.92	4	0.08	0.31
Cd	July	no eggs	0.17	9	0.66	0.97
	August	no eggs	0.034	6	0.95	0.29
	August	eggs(10-14mm)	0.583	4	0.42	0.16
Cu	July	no eggs	-0.278	9	0.47	0.81
	August	no eggs	0.513	6	0.30	0.99
	August	eggs(10-14mm)	0.862	4	0.14	1.0
Ni	July	no eggs	-0.003	9	0.99	0.11
	August	no eggs	0.464	6	0.35	0.06
	August	eggs(10-14mm)	--	4	--	--
Pb	July	no eggs	-0.037	9	0.92	0.09
	August	no eggs	0.250	6	0.63	0.05
	August	eggs(10-14mm)	--	4	--	--
Zn	July	no eggs	-0.318	9	0.40	1.0
	August	no eggs	0.075	6	0.89	1.0
	August	eggs(10-14mm)	-0.77	4	0.23	1.0

Table B-6

Pearson product-moment correlation coefficients of metal concentration (μg/g dry wt.) in sand crab tissue ("no eggs" category) versus distance south of Cabrillo beach [L.A. Harbor, 79 km North] during August 1983. Metal concentrations were transformed using ln(x + 1/6 min.). * indicates a significant (p < 0.5) result.

METAL	R	N	P
Cd	-0.22	10	0.53
Cr	-0.29	10	0.42
Cu	-0.79	10	0.007*
Fe	-0.46	10	0.18
Mn	-0.46	10	0.18
Ni	0.34	10	0.34
Pb	0.15	10	0.68
Zn	-0.08	10	0.82

Table B-7

Regressions of mean metal concentration (µg/g dry wt.) in sand crab tissue versus metal concentration (µg/g dry wt.) in sediments during 1983. Metals were transformed using ln(x + 1/6 min). Sites with large studentized residuals (greater than 2) are tabulated ("+" = actual > predicted, "-" = predicted > actual). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: metal concentration in tissues is directly proportional to metal concentration in sediments.

METAL	MONTH	CRAB TYPE	SLOPE	R^2	LARGE RESIDUALS NEAR SONGS	N	P	POWER
Cd	July	no eggs	-0.42	0.60	–	12	0.003*	1.0
	August	no eggs	0.04	0.02	–	10	0.70	1.0
	August	eggs(10-14mm)	0.04	0.001	–	7	0.94	0.41
Cr	July	no eggs	-0.59	0.11	–	12	0.29	0.40
	August	no eggs	-0.39	0.24	–	10	0.15	0.95
	August	eggs(10-14mm)	-0.22	0.02	0.4KN(+)	7	0.79	0.18
Cu	July	no eggs	0.61	0.23	6.5KN(+)	12	0.11	0.72
	August	no eggs	0.23	0.36	–	10	0.06	1.0
	August	eggs(10-14mm)	0.54	0.77	–	7	0.009*	1.0
Fe	July	no eggs	0.63	0.20	–	12	0.15	0.62
	August	no eggs	0.10	0.04	1.5KN(+)	10	0.58	1.0
	August	eggs(10-14mm)	0.28	0.02	–	7	0.77	0.15
Mn	July	no eggs	0.67	0.79	6.5KS(-)	12	0.0001*	1.0
	August	no eggs	0.02	0.003	–	10	0.89	1.0
	August	eggs(10-14mm)	0.61	0.54	–	7	0.06	0.89
Ni	July	no eggs	1.58	0.02	–	12	0.69	0.04
	August	no eggs	-1.64	0.09	–	10	0.41	0.07
	August	eggs(10-14mm)	6.14	0.38	–	7	0.14	0.04
Pb	July	no eggs	-0.94	0.15	–	12	0.21	0.25
	August	no eggs	-0.71	0.14	–	10	0.29	0.29
	August	eggs(10-14mm)	2.30	0.27	–	7	0.23	0.07
Zn	July	no eggs	0.39	0.10	6.5KN(+)	12	0.33	0.67
	August	no eggs	-0.02	0.07	–	10	0.47	1.0
	August	eggs(10-14mm)	-0.005	0.0001	–	7	0.99	0.83

Table B-8

T-tests comparing mean metal concentration (μg/g dry wt.) in sand crab tissue (10 - 13 mm size range) between Near (impact) versus Far (control) beaches during 1986. Metals were transformed using ln(x + 1/6 min). Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration differs two-fold between Near and Far beaches.

	NEAR BEACHES			FAR BEACHES						
METAL	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
Cr	0.027	0.078	12	-0.283	0.085	14	24	-2.64	0.01*	1.0
Fe	6.14	0.099	12	6.03	0.139	14	24	-0.64	0.53	0.96
Mn	3.63	0.11	12	3.69	0.149	14	24	0.324	0.75	0.94

Pearson product-moment correlation coefficients of mean metal concentration (μg/g dry wt.) in sand crab tissue (10 - 13 mm size range) versus distance from SONGS during 1986. Only beaches within 20 km of SONGS were used. Metals were transformed using ln(x + 1/6 min). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: concentration changes by two-fold over a distance of 10 km.

METAL	R	N	P	POWER
Cr	-0.5	24	0.01*	1.0
Fe	0.06	24	0.80	0.87
Mn	0.28	24	0.19	0.93

Table B-9

T-tests comparing mean isotope activity levels (picocuries/g dry wt) in sand crab tissue between Near (impact) versus Far (control) beaches during August 1986. Activity levels were transformed using ln(x + 1/6 min). Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: activity level differs two-fold between Near and Far beaches.

		Near Beaches			Far Beaches						
	Size	Mean	SE	N	Mean	SE	N	DF	T	P	Power
^{40}K	10-13mm	1.15	0.057	13	1.04	0.064	13	24	-1.26	0.22	1.0
	> 13mm	1.25	0.113	4	1.01	0.128	9	11	-1.15	0.27	0.85
^{54}Mn	10-13mm	-4.2	0.41	13	-5.13	0.444	13	24	-1.53	0.14	0.20
	> 13mm	-5.3	0	4	-5.08	0.216	9	11	0.65	0.53	0.48
^{60}Co	10-13mm	-3.47	0.282	13	-4.62	0.344	13	24	-2.57	0.017*	0.32
	> 13 mm	-5.01	0	4	-4.54	0.314	9	11	0.979	0.35	0.26

Pearson product-moment correlation coefficients of mean isotope activity levels (picocuries/g dry wt) in sand crab tissue versus distance from SONGS during August 1986. Only beaches within 20 km of SONGS were used. Activity levels were transformed using ln(x + 1/6 min). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis activity level changes by two-fold over a distance of 10 km.

Isotope	Size	R	N	P	Power
^{40}K	10-13 mm	-0.13	24	0.54	1.0
	> 13 mm	-0.14	12	0.66	0.35
^{54}Mn	10-13 mm	-0.40	24	0.052	0.17
	> 13 mm	0.28	12	0.38	0.18
^{60}Co	10-13 mm	-0.63	24	0.001*	0.34
	> 13 mm	0.18	12	0.57	0.10

Table B-10

Radionuclide activity (picocuries/g dry wt.) levels in samples of sand crabs sorted by reproductive category for the August 1986 survey. Results are given only for ^{54}Mn and ^{60}Co since these are the radionuclides released by SONGS that had more than one non-zero value.

10-13 mm Crabs

Radionuclide	Normal	Abnormal	Spent	Clean Pleopods
^{60}Co	0	0.04	0	0.04
^{54}Mn	0	0.07	0	0.05

> 13 mm Crabs

Radionuclide	Normal	Abnormal	Spent	Clean Pleopods
^{60}Co	0.04	0	0	0
^{54}Mn	0.03	0	0	0.06

Table B-11

Regressions between metal concentrations (μg/g dry wt.) and isotope activity level (picocuries/g dry wt.) in sand crab tissue (10-13 mm size range) during August 1986. Metal levels and activity levels were transformed using ln(x + 1/6 min). * indicates a significant ($p < 0.05$) result. Power is calculated ($\alpha = 0.05$) for the alternative hypothesis: the dependent variable is directly proportional (slope = 1) to the independent variable.

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	SLOPE	R^2	N	P	POWER
^{54}Mn	^{60}Co	0.996	0.625	26	0.0001*	1.0
Mn	^{60}Co	-0.012	0.001	25	0.88	1.0
Fe	^{60}Co	0.009	0.0007	25	0.90	1.0
Cr	^{60}Co	0.119	0.198	25	0.03*	1.0
Mn	^{54}Mn	-0.033	0.011	25	0.62	1.0

Table B-12a

Pearson product-moment correlation coefficients of the biological variables versus chromium concentration ($\mu g/g$ dry wt.) in sand crab tissue during 1983. Metals were transformed using ln(x + 1/6 min).

DEPENDENT VARIABLE	JULY WITHOUT EGGS			AUGUST WITHOUT EGGS			AUGUST 10-14 MM WITH EGGS		
	R	N	P	R	N	P	R	N	P
Female catch per unit effort	-0.53	14	0.053	-0.34	12	0.28	-0.13	8	0.77
Male catch per unit effort	-0.56	14	0.04*	-0.14	12	0.67	0.44	8	0.27
Total catch per unit effort	-0.58	14	0.03*	-0.23	12	0.47	0.57	8	0.14
Medium-large fraction reproductive	-0.20	13	0.52	-0.43	11	0.19	0.28	8	0.51
Large fraction reproductive	-0.52	10	0.12	-0.70	9	0.04*	0.92	6	0.008*
Medium-small fraction spent	0.18	14	0.53	0.55	11	0.08	0.72	7	0.07
Medium-large fraction spent	0.17	13	0.59	0.71	11	0.02*	0.10	8	0.82
Large fraction spent	0.25	10	0.49	0.74	9	0.02*	-0.95	6	0.004*
Mean maximum male size	-0.41	14	0.14	-0.15	12	0.63	-0.60	8	0.12
Mean maximum female size	-0.52	14	0.058	-0.07	12	0.82	-0.38	8	0.36
Minimum size of reproduction	0.24	12	0.45	-0.07	11	0.84	-0.34	8	0.41

Table B-12b

Pearson product-moment correlation coefficients of the biological variables versus chromium concentration (µg/g dry wt.) in sand crab tissue (10 - 13 mm size range) during August 1986. Metals were transformed using ln(x + 1/6 min).

Dependent Variable	R	N	P
Medium-Large Catch per Unit Effort	0.18	23	0.41
Large Catch per Unit Effort	0.38	17	0.14
Medium-Large Fraction Reproductive	0.09	23	0.69
Large Fraction Reproductive	0.31	17	0.22
Medium-Large Fraction Spent	0.13	23	0.55
Large Fraction Spent	0.27	17	0.29
Medium-Large Fraction Partially Spent	0.37	23	0.08
Large Fraction Partially Spent	0.44	17	0.08

Table B-12c

Pearson product-moment correlation coefficients of the biological variables versus manganese concentration (μg/g dry wt.) in sand crab tissue during 1983. Metals were transformed using ln(x + 1/6 min).

DEPENDENT VARIABLE	JULY WITHOUT EGGS			AUGUST WITHOUT EGGS			AUGUST 10-14 MM WITH EGGS		
	R	N	P	R	N	P	R	N	P
Female catch per unit effort	-0.67	14	0.009*	-0.51	12	0.09*	-0.60	8	0.12
Male catch per unit effort	-0.50	14	0.07*	0.15	12	0.63	-0.01	8	0.99
Total catch per unit effort	-0.52	14	0.054*	0.07	12	0.83	0.11	8	0.80
Medium-large fraction reproductive	-0.17	13	0.57	-0.45	11	0.16	-0.02	8	0.96
Large fraction reproductive	0.07	10	0.85	-0.84	9	0.005*	-0.26	6	0.62
Medium-small fraction spent	0.27	14	0.35	0.67	11	0.02*	0.52	7	0.24
Medium-large fraction spent	0.64	13	0.02*	0.84	11	0.001*	0.29	8	0.49
Large fraction spent	0.22	10	0.55	0.80	9	0.009*	0.19	6	0.71
Mean maximum male size	0.08	14	0.77	-0.42	12	0.17	-0.44	8	0.28
Mean maximum female size	-0.51	14	0.06*	-0.55	12	0.07*	-0.84	8	0.01*
Minimum size of reproduction	-0.30	12	0.35	0.18	11	0.60	0.36	8	0.38

Table B-12d

Pearson product-moment correlation coefficients of the biological variables versus manganese concentration (μg/g dry wt.) in sand crab tissue (10 - 13 mm size range) during August 1986. Metals were transformed using ln(x + 1/6 min).

DEPENDENT VARIABLE	R	N	P
MEDIUM-LARGE CATCH PER UNIT EFFORT	0.05	23	0.80
LARGE CATCH PER UNIT EFFORT	0.08	17	0.77
MEDIUM-LARGE FRACTION REPRODUCTIVE	0.30	23	0.17
LARGE FRACTION REPRODUCTIVE	0.43	17	0.08
MEDIUM-LARGE FRACTION SPENT	-0.21	23	0.33
LARGE FRACTION SPENT	-0.44	17	0.08
MEDIUM-LARGE FRACTION PARTIALLY SPENT	0.03	23	0.89
LARGE FRACTION PARTIALLY SPENT	-0.09	17	0.72

Table B-12e

Pearson product-moment correlation coefficients of the biological variables versus iron concentration (µg/g dry wt.) in sand crab tissue during 1983. Metals were transformed using ln(x + 1/6 min).

DEPENDENT VARIABLE	JULY WITHOUT EGGS			AUGUST WITHOUT EGGS			AUGUST 10-14 MM WITH EGGS		
	R	N	P	R	N	P	R	N	P
Female catch per unit effort	-0.82	14	0.0004	-0.34	12	0.28	0.20	8	0.63
Male catch per unit effort	-0.57	14	0.03	-0.28	12	0.38	0.65	8	0.08
Total catch per unit effort	-0.55	14	0.04	-0.29	12	0.36	0.71	8	0.049
Medium-large fraction reproductive	-0.20	13	0.51	-0.24	11	0.48	0.01	8	0.98
Large fraction reproductive	-0.10	10	0.78	-0.57	9	0.11	0.33	6	0.52
Medium-small fraction spent	0.64	14	0.01	0.16	11	0.63	0.44	7	0.32
Medium-large fraction spent	0.86	13	0.0002	0.50	11	0.12	0.27	8	0.52
Large fraction spent	0.57	10	0.08	0.58	9	0.10	-0.39	6	0.45
Mean maximum male size	-0.11	14	0.71	-0.36	12	0.26	-0.22	8	0.60
Mean maximum female size	-0.57	14	0.03	-0.38	12	0.23	-0.18	8	0.67
Minimum size of reproduction	-0.32	12	0.32	0.01	11	0.98	0	8	1.0

Table B-12f

Pearson product-moment correlation coefficients of the biological variables versus iron concentration (μg/g dry wt.) in sand crab tissue (10 - 13 mm size range) during August 1986. Metals were transformed using ln(x + 1/6 min).

DEPENDENT VARIABLE	R	N	P
MEDIUM-LARGE CATCH PER UNIT EFFORT	0.55	23	0.007
LARGE CATCH PER UNIT EFFORT	0.55	17	0.02
MEDIUM-LARGE FRACTION REPRODUCTIVE	0.07	23	0.76
LARGE FRACTION REPRODUCTIVE	0.15	17	0.57
MEDIUM-LARGE FRACTION SPENT	-0.03	23	0.89
LARGE FRACTION SPENT	-0.01	17	0.97
MEDIUM-LARGE FRACTION PARTIALLY SPENT	-0.03	23	0.87
LARGE FRACTION PARTIALLY SPENT	-0.49	17	0.047

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Attachment 1: **Tables of metal concentrations and radionuclide activity in sand crab tissues for each beach survey.**

Table BA1-1

Metal concentration ($\mu g/g$ dry wt.) in sediments for all beaches during July 1983.

XLOCBCH	CD	CR	CU	FE	MN	NI	PB	ZN
-115000	0.0223	0.302	0.308	104	5.15	0.462	1.58	2.93
-100000	0.0128	0.428	0.197	124	2.403	0.677	1.52	3.02
-79000	0.363	2.27	2.38	943	34.6	1.18	3.32	13.8
-15500	0.0208	0.109	0.277	104	9.42	0.623	0.261	1.39
-12000	0.0158	0.130	0.184	98.1	5.57	0.440	0.197	1.36
-6500	0.006	0.172	0.101	82.4	4.08	0.699	0.373	1.61
-1500	0.0105	0.153	0.173	84.3	6.43	0.559	1.21	1.39
-400	0.00725	0.116	0.169	79.4	4.61	0.490	0.251	1.13
1500	0.00675	0.085	0.125	52.0	2.52	0.487	0.183	1.20
6500	0.006	0.193	0.132	56.4	4.56	0.497	0.183	1.14
12000	0.00350	0.167	0.130	46.6	2.85	0.603	0.1003	1.13
18000	0.00575	0.188	0.0985	86.8	2.94	0.648	0.216	1.33
25000	0.00500	0.186	0.149	118	5.50	0.609	0.242	1.43
45000	0.00325	0.192	0.101	68.9	1.67	0.632	0.471	1.44
65000	0.00500	0.340	0.173	50.4	1.89	0.614	0.944	1.54

Table BA1-2

Metal concentration (μg/g dry wt.) in sediments for all beaches during August 1983.

XLOCBCH	CD	CR	CU	FE	MN	NI	PB	ZN
-450000	0.006	0.357	0.0713	107	2.03	0.718	0.113	1.44
-115000	0.0095	0.339	0.208	99.4	4.83	0.586	1.50	2.75
-100000	0.0120	0.582	0.231	165	3.39	0.336	1.48	3.50
-79000	0.338	2.46	0.606	1144	30.8	1.36	4.81	14.1
-15500	0.0215	0.0703	0.227	93.7	9.27	0.606	0.242	1.34
-12000	0.0138	0.051	0.199	72.9	5.56	0.513	0.203	1.10
-6500	0.0070	0.0938	0.133	88.5	2.58	0.507	0.271	1.52
-1500	0.0075	0.0590	0.187	340	4.52	0.519	0.848	1.19
-400	0.00375	0.0523	0.112	53.5	3.11	0.466	0.208	1.12
1500	0.00425	0.116	0.138	59.3	2.30	0.517	0.197	1.11
6500	0.0053	0.0593	0.115	38.8	2.69	0.483	0.136	1.02
12000	0.0060	0.0985	0.122	45.6	2.54	0.538	0.145	1.81
18000	0.00625	0.166	0.0913	47.6	2.76	0.454	0.150	1.22
25000	0.00675	0.178	0.138	114	4.49	0.557	0.246	1.43
45000	0.00725	0.183	0.106	57.9	1.76	0.604	0.358	1.35
65000	0.00573	0.177	0.093	80.0	2.60	0.694	0.491	1.78

Table BA1-3

Metal concentration (μg/g dry wt.) in sand crab tissue for the "no eggs" category during July 1983 for all sites.

XLOCBCH	CD	CR	CU	FE	MN	NI	PB	ZN
-115000	1.08	0.323	366	107	35.8	0	1.57	92.4
-100000	1.09	0.694	267	90.0	15.8	2.42	0.535	102
-15500	1.56	1.33	181	200	73.7	0	0	71.2
-12000	1.76	0.615	165	239	49.2	0	0	77.2
-6500	2.62	0.284	198	135	38.0	0.618	0.166	131
-1500	1.81	0.592	148	370	62.1	0	0	82.4
-400	1.69	0.306	124	220	44.9	0	0	86.9
1500	2.41	0.466	110	139	31.8	2.09	0.478	85.6
6500	2.94	0.721	99.6	147	28.3	2.96	0.302	92.1
12000	3.59	0.441	73.1	85.3	31.1	0.880	0.376	88.3
18000	2.71	0.271	59.7	108	37.9	0.766	0.068	81.0
25000	3.76	0.115	98 5	117	41.3	1.07	0.348	85.1
45000	2.35	0.308	81.2	113	25.8	0	0	83.2
65000	3.38	0.398	80.1	103	18.0	5.28	0.120	92.2

Table BA1-4

Metal concentration (μg/g dry wt.) in sand crab tissue for the "no eggs" category during August 1983 for all sites.

XLOCBCH	CD	CR	CU	FE	MN	NI	PB	ZN
-450000	2.23	0.20	76.1	119	17.5	0	0	76.5
-100000	2.76	1.10	281	194	16.0	2.60	0.796	110
-79000	2.34	0.551	240	464	28.3	0	0	95.8
-12000	1.10	4.57	249	228	47.8	0	1.07	95.8
-6500	2.18	0.491	237	158	36.5	0.617	0.895	109
-400	1.14	1.22	179	383	63.2	0	0	95.5
1500	2.15	2.25	183	386	33.9	0	0.137	109
6500	3.07	1.91	205	571	39.3	2.40	1.28	107
12000	2.21	1.09	183	319	32.5	2.93	0	109
25000	2.86	0.739	165	327	30.1	0.983	0.224	96.8
45000	2.22	0.242	182	115	21.3	3.31	1.67	104
65000	0.949	0.384	125	231	15.4	0	0	88.9

Table BA1-5

Metal concentration (μg/g dry wt.) in sand crab tissue for the "with eggs, size 10-14 mm" category, for all sites during August 1983.

XLOCBCH	CD	CR	CU	FE	MN	NI	PB	ZN
-100000	0.887	0.634	276	184	11.5	4.19	0.865	94.7
-15500	2.11	0.618	286	153	59.5	0	0	88.0
-6500	2.18	0.364	199	236	36.8	0	0	113
-400	1.41	4.40	193	779	56.7	0	0	110
12000	4.93	0.396	218	234	22.2	0	0	106
25000	3.56	1.43	240	769	41.1	1.89	2.13	113
45000	6.63	1.20	217	181	23.3	3.52	0.286	125
65000	2.09	1.09	161	445	21.5	1.90	0.536	109

Table BA1-6

Isotope activity levels (picocuries/g dry wt.) in sand crab tissue for the " > 13 mm" category during August 1986.

XLOCBCH	^{40}K	^{54}Mn	^{60}Co
-11500	1.3	0	0
-8500	2.1	0	0
-7500	3.4	0	0.04
-6500	3.6	0	0
2500	4.0	0	0
4500	2.3	0	0
6500	3.4	0	0
7500	2.2	0	0
8500	2.2	0	0
9500	2.7	0	0
10500	2.4	0.03	0.06
12500	6.0	0	0
65000	2.2	0	0

Isotope activity levels (picocuries/g dry wt.) in sand crab tissue for the "10-13 mm" category during August 1986.

XLOCBCH	^{40}K	^{54}Mn	^{60}Co
-17500	3.0	0	0
-14000	3.3	0.01	0.02
-12500	2.5	0	0
-11500	2.6	0	0
-10500	2.6	0	0
-8500	2.7	0.03	0.02
-7500	2.4	0	0.03
-6500	3.8	0	0
-5500	2.3	0.02	0.03
-4500	3.2	0	0
-1500	3.4	0.04	0.06
-400	2.7	0.03	0.04
0	4.2	0	0.04
500	2.6	0.06	0.06
1500	3.6	0.04	0.06
2500	2.1	0.05	0.05
3500	2.5	0.03	0.05

XLOCBCH	^{40}K	^{54}Mn	^{60}Co
4500	3.7	0.03	0.03
5500	2.9	0	0.04
6500	2.4	0.04	0.03
7500	2.9	0.07	0.04
8500	2.9	0.04	0.04
10500	3.2	0.07	0.05
12000	2.8	0	0
45000	3.0	0	0
65000	1.2	0	0

Metal concentration (μg/g dry wt.) in sand crab tissue for the "10-13 mm" category during 1986.

XLOCBCH	Cr	Fe	Mn
-17500	0.470	439	55.4
-14000	1.060	934	44.8
-12500	0.542	353	61.3
-11500	0.453	232	104
-10500	0.562	296	46.0
-8500	0.540	201	23.7
-7500	1.360	932	53.2
-6500	1.160	891	33.7
-5500	0.595	333	31.0
-4500	0.543	305	26.2
-1500	1.100	617	44.4
-400	0.907	296	64.7
500	1.200	445	58.7
1500	1.160	396	31.7
2500	0.944	235	46.0
3500	1.190	538	14.4
4500	1.100	516	25.4
5500	1.250	535	40.2
6500	0.667	409	41.7
7500	0.523	279	17.9
8500	0.742	306	27.1
9500	0.875	817	37.4
10500	0.510	179	64.4
12000	1.13	646	49.8
45000	0.636	329	19.1
65000	0.645	266	12.0

Attachment 2

Summary of Paired t-tests of metal concentrations in sand crab tissues, between size classes on reproductive categories for July and August 1983. Entries indicate number of significant ($p < 0.05$) and nonsignificant tests.

For comparisons between reproductive classes, G indicates the "with eggs" category had significant higher concentrations than the "no eggs" category, L indicates significantly lower concentrations, and N.S. indicates no significant difference.

For comparisons between size classes, G indicates the larger size class had significantly higher concentrations, L indicates significantly lower concentrations, and N.S. indicates no significant difference from the smaller size class. For each metal, month, and reproductive category there were two possible comparisons between size classes (> 14 mm vs. 10-14 mm and 10-14 mm vs 8-10 mm).

	Size	G	L	N.S.
COMPARISONS BETWEEN REPRODUCTION CLASSES (SIZE FIXED)	> 14 mm	1	0	5
	10-14 mm	3	0	13
	8-10 mm	2	0	13
COMPARISONS BETWEEN SIZE CLASSES (REPRODUCTIVE TYPE FIXED)	with eggs	5	1	25
	with no eggs	1	0	30

Attachment 3

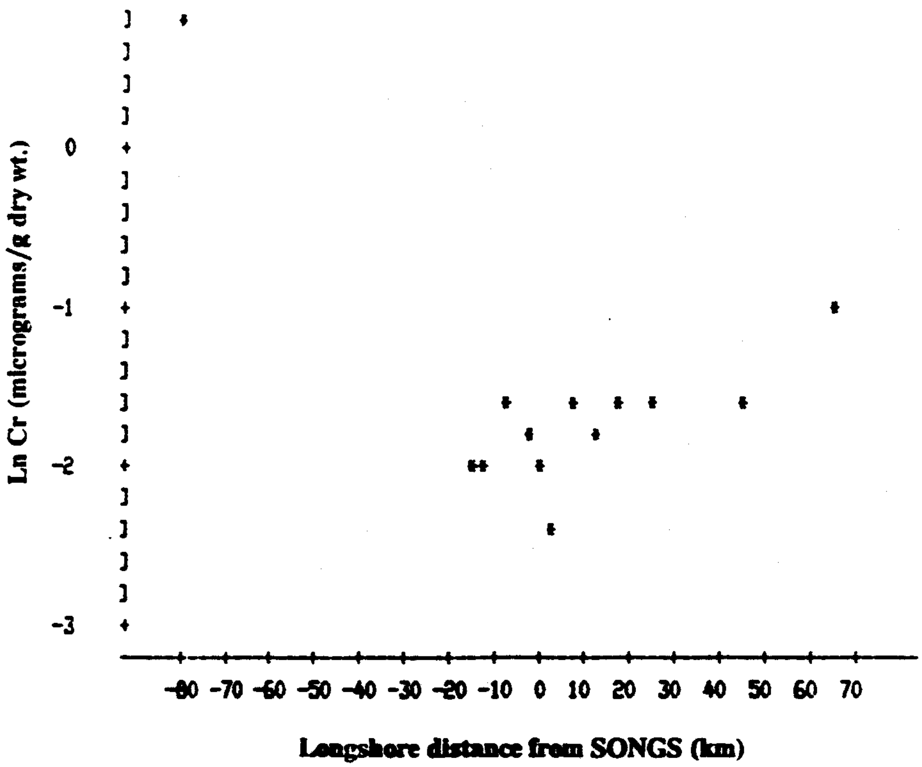
Isotopes assayed for activity in sand crab tissues during the 1986 sand crab study.

NAME	SYMBOL
Isotope 100 of Silver	^{100}Ag
Isotope 141 of Cerium	^{141}Ce
Isotope 144 of Cerium	^{144}Ce
Isotope 57 of Cobalt	^{57}Co
Isotope 58 of Cobalt	^{58}Co
Isotope 60 of Cobalt	^{60}Co
Isotope 134 of Cesium	^{134}Cs
Isotope 137 of Cesium	^{137}Cs
Isotope 59 of Iron	^{59}Fe
Aqueous Tritium	^{3}H
Bound Tritium	^{3}H
Isotope 131 of Iodine	^{131}I
Isotope 40 of Potassium	^{40}K
Isotope 54 of Manganese	^{54}Mn
Isotope 99 of Molybdenum	^{99}Mo
Isotope 226 of Radium	^{226}Ra
Isotope 106 of Ruthenium	^{106}Ru
Isotope 65 of Zinc	^{65}Zn
Isotope 95 of Zirconium	^{95}Zr

APPENDIX B: Figures

Figure B-1: Log transformed chromium concentrations in beach sediments for July and August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Metal Concentration In Sediments During July 1983



Metal Concentration In Sediments During August 1983

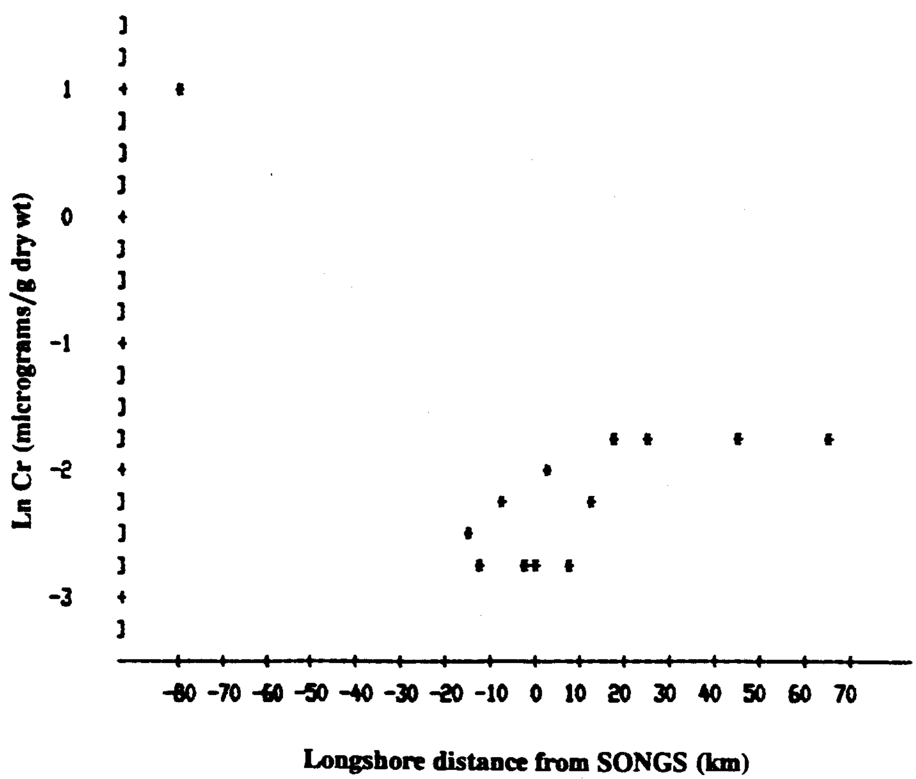
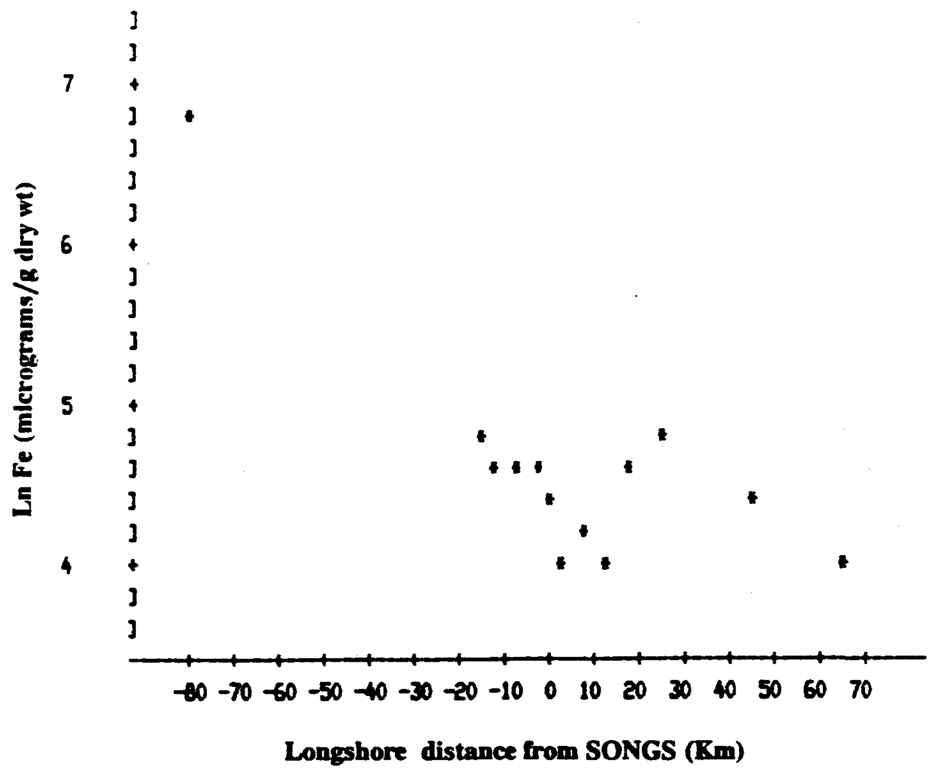


Figure B-2: Log transformed iron concentrations in beach sediments for July and August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Metal Concentration In Sediments During July 1983



Metal Concentration In Sediments During August 1983

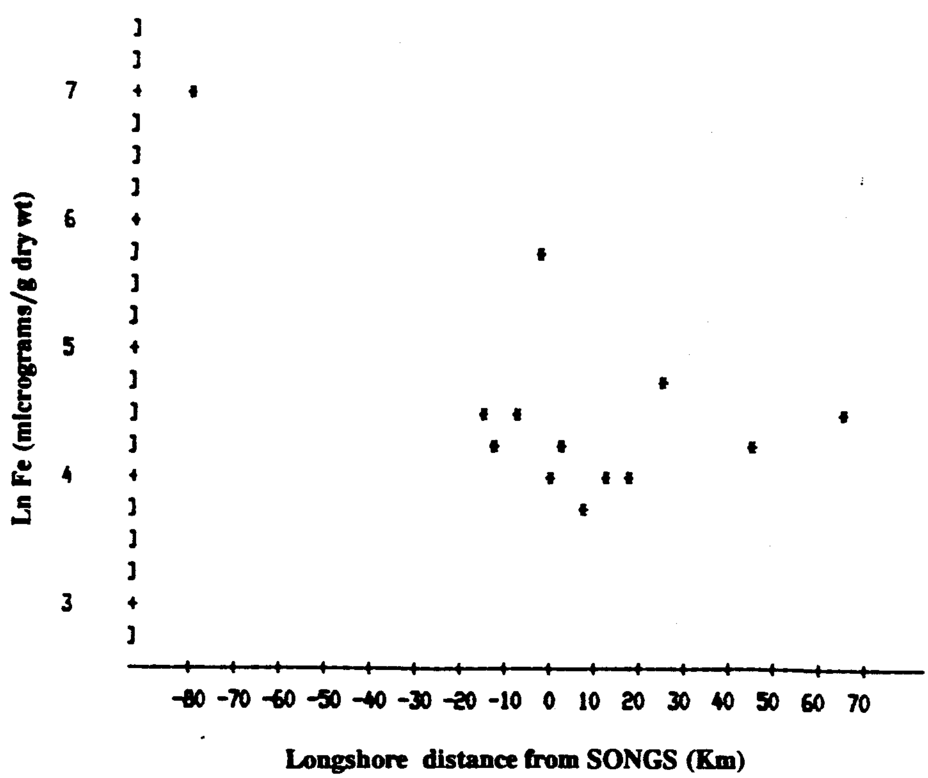
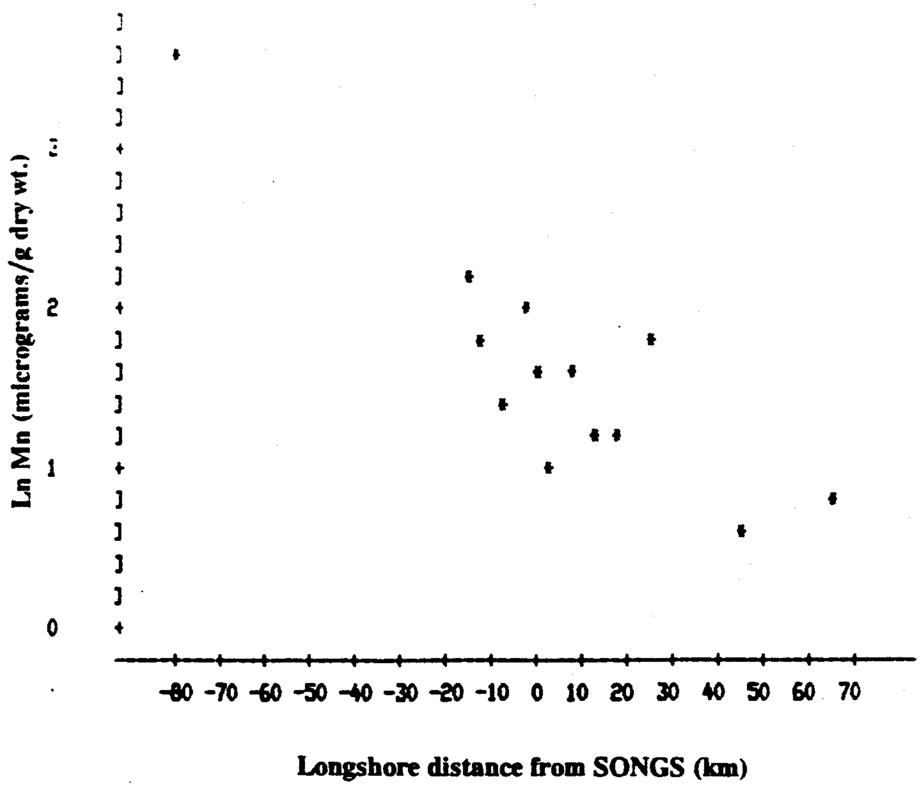


Figure B-3: Log transformed manganese concentrations in beach sediments for July and August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Metal Concentration In Sediments During July 1983



Metal Concentration In Sediments During August 1983

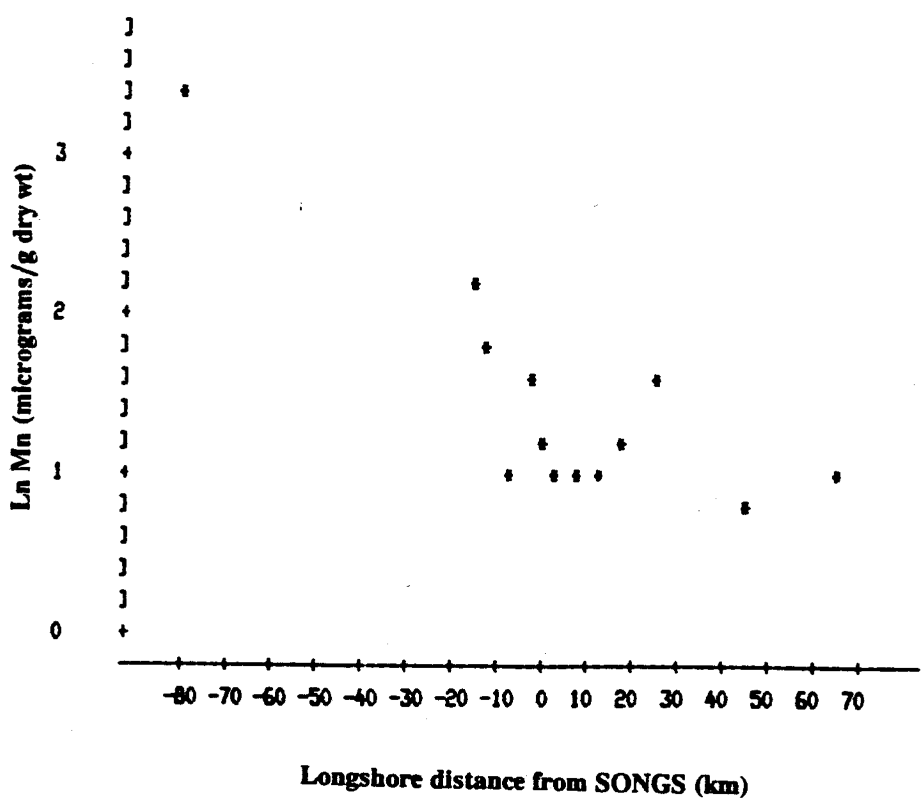
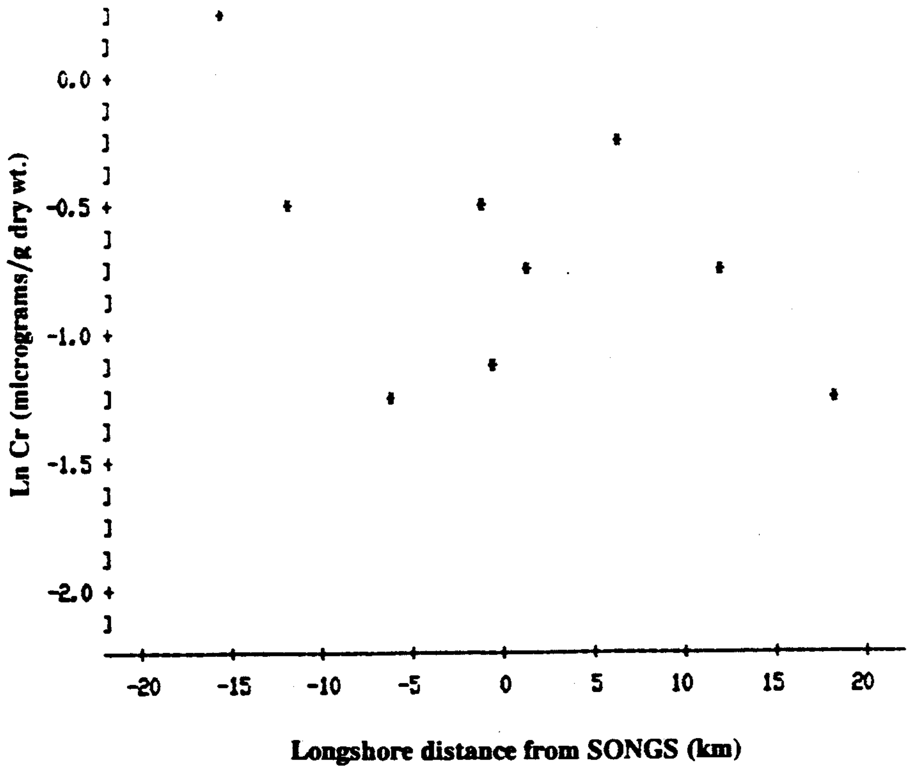


Figure B-4: Log transformed chromium concentrations in female sand crabs without eggs for July and August 1983 plotted against longshore location. Negative numbers indicate to the north of SONGS.

Metal Concentration In Tissue During July 1983

Females Without Eggs



Metal Concentration In Tissue During August 1983

Females Without Eggs

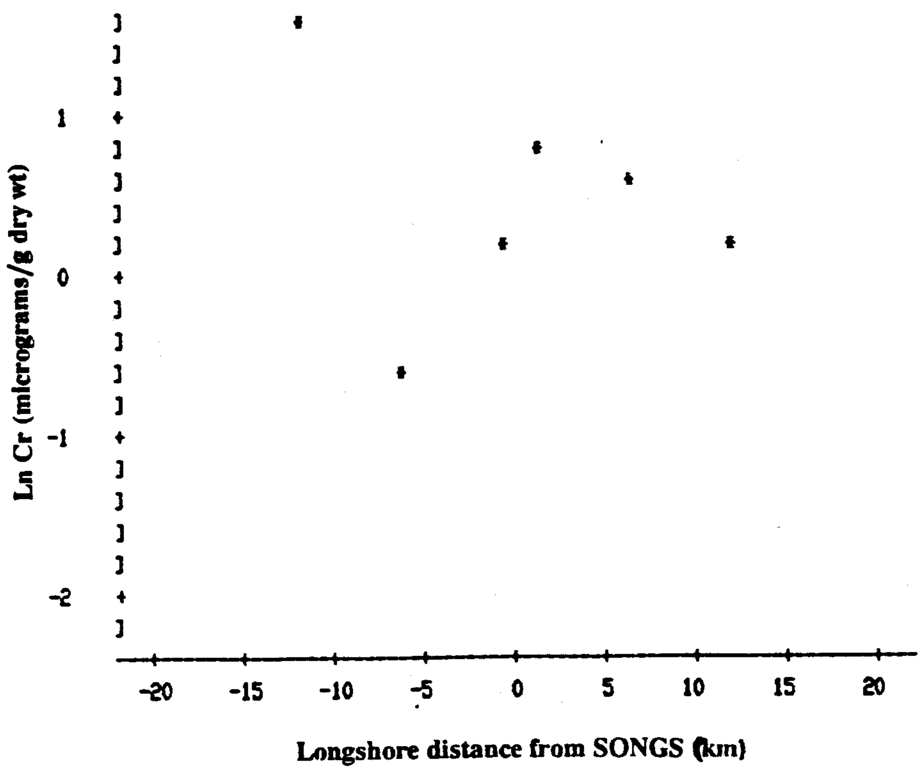
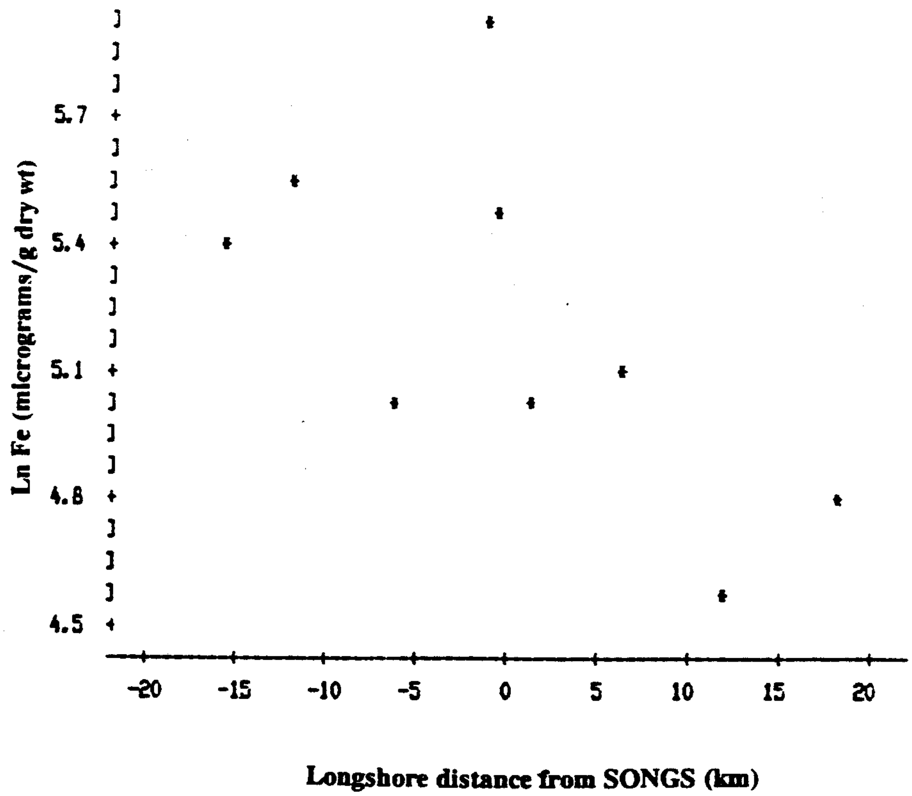


Figure B-5: Log transformed iron concentrations in female sand crabs without eggs for July and August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Metal Concentration In Tissue During July 1983

Females Without Eggs



Metal Concentration In Tissue During August 1983

Females Without Eggs

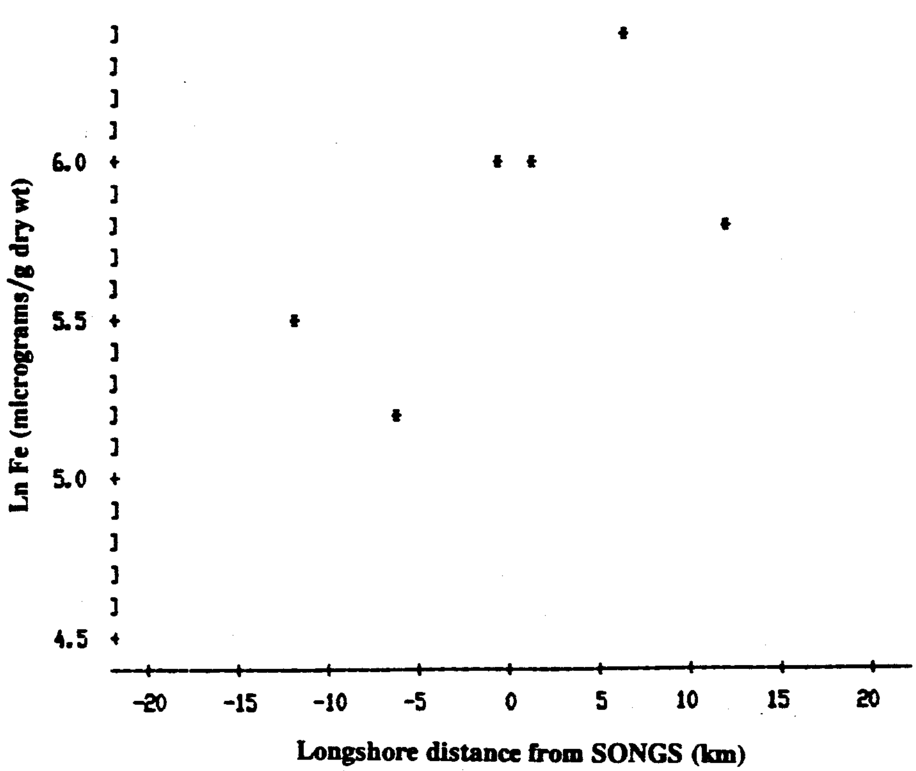
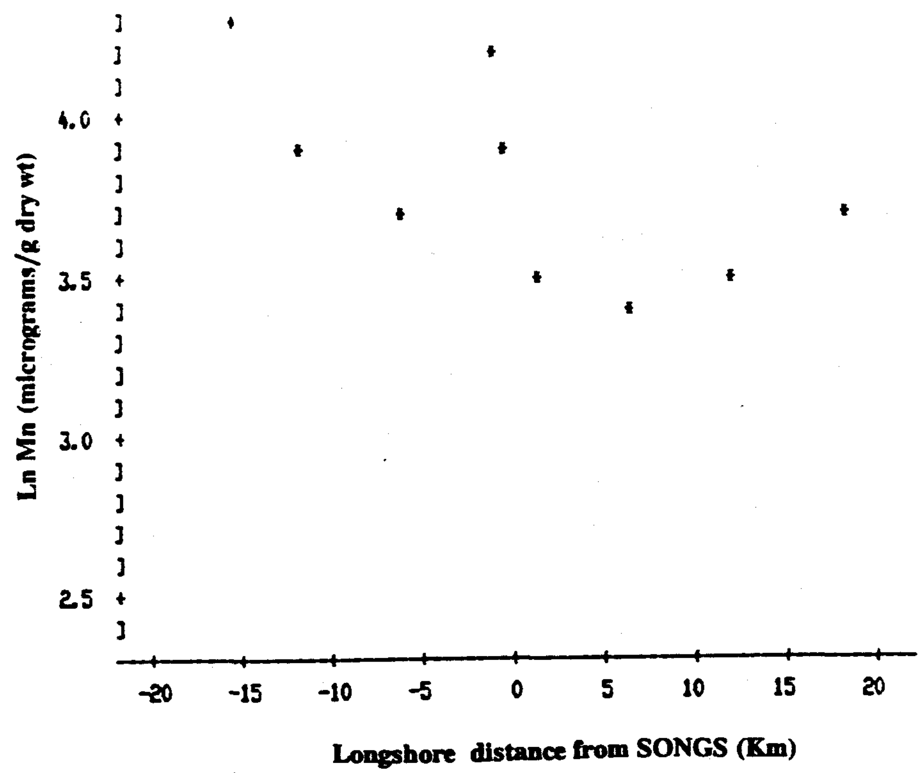


Figure B-6: Log transformed manganese concentrations in female sand crabs without eggs for July and August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Metal Concentration In Tissue During July 1983

Females Without Eggs



Metal Concentration In Tissue During August 1983

Females Without Eggs

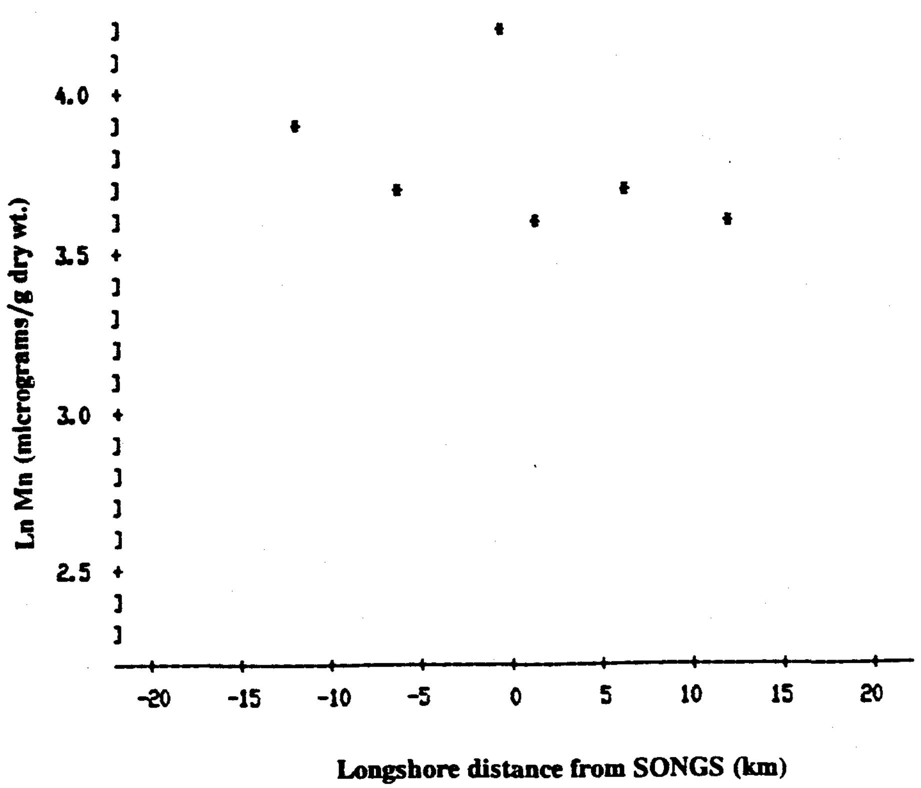
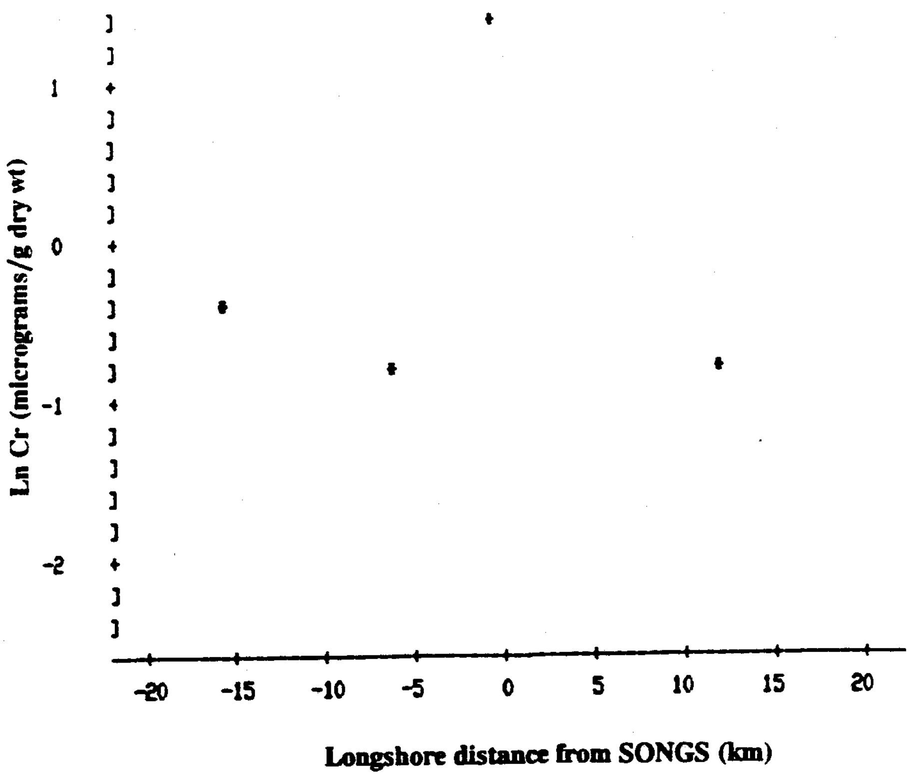


Figure B-7: Log transformed metal concentrations in 10-14 mm female sand crabs with eggs for August 1983 plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

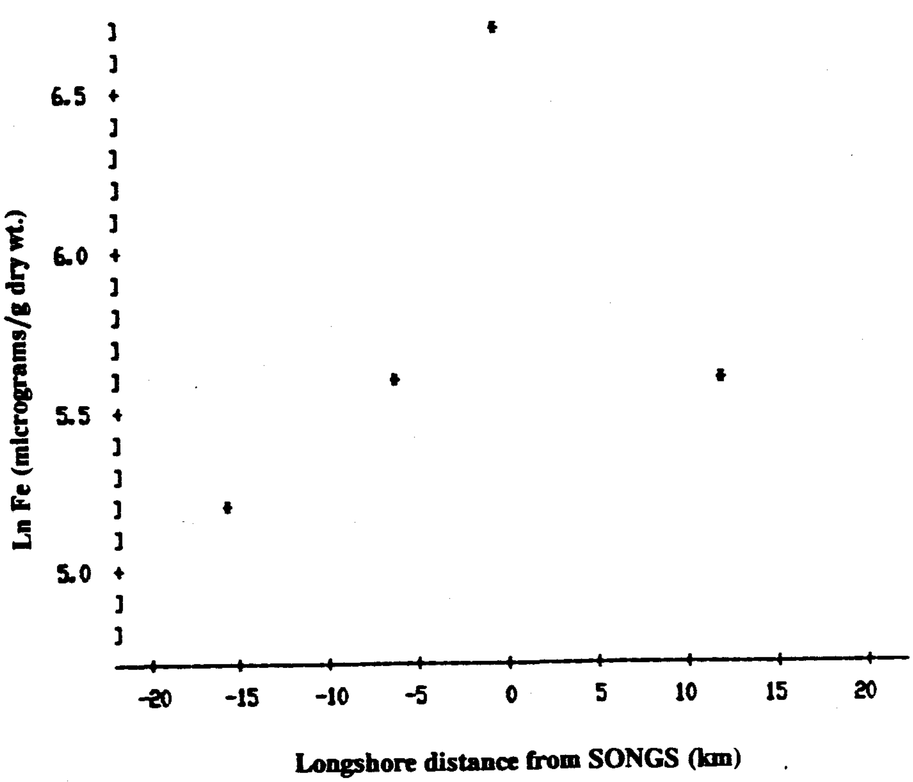
Metal Concentration In Tissue During August 1983

Females With Eggs (10-14mm)



Metal Concentration In Tissue During August 1983

Females With Eggs (10-14mm)



Metal Concentration In Tissue During August 1983

Females With Eggs (10-14mm)

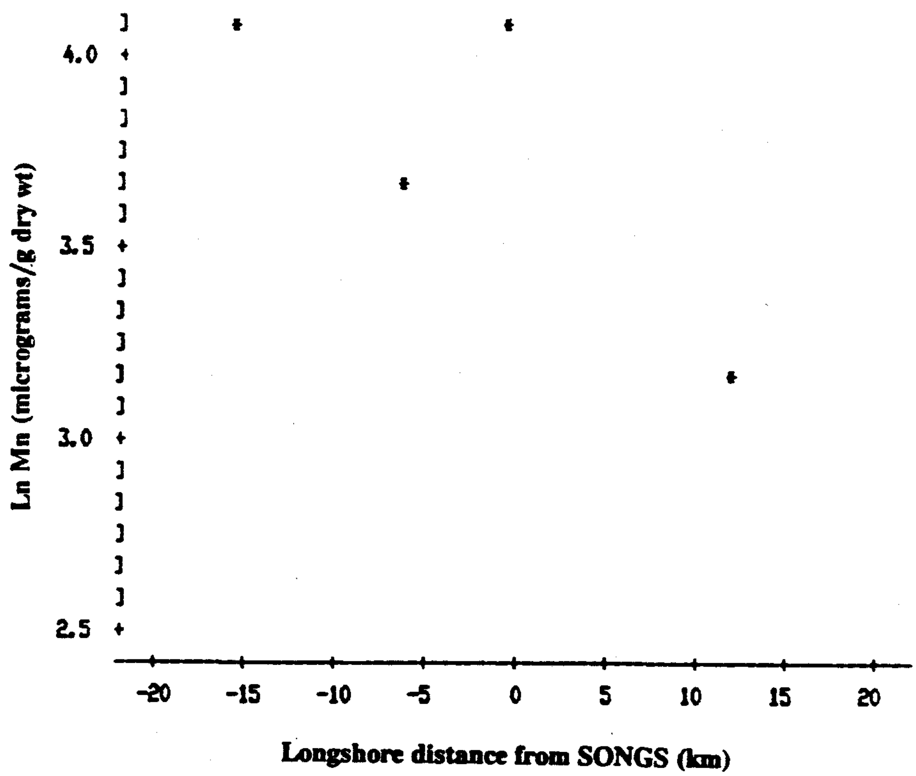


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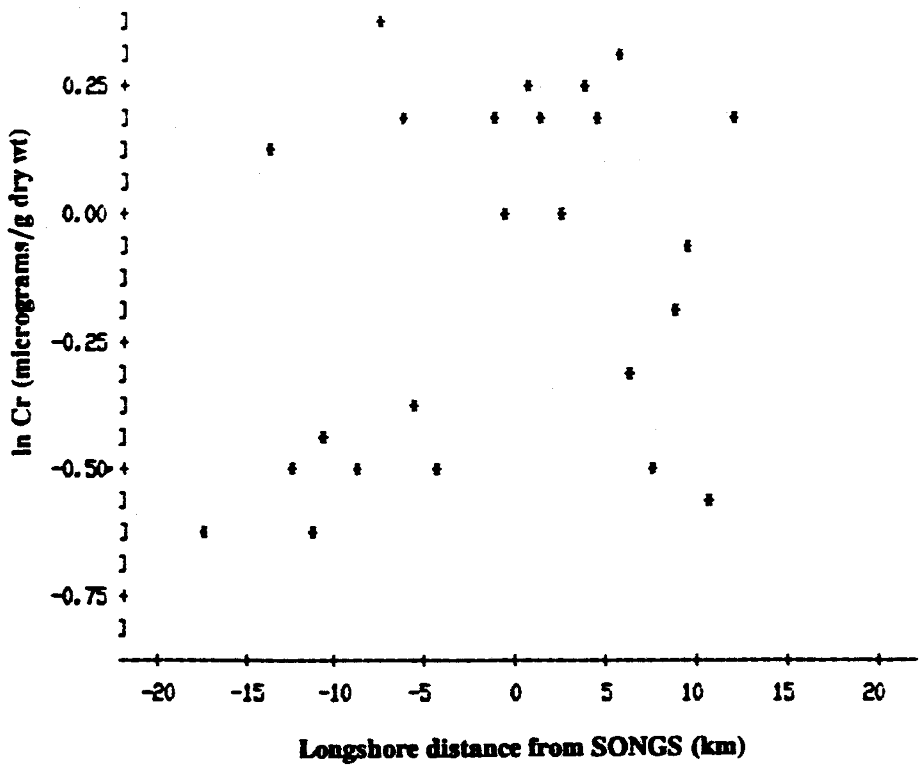
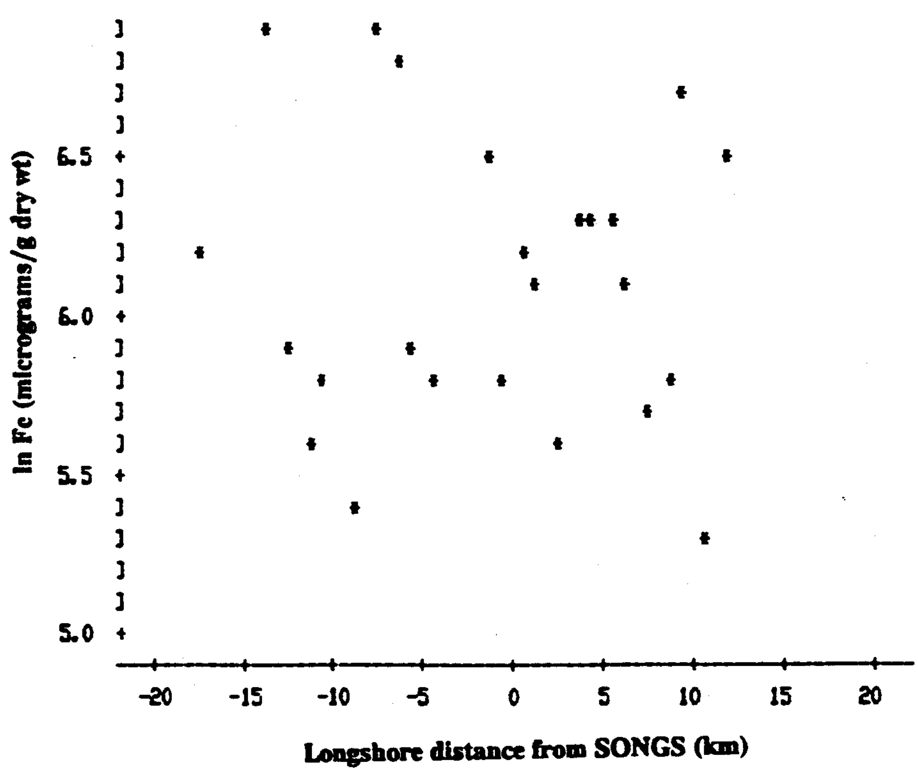
Figure B-8: Log transformed metal concentrations in 10-13 mm female sand crabs for August 1986 plotted against longshore location. Negative numbers indicate to the north of SONGS.

Metal Concentration In Sand Crab Tissue (10-13 mm) During 1986



Metal Concentration In Sand Crab Tissue (10-13 mm) During 1986



Metal Concentration In Sand Crab Tissue (10-13 mm) During 1986

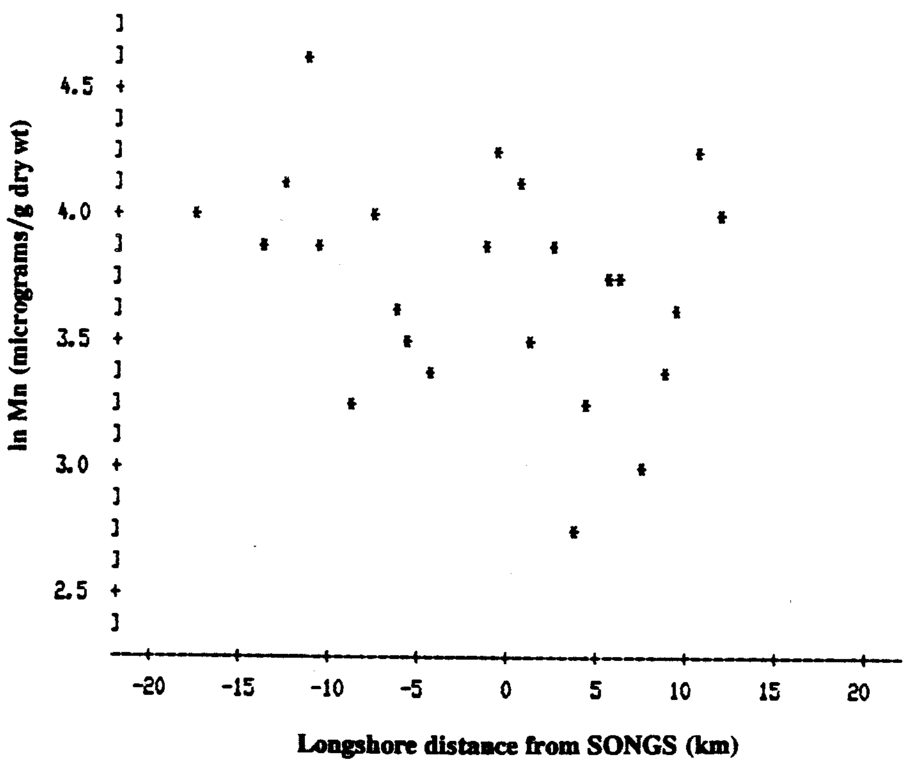


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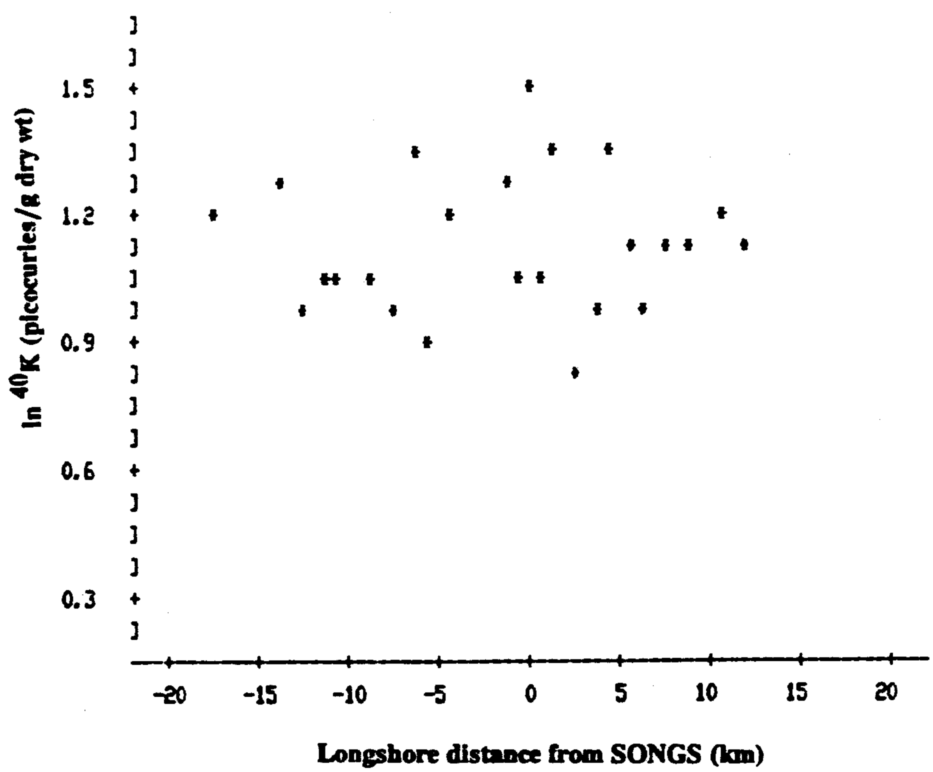
Figure B-9: Log transformed ^{40}K activity level in 10-13 mm and > 13 mm sand crabs plotted against longshore. Negative numbers indicate distance to the north of SONGS.

Isotope Activity Level In Sand Crab Tissue (10-13 mm) During 1986



Isotope Activity Level In Sand Crab Tissue (> 13 mm) During 1986

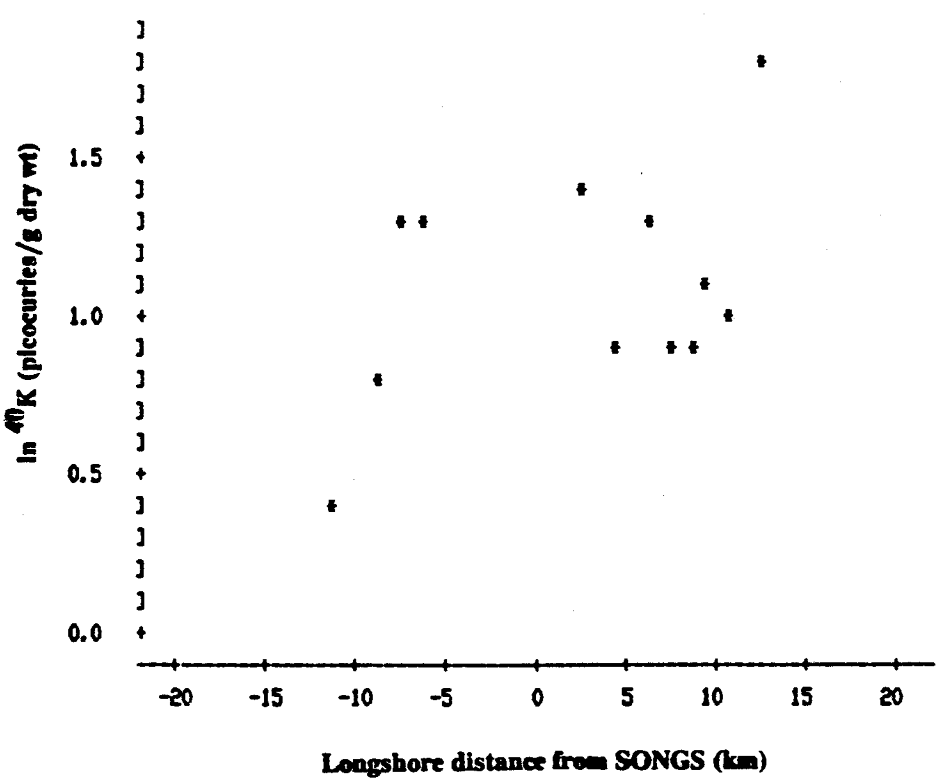
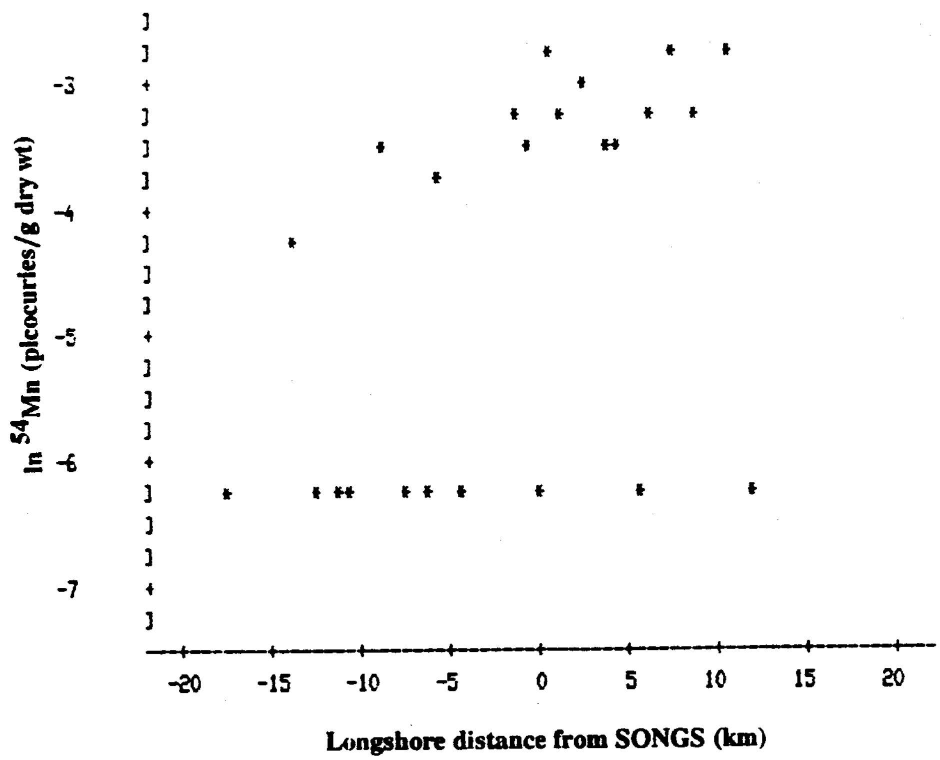


Figure B-10: Log transformed ^{54}MN activity in 10-13 mm and > 13 mm sand crabs plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Isotope Activity Level In Sand Crab Tissue (10-13 mm) During 1986



Isotope Activity Level In Sand Crab Tissue (> 13 mm) During 1986

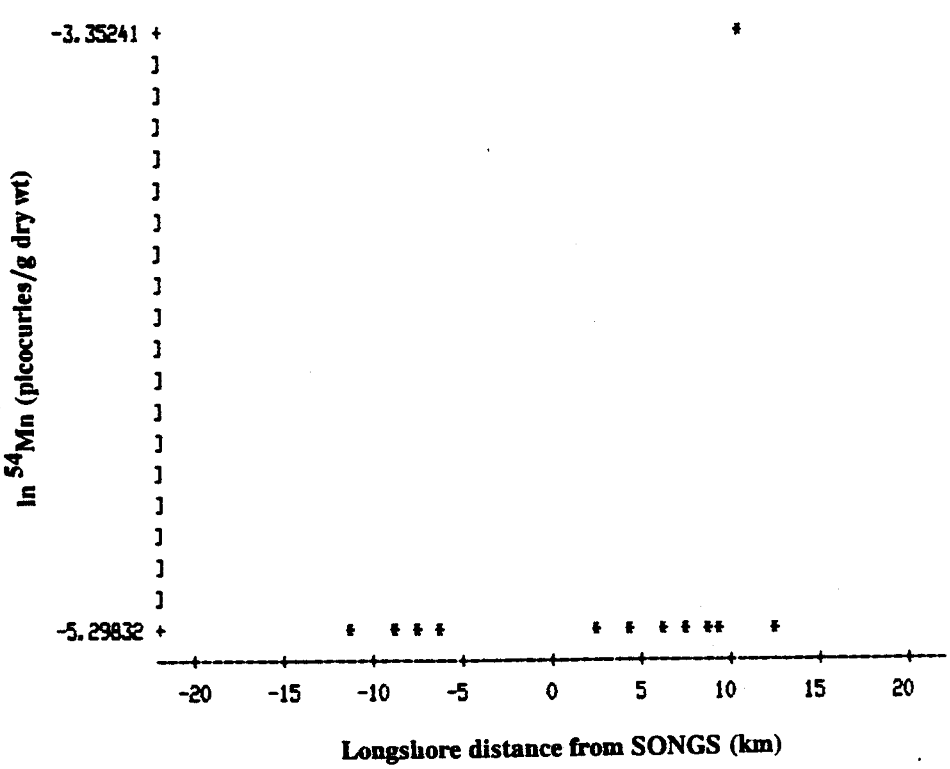
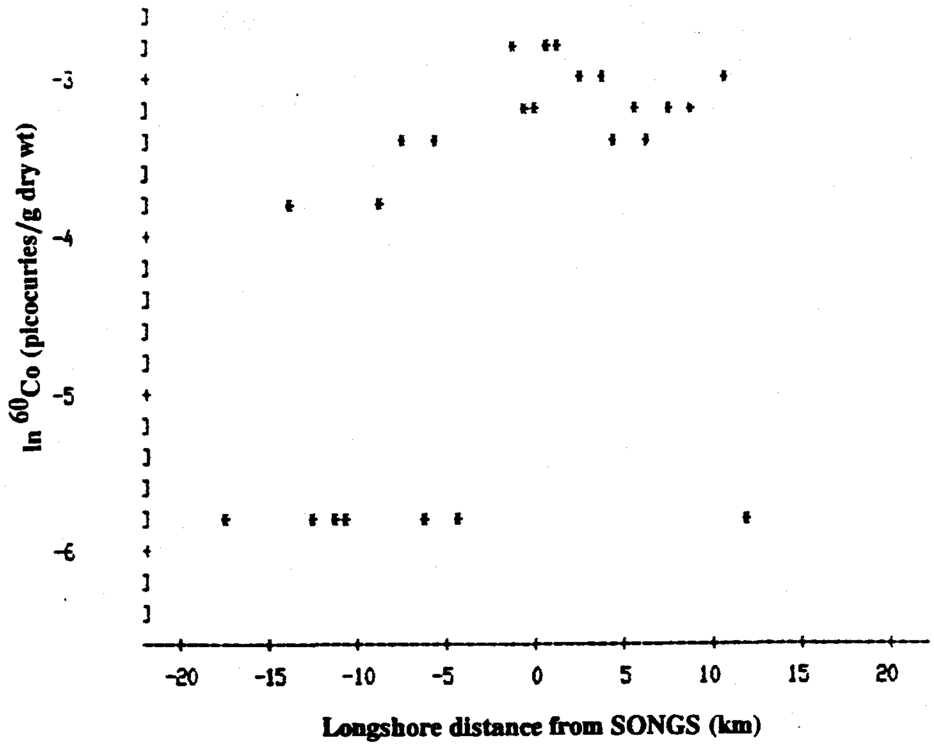
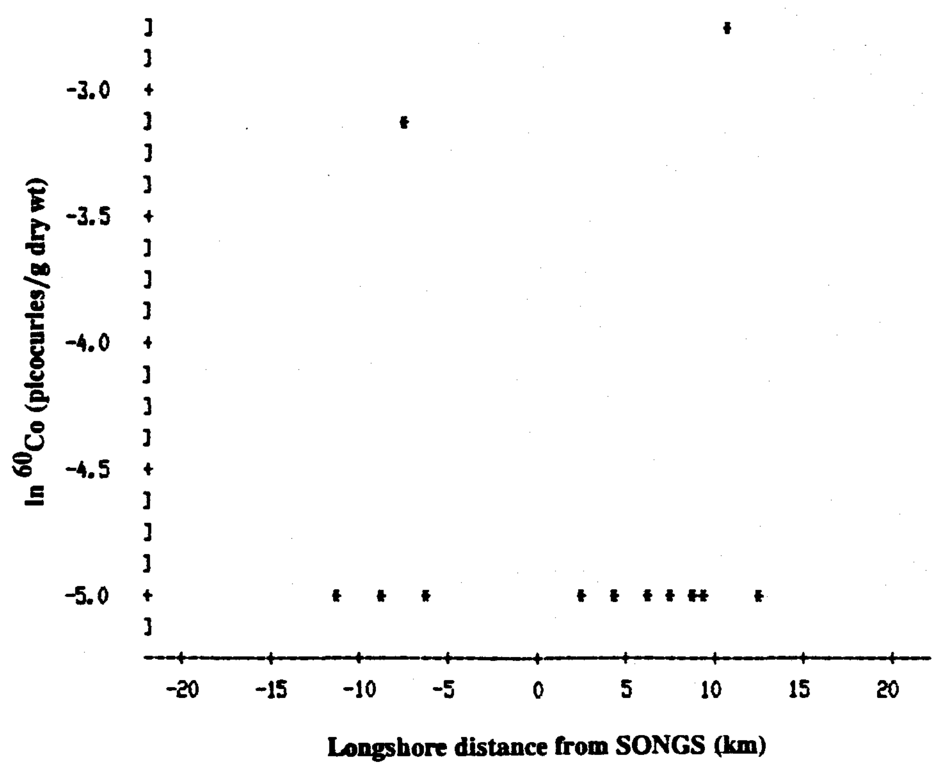


Figure B-11: Log transformed ^{60}Co activity level in 10-13 mm and > 13 mm sand crabs plotted against longshore location. Negative numbers indicate distance to the north of SONGS.

Isotope Activity Level In Sand Crab Tissue (10-13 mm) During 1986



Isotope Activity Level In Sand Crab Tissue (> 13 mm) During 1986



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APPENDIX C: RELATIONSHIPS BETWEEN SAND CRAB BIOLOGY AND THE PHYSICAL ENVIRONMENT

C.1. Introduction

At times, sand crab populations in the general area about SONGS, and especially at the beaches most proximate to the plant, appeared to differ in several aspects of their biology from other populations more distant from the plant. We failed to find evidence that these differences were more accentuated during periods of peak operation by SONGS (Main text, Results), and neither releases of stable metals nor radionuclides by SONGS appear to be responsible for the patterns (Appendix B). In this appendix, we explore whether the biological attributes of sand crabs are associated with physical characteristics of the environment, and whether distinctive features of the sand crab populations living on beaches near SONGS might simply be responses to environmental factors unaffected by SONGS.

C.2. Methods

Two sets of data are available from studies when information on a number of physical/chemical variables were collected. During the June, July, and August 1983 surveys, a large number of physical/chemical variables was measured, including characteristics of beach composition, seston and organic carbon concentration in both the water and sediments, and the concentrations of eight metals in the sediments. For the August 1986 survey, a more limited set of variables describing beach composition was collected. The biological (dependent) and physical (independent) variables used in our analyses are given in Tables C-1 and C-2.

C.2.1. Field and Laboratory Methods

Methods used to collect sand crabs and estimate the various biological parameters are described in the main text of this volume. A description of the methods used to estimate metal concentrations in sediments and tissues is given in Appendix B. A list of the variables used in analyses of the 1983 data is in Table C-1, and a list of the variables used in the 1986 analyses is in Table C-2. References to the appropriate source document for each variable are also included in these tables, except for the independent variables for the 1986 study. All of the independent variables in 1986, with the exception of the percent cobble cover, were measured in the same way as the corresponding variables during 1983. In 1986, cobble cover is defined as the percentage of the beach that was cobble, and was estimated visually at the time that sand crabs were collected. As in the main text of this report, the following size categories of crabs were used in the analyses: medium-small (7-10 mm carapace length), medium-large (10-13 mm carapace length), and large (greater than 13 mm carapace length).

For 1983, the data consist of a set of biological and physical variables from each of 15 or 16 beaches for three surveys taken during June, July, and August. These beaches included seven beaches 12 km or closer to SONGS and nine other beaches ranging from north of Los Angeles to La Jolla.

During 1986, 27 sites were sampled within 20 km of SONGS, at roughly one kilometer intervals. Two additional sites at 45, and 65 km south of SONGS were also sampled. With the exception of the site 0.4 km north of SONGS, each site was only sampled once during August. The 0.4 K North site was sampled twice in

August, about two weeks apart. Unless otherwise stated, analyses use the averages over the two surveys at this site.

One hypothesis that could account for the scarcity of large sand crabs at beaches proximate to SONGS (Main text, Results), is that extensive cobble cover in the shallow subtidal and intertidal regions during the winter would prevent crabs from overwintering in the local area (see Efford 1970 for a similar hypothesis applied to a different population of sand crabs). During December 1986, a single sonar survey of sediment composition in the shallow subtidal was conducted Ecosystems Management to assess the extent of cobble in the shallow subtidal from approximately 16 km north to 12 km south of SONGS. A description of the SONAR technique is given in Eco-M (1987).

C.2.2. Multiple Regressions

Multiple regression models of biological variables against physical/chemical variables were developed as described below. For each final regression model we examined the residual values (i.e. differences between observed and predicted values) for each beach to determine whether there was any pattern to the residuals, especially with regard to proximity to SONGS. We also examined how well regressions based on all the data except those collected at a given beach, predicted the results at that beach. We did this by examining the influence statistics suggested by Belsley *et al.* (1980, also see SAS 1985 pp. 676-677). Particular attention was paid to the DFFITS statistic, which is a scaled measure of the change in the predicted value for the *ith* observation when that observation is not used to fit the regression model. Our interest is in whether especially large values for this statistic occurred on beaches near the plant. Because of the extensive nature of the output, these residual values and statistics for each data point in each regression are not reproduced in this report. In principle, cases where especially large or influential observations occur for the beaches most proximate to SONGS, were to be included as an appendix. Since such patterns were not obvious in any of the output, we include an example of some typical results in Attachment 1.

The 1983 Study

There were more potential independent variables than observations, so our first task was to reduce the number of variables. First, we replaced several sets of the original variables with their first principal component. For example, we replaced eight sediment metal concentration variables with a single variable (the first principal component of sediment metal concentrations), which can be regarded as a weighted average of the concentration of the eight metals. The use of principal components for variable reduction is a well known procedure (Freund and Littell 1986).

After carrying out the above procedure, we still had seven potential independent variables and, at most, sixteen observations. We therefore adopted the following protocol to choose the "best" regression model for each biological (dependent) variable, including only a subset of the independent variables. First, we chose the best one variable model, two variable model, three variable model, etc., up to the full seven variable model, choosing as the best model for a given sized model, the one yielding the highest R^2. Then, starting with the full seven variable model, we moved progressively to the best model with one fewer variable than the previous one, until the value of Mallow's C(p) became less than the number of variables remaining in the model (see Freund and Littell 1986, Draper and Smith 1981). There were two exceptions to this procedure: (1) if there were seven or fewer observations available for analysis, no model was developed; (2) if C(p) never went below the number of independent variables, our choice was the model where C(p) most closely approached the number of variables, before it began increasing.

After choosing the "best" model by the C(p) criteria, we continued to reduce the number of independent variables included in the model (still choosing as the best model of a given size the one with the highest R^2) until a further reduction lead to a decline in R^2 of more than 0.02. At this point, dependent variables with models whose overall p values were greater than 0.1 were excluded from further consideration (i.e. we did not develop a final regression model in these cases). The attained significance level (i.e. p-value) of each of the independent variables remaining in the model was then evaluated for cases that passed this screen, and any independent variables with p-values greater than 0.1 were eliminated. The resulting model, consisting of the remaining independent variables, was deemed our best model. It is possible for the slope parameter associated with an independent variable in the final model to have a p-value greater than 0.10, since the final model was refit to the data after the variables to be included were determined.

Originally, we had hoped to develop a single model that would apply to all three 1983 surveys. We were unable to do this, as the models developed for a given dependent variable often varied substantially across months, sometimes with no variables in common. Because of the sparseness of the data, the dependent variable "partially spent" is analyzed for July and August only, by pooling the data over the two months (and size classes; see Main text). In regressions for this variable, the independent variables are also averaged over the values recorded for July and August.

The 1986 Study

For 1986, fewer independent variables were measured, and more sites were sampled. Consequently, the only step taken to reduce the number of independent variable was to replace grain size variables (e.g. mean and dispersion of grain size, see Table C-2) by their first principal component. This left us with three independent variables in 1986: the first principal component of the grain size variables, the percentage of the beach which was cobble, and beach slope.

Interpretation of principal component variables

A principal component variable, Y, is created from a set of k original variables $X_1, X_2, ..., X_k$. First, the original variables are centered and standardized to obtain $X_1^*, X_2^*...X_k^*$ (i.e. $X_i^* = (X_i - X.)/s_{X.}$). Y is then obtained by forming a unit-length linear combination: $b_1X_1^* + b_2X_2^* + ... + b_kX_k^*$. For the first principal component, the coefficients (b_i's) are chosen to produce the unit-length linear combination that has the maximum among-beach variance of all possible linear combinations. Obviously, the physical interpretation of a principal component variable depends upon what coefficients are chosen.

The coefficients chosen for each principal component variable are given in Table C-3, along with a short verbal interpretation of each variable. To keep the physical interpretation of the principal component variables constant across the surveys during 1983, a single principal component was generated for each set of variables, based on the data collected during all surveys taken that year.

C.3. Results

C.3.1. Multiple regressions on 1983 data

As we discuss below, in most cases (for most dependent variables and months) our final models explained more than 50% of the variability in the dependent variable, and were significant at the 0.05 level (Table C-4). These results should be interpreted cautiously, however, because we used the data to select our final ("best") models. When the variables included in a "best" model are selected from among a large number (relative to the number of observations) of potential candidates, the type I error can become inflated (e.g. Myers 1986, Draper and Smith 1981, Freund and Littell 1986). Consequently, we regard the analyses of the 1983 data as exploratory, and we look for systematic patterns in the results (for example, the same variable appearing in a number of models, especially at different times, or in different size categories of crabs), and confirmation in the 1986 results.

Residuals from the regression models were typically no larger from beaches near SONGS than from other beaches, and showed no pattern in the region about SONGS. There was also no indication that values from sites proximate to SONGS were more poorly predicted by the models than values from elsewhere.

Maximum size

Models could be developed for mean maximum female size during June, and mean maximum male size during June and July. Although each of the models was significant and explained from 30 to 64% of the variability, they shared no variables in common (Table C-4). The model for mean maximum female size in June included the principal component of organic substances in water, and beach slope.

The model for mean maximum male size in June included the principal component of the cobble variables and the principal component of organic substances in sediments. During July, the only variable included in the final model for mean maximum male size was the principal component of sediment metals (Table C-4).

Minimum size of reproduction

Models for the mean minimum size of reproduction for females were developed for July and August, and explained 43 and 55% of the variability respectively (Table C-4). These models shared only a single variable, and the parameter for that variable (principal component of grain size variables) had a different sign in the different months (Table C-4).

Catch per unit effort

We were able to develop regression models for male and female abundance during June and July, and for total abundance during all three months. The one obvious pattern in the results is that the principal component of the grain size variables was significant in five of the seven models (Table C-4). In each case the parameter was negative, indicating that abundance tended to be lower on beaches with coarser and more variable grain sizes in the sediments. The principal components of the sediment metal variables and sediment organic substances were each significant in two models, taking the same sign (negative) each time (Table C-4). Other independent variables were either non-significant, occurred significantly in just one model, or appeared with different signs in different models.

Reproductive variables

There were several relationships between the reproductive variables and beach slope, and/or the principal component of the cobble variables. In four of seven of the regressions on the fraction reproductive, fraction partially spent, and fraction spent, beach slope had a significant effect (Table C-4). Reproduction may have been poorer on beaches with steeper slopes as evidenced by a lower fraction reproductive in large crabs, and higher fractions spent and partially spent (Table C-4). There was also a significant positive relationship between the fraction partially spent and the principal component of cobble variables, indicating that this condition was more prevalent on beaches where cobble was prevalent. The principal component of the cobble variables, however, significantly affected the fraction reproductive in this same direction during July.

Tissue metal concentrations

Here we regard tissue metal concentrations as biological (dependent) variables, and ask whether their variability among beaches can be explained by the physical environment. Significant models were obtained for tissue levels of chromium and iron in August (Table C-4). The two models shared the principal component of grain size as an independent variable, with negative slopes in both cases. Beach slope and the principal component of cobble variables showed significant positive relationships with tissue concentrations of chromium and iron, respectively (Table C-4). A model was developed for the principal component of tissue metals for July that included the principal component of sediment metals, and seston. This model explained 56% of the total variability (Table C-4). It is interesting that in this case "total tissue burden" of metals can be explained by a composite variable of all the metals in the sediments, while the concentration of individual metals in the tissues is poorly explained by the concentration of the same metal in the sediments (Appendix B).

Overall evaluation of important independent variables in 1983

Beach slope was included in a number of models, and appeared to have a systematic effect on the reproductive variables, with poorer or "abnormal" reproduction associated with steeper slopes (Table C-4). The principal component of grain size also appeared in a number of models and appeared to have a consistent effect on the CPUE variables. It appears that abundance was lower on beaches with coarse and variable grain sizes (Table C-4). The principal component of cobble variables was also included in a number of models. When cobble was prevalent, the fraction partially spent (July and August combined) was higher, the maximum size reached by males was lower (June), and the concentration of iron in tissues higher (Table C-4). An apparently contradictory result (in the sense that it indicates an "enhancement" of reproduction by cobble) is that the fraction of large (>13 mm) reproductive females increased with increasing prevalence of cobble during July (Table C-4). The principal component of sediment metals appeared in a number of models, but did not appear to have systematically "adverse" effects. For example, the fraction of medium-large (10-13 mm) females with spent eggs tended to decrease with increasing values of the principal component of metals, while crab CPUE also tended to decrease with increasing values of this variable (Table C-4).

C.3.2. Multiple regressions on 1986 Data

In contrast with 1983, the regression models for 1986 were often not significant, and explained relatively little of the variability in the data (Table C-5). Only two of eleven models were significant ($p<0.05$). The model for the sand crab catch per unit effort (CPUE) for the medium-large size class was significant and explained 37% of the variability. The amount of cobble had a significant effect, with CPUE declining with increasing cobble cover (Table C-5). The second significant model was for the fraction partially spent for the medium-large (10-13 mm) size class, in which cobble was also the only significant variable. In this case, the fraction partially spent increased with increasing cobble cover.

Residuals from all regression models were typically small, with no pattern in the region about SONGS. There was no indication that values proximate to SONGS were more poorly predicted by the models than values elsewhere. This is a bit surprising since the models did not explain much of the variability in the biological data. However, in 1986 the only significant location effect was for the fraction partially spent in the medium-large size class (main text), and one of our two significant regression models was for these data (Table C-5). In addition, the significant effect of cobble seen in 1986 for fraction partially spent was also evident in the 1983 data (Table C-4).

C.3.3. Temporal variability in the physical characteristics of beaches

Data on the cobble variables for each survey and beach are in Tables C-6 and C-7. It is evident that cobble tends to be more prevalent near SONGS, but it is also obvious (not surprisingly) that beaches are dynamic environments. For example, none of the beach at 0.4 km north of SONGS was classified as uninhabitable (>80% cobble) during the July 1983 survey, while more than 70% of the same shoreline was classified as such one month later. With this variability in mind we repeated our multiple regression procedure for the August 1983 biological data, now using the average of the physical chemical data over the three 1983 surveys. The results, however, were disappointing with relatively few significant models in comparison with the month by month analyses.

It is somewhat puzzling that the grain size variables and beach slope did not appear to be of much importance in 1986, given their inclusion in many of the models for 1983. It might be that sampling these variables on a single date does not give an accurate portrayal of the average conditions that crabs have been exposed to. We have some limited evidence that these physical characteristics of the beach can change rapidly. Table C-8 gives the data on the beach composition at 0.4 K North for the two dates on which it was sampled during 1986. Obviously, the grain size distribution had changed dramatically between the two sample dates separated by only two weeks.

C.3.4. Subtidal cobble

It is possible that the presence of subtidal cobble could make the area about SONGS of poor quality for sand crabs to overwinter, thereby influencing the abundance of large crabs and maximum sizes reached by females. Historically, the shallow subtidal near SONGS and extending about four km to the north is known to consist largely of cobble (J. Kastendiek, *personal communication*). During January 1987, Eco-M conducted a survey of the shallow subtidal (Eco-M 1987). The results indicate that cobble was indeed more prevalent (at least this one time) in the area nearest SONGS than elsewhere (Fig. C-1). We do not attempt to establish statistical relationships between biological variables and subtidal substrate composition since the data come from different times, and the subtidal composition in a particular location is likely to be quite dynamic over the period of a year or more (see discussion below).

C.4. Discussion

It is possible that natural differences in the environment, unrelated to SONGS, could be responsible for the observed location effects. There is no good evidence implicating SONGS, aside from the occasional differences between populations proximate to SONGS and populations elsewhere. Chromium burden in tissues did not provide a general or consistent explanation for patterns in the biological variables (Appendix B), and location effects on sand crabs were not accentuated when SONGS was operating at higher capacity (see Main text).

The results from 1983 suggested that aspects of the beach environment might be influencing sand crab biology. Beach slope, grain size distribution, and the prevalence of cobble, had significant effects on a number of biological variables. These aspects of the physical environment can account for many of the biological attributes of sand crabs living near SONGS.

The details of the 1983 results were not always confirmed in 1986. In 1986, however, few location effects on biological variables were detected. The one significant location effect for 1986 was in the variable "fraction partially spent" for the 10-13 mm (medium-large) size class (Main text, Results). Our regression model for this variable was also one of the two significant models for 1986, and indicated that the prevalence of the partially spent condition is associated with high cobble cover on a beach. This corroborates the relationship between the partially spent condition and the prevalence of cobble seen in the 1983 data (see also Barnett and Green 1984). Other studies of sand crabs have also indicated that beach characteristics such as grain size or the presence of cobble can influence abundance or size distributions of sand crabs (Straughan 1978, Smith and Straughan 1978, Efford 1970).

Given the dynamic nature of the beach environment, combined with site specific, within-year dynamics in the reproductive structure of populations (Appendix D), the lack of completely consistent relationships across sampling dates is not too surprising. Our point estimates of beach characteristics may, at least at times, not accurately reflect the environment to which sand crabs on the beach have been exposed to, and our point samples of the sand crabs may not capture the "average characteristics" of the populations. In addition, different physical factors might be operating at different times, and sand crabs may move, to some extent, among beaches.

Our results do indicate that the beach environment near SONGS differs from beaches farther from the plant. This is obvious when variables related to incidence of cobble are examined: beaches near SONGS tend to be mixed sand and cobble, while most of the other beaches sampled are largely sand. This also appears to be the case subtidally, although the data on this subject are limited. It is not surprising that mixed cobble and sand beaches support less robust sand crab populations (i.e. larger individuals are scarcer, and the spent condition is more prevalent) than beaches composed entirely of sand; after all, sand crabs live and bury themselves in the sand substrate. We are not able to critically distinguish between effects due to beach characteristics and those arising from plant operations at beaches proximate to SONGS, however, because the type of physical environment near SONGS is not found among the other study beaches.

Activities associated with the construction of SONGS Units 2 and 3 undoubtedly had some effects on beaches in the vicinity of the power plant. Sand and other sediments were deposited on the beaches during 1977, and may have contributed to location effects observed that year. In May, 1974, a steel sheet seawall was placed seaward of the eventual site of Units 2 and 3. The area behind the seawall was filled with approximately 150,000 m^3 of sand from nearby bluffs. This construction laydown pad for Units 2 and 3 was in place for a ten-year period (1974-1984) and certainly impacted longshore sand movements (Wanetick and Flick 1986). There appears to have been substantial accretion of sand on the beach extending approximately 1 km immediately upcoast of the laydown pad until 1977 or 1978. At that time, the widening beach reached the end of the laydown pad, and presumably, greater longshore movement of sand ensued (Wanetick and Flick 1986).

During 1977 and 1978, sand spoils from dredging were deposited on the beach downcoast of the plant. Some downcoast erosion of the beach was seen prior to 1978, but was not apparent later on. The steel sheeting holding the laydown pad in place was then removed in December 1984, exposing to longshore transport the sand in the laydown pad, and approximately 450,000 m^3 of sand that had accumulated on the upcoast beach (Wanetick and Flick 1986). Much of this material then moved offshore or downcoast, with the peak of the accretion wave moving downcoast at a rate of approximately 0.6 to 1.1 km per year (Inman 1987).

Exactly how such "construction" impacts on the beaches near SONGS would affect local sand crab populations is unclear, but biological effects cannot be ruled out. The accretion of sand upcoast of SONGS might have even temporarily improved this area as sand crab habitat, by increasing the supply of sand relative to cobble. It is also possible that the release of the sand in the construction laydown pad in 1984 is responsible for some of the differences between the 1983 and 1986 sand crab studies.

If apparent "location effects" are not due to either the construction or operation of SONGS, then it is reasonable to hypothesize that sand crab populations in that vicinity differed from populations at other beaches even before Unit 1 was constructed. To properly assess this hypothesis, detailed data on sand crabs from beaches both near and far from the plant, taken prior to the construction and operations of SONGS, are needed. Unfortunately, such data are unavailable. Limited information on beach characteristics and sand crabs near SONGS was collected prior to the MRC's studies, as part of SCE's monitoring programs for the construction and operation of Units 1, 2 and 3. Results of these studies are reported in the quarterly and semiannual reports to SCE of the San Onofre Oceanographic Survey by Marine Advisors (1963-1972) and Intersea Research (1972-1974), and in SCE's semiannual and annual Environmental Technical Specification operating reports prepared by Lockheed (1974-1976). Note that Unit 1 construction began in 1964, and operations began in 1968, so that even in these early studies the sand crab populations could have potentially been impacted by the construction or operations of Unit 1. Sampling methods changed greatly over the various surveys and were sometimes inappropriate for use on sandy beaches (see independent review in EQA and MBC 1973). Although sampling was done at a range of beaches, the control beaches in these studies were within two km of SONGS.

In spite of their limitations, a few conclusions are possible based on a review of these early data. First, the prevalence of cobble on beaches near SONGS seen during the MRC's studies, is not a new phenomenon. Sometimes sieving of beach samples was not possible because sediments at a location consisted almost entirely of cobble. In addition, the scarcity of larger females at beaches within a few kilometers of SONGS might also not be a new phenomenon. Limited data on sand crab sizes are given in a number of the early reports. These documents indicate that sand crabs in excess of 13 mm in carapace length were rare (less than a few percent) near SONGS. No quantitative comparisons are attempted because sand crab sizes were not always reported, sample sizes were generally small, and collection techniques differed from those of the MRC's contractors. Although there are no comparable data from beaches less proximate to SONGS during this period, these early data suggest that large sand crabs were not common in populations near SONGS, even before Unit 1 began operating, whereas well over half of the individuals in sand crab populations in some other locations (e.g. Efford 1970, Wenner *et al.* 1974), may be in excess of 13 mm in carapace length.

Table C-1

Independent and dependent variables used in regression procedures during 1983. * indicates that the variables were used in principal components, but not separately. References to where these variables are described are included.

Dependent Variables

Variable	Reference
Mean maximum male size.	Main Text
Mean maximum female size.	Main Text
Mean minimum size of females at reproduction.	Main Text
Log of male catch per unit effort.	Main Text
Log of female catch per unit effort.	Main Text
Log of total catch per unit effort.	Main Text
Proportion of medium-small females with spent eggs.	Main Text
Proportion of medium-large females with spent eggs.	Main Text
Proportion of large females with spent eggs.	Main Text
Log of chromium concentration in sand crab tissue.	Appendix B
Log of iron concentration in sand crab tissue.	Appendix B
First principal component of metals in sand crab tissue: (log cadmium, log chromium, log copper, log iron, log manganese, log nickel, log lead, log zinc).	This Appendix

Independent Variables

Variable	Description	Reference
BSLOPE	Beach slope	see Barnett and Green, 1984
SESTON	Seston (mg/liter)	see Barnett and Green, 1984
* COBWAT	Percent of cobble in water	see Barnett and Green, 1984
* COBSAND	Percent of cobble in sand	see Barnett and Green, 1984
* COBWAVE	Percent of cobble in wave	see Barnett and Green, 1984
* GSSKEW	Grain size skewness	see Barnett and Green, 1984
* GSMEDIAN	Grain size median Phi	see Barnett and Green, 1984
* GSDISP	Grain size dispersion	see Barnett and Green, 1984
* GT1PHI	% Coarse sand	see Barnett and Green, 1984
* LT4PHI	% Silt/Clay	see Barnett and Green, 1984
* SEDCARB	Sediment carbon (mg/liter)	see Barnett and Green, 1984
* SEDCHLOR	Sediment chlorophyll (microgram/cm^2)	see Barnett and Green, 1984
* SEDPHAEO	Sediment phaeophyton (microgram/cm^2)	see Barnett and Green, 1984
* WATCARB	Water carbon (mg/liter)	see Barnett and Green, 1984
* WATCHLOR	Water chlorophyll (mg/liter)	see Barnett and Green, 1984
* WATPHAEO	Water phaeophyton (mg/liter)	see Barnett and Green, 1984
PCWATOR1	First principal component of water organic substances: WATCARB, WATCHLOR, WATPHAEO.	This Appendix
PCCOB1	First principal component of cobble variables: COBSAND, COBWAT, COBWAVE.	This Appendix
PCSEDOR1	First principal component of sediment organic substances: SEDCARB, SEDCHLOR, SEDPHAEO.	This Appendix
PCGS1	First principal component of grain size variable: GSDISP, GSMEDIAN, GSSKEW, GT1PHI, LT4PHI.	This Appendix
PCMET1	First principal component of metal concentration in sediment: log cadmium, log chromium, log copper, log iron, log manganese, log nickel, log lead, log zinc.	This Appendix

Table C-2

Independent and dependent variables used in regression procedures during 1986. * indicates that the variables were used in principal components, but not separately. References to where these variables are described are included.

Dependent Variables

Variable	Reference
Proportion of medium-large reproductive females	Main Text
Proportion of large reproductive females	Main Text
Proportion of medium-large females with spent eggs	Main Text
Proportion of large females with spent eggs	Main Text
Proportion of medium-large females with partially spent eggs	Main Text
Proportion of large females with partially spent eggs	Main Text
Catch per unit effort of medium-large female sand crabs	Main Text
Catch per unit effort of large female sand crabs	Main Text
Log of chromium concentration in sand crab tissue	Appendix B
Log of iron concentration in sand crab tissue	Appendix B
Log of manganese concentration in sand crab tissue	Appendix B

Independent Variables

BSLOPE	Beach slope
COBBLE	Per cent cobble cover (GR = gravel)
* GSSKEW	Grain size skewness
* GSMEDIAN	Grain size median PHI
* GSDISP	Grain size dispersion
* GT1PHI	% Coarse sand
* LT4PHI	% Silt/clay
PCGS1	First principal component of grain size variables: (GSDISP, GSMEDIAN, GSSKEW, GT1PHI, LT4PHI).

Table C-3

Coefficients for principal component variables. Asterisks emphasize that coefficients apply to centered and standardized variables (see text).

(1983) PCWATOR1 = 0.52WATCARB* + 0.55WATCHLOR* - 0.65WATPHAEO*

Takes larger values when total organic carbon and chlorophyll are large, but phaeophytin in the water is low.

(1983) PCCOB1 = 0.44COBSAND* + 0.62COBWAT* + 0.65COBWAVE*

Takes larger values when cobble is prevalent.

(1983) PCGS1 = 0.54GSDISP* - 0.55GSMEDIAN* - 0.21GSSKEW* + 0.60GTIPHI* - 0.11LT4PHI*

(1986) PCGS1 = -0.49GSDISP* + 0.55GSMEDIAN* + 0.22GSSKEW* - 0.52GTIPHI* + 0.37LT4PHI*

Larger values indicate a coarser and more variable composition in 1983. The signs of all the coefficients are reversed in 1986, so for that year smaller values indicate coarser and more variable composition.

(1983) PCSEDOR1 = 0.51SEDCARB* + 0.53SEDCHLOR* + 0.67SEDPHAEO*

Larger values indicate more organic material (total carbon, chlorophyll, phaeophytin) in the sediments.

(1983) PCMET1 = 0.38LOGCD* + 0.34LOGCR* + 0.37LOGCU* + 0.37LOGFE* + 0.34LOGMN* + 0.30LOGNI* + 0.33LOGPB* + 0.39LOGZN*

Larger values indicate higher concentrations of metals in sediments.

(1983) First principal component of tissue metals = (0.38LOGCR* + 0.31LOGCU* + 0.44LOGFE* + 0.37LOGMN*) - (0.41LOGCD* + 0.45LOGNI* + 0.25LOGPB* + 0.05LOGZN*)

Larger values indicate that Cr, Mn, Fe and Cu tend to be at high concentration while other metals tend to be scarce.

Table C-4

page 1 of 4

Summary of final multiple regressions of biological variables against physical-chemical variables for 1983.
+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	INDEPENDENT VARIABLES: Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
Mean maximum female size	June	0.64	0.006	Partial R^2	0.5	0.14	—	—	—	—	—
				parameter estimate	2.1*	30.7+	—	—	—	—	—
Mean Maximum Male Size	June	0.64	0.002	Partial R^2	—	—	0.25	0.39	—	—	—
				parameter estimate	—	—	-0.79**	-0.87**	—	—	—
	July	0.30	0.04	Partial R^2	—	—	—	—	—	0.30	—
				parameter estimate	—	—	—	—	—	-0.14*	—
Minimum Size of Reproduction	July	0.43	0.15	Partial R^2	—	0.27	—	—	0.11	—	0.05
				parameter estimate	—	21.4*	—	—	-0.47	—	-0.03
	August	0.55	0.02	Partial R^2	—	—	—	—	0.45	0.10	—
				parameter estimate	—	—	—	—	1.1*	-1.2	—

Table C-4
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Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
					INDEPENDENT VARIABLES						
Male Catch per Unit Effort	June	0.78	0.0001	Partial R^2	—	—	—	0.16	0.62	—	—
				parameter estimate	—	—	—	-1.3*	-1.2***	—	—
	July	0.70	0.0008	Partial R^2	—	—	—	—	0.45	0.25	—
				parameter estimate	—	—	—	—	-1.1**	-0.54***	—
Female Catch per Unit Effort	June	0.49	0.004	Partial R^2	—	—	—	—	0.49	—	—
				parameter estimate	—	—	—	—	-0.95**	—	—
	July	0.52	0.01	Partial R^2	0.26	—	—	—	—	—	0.25
				parameter estimate	1.7*	—	—	—	—	—	-0.1*
Total Catch per Unit Effort	June	0.91	0.0001	Partial R^2	—	—	—	0.14	0.72	—	0.05
				parameter estimate	—	—	—	-1.5***	-1.6***	—	0.03*
	July	0.60	0.004	Partial R^2	—	—	—	—	0.23	0.36	—
				parameter estimate	—	—	—	—	-1.0**	-0.42**	—
	August	0.02	0.58	Partial R^2	—	0.02	—	—	—	—	—
				parameter estimate	—	-4.3	—	—	—	—	—

Table C-4
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Summary of final multiple regressions of biological variables against physical-chemical variables for 1983.
+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	Independent Variables: Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
Mean maximum female size	June	0.64	0.006	Partial R^2	0.5	0.14	—	—	—	—	—
				parameter estimate	2.1*	30.7+	—	—	—	—	—
Mean Maximum Male Size	June	0.64	0.002	Partial R^2	—	—	0.25	0.39	—	—	—
				parameter estimate	—	—	-0.79**	-0.87**	—	—	—
	July	0.30	0.04	Partial R^2	—	—	—	—	—	0.30	—
				parameter estimate	—	—	—	—	—	-0.14*	—
Minimum Size of Reproduction	July	0.43	0.15	Partial R^2	—	0.27	—	—	0.11	—	0.05
				parameter estimate	—	21.4*	—	—	-0.47	—	-0.03
	August	0.55	0.02	Partial R^2	—	—	—	—	0.45	0.10	—
				parameter estimate	—	—	—	—	1.1*	-1.2	—

Table C-4
page 2 of 4

Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	Independent Variables: Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
Male Catch per Unit Effort	June	0.78	0.0001	Partial R^2	—	—	—	0.16	0.62	—	—
				parameter estimate	—	—	—	-1.3*	-1.2***	—	—
	July	0.70	0.0008	Partial R^2	—	—	—	—	0.45	0.25	—
				parameter estimate	—	—	—	—	-1.1**	-0.54***	—
Female Catch per Unit Effort	June	0.49	0.004	Partial R^2	—	—	—	—	0.49	—	—
				parameter estimate	—	—	—	—	-0.95**	—	—
	July	0.52	0.01	Partial R^2	0.26	—	—	—	—	—	0.25
				parameter estimate	1.7*	—	—	—	—	—	-0.1*
Total Catch per Unit Effort	June	0.91	0.0001	Partial R^2	—	—	—	0.14	0.72	—	0.05
				parameter estimate	—	—	—	-1.5***	-1.6***	—	0.03*
	July	0.60	0.004	Partial R^2	—	—	—	—	0.23	0.36	—
				parameter estimate	—	—	—	—	-1.0**	-0.42**	—
	August	0.02	0.58	Partial R^2	—	0.02	—	—	—	—	—
				parameter estimate	—	-4.3	—	—	—	—	—

Table C-4
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Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
					INDEPENDENT VARIABLES						
Large Fraction Reproductive	July	0.97	0.0001	Partial R^2	—	0.94	0.03	—	—	—	—
				parameter estimate	—	-6.0***	0.04*	—	—	—	—
Fraction Partially Spent	—	0.59	0.0001	Partial R^2	—	0.14	0.09	—	—	—	0.35
				parameter estimate	—	1.5*	0.05*	—	—	—	0.01**
Medium-small Fraction Spent	August	0.53	0.046	Partial R^2	—	0.37	0.16	—	—	—	—
				parameter estimate	—	0.65*	-0.01	—	—	—	—
Medium-Large Fraction Spent	July	0.29	0.21	Partial R^2	—	—	0.18	0.11	—	—	—
				parameter estimate	—	—	0.02	-0.06	—	—	—
	August	0.38	0.02	Partial R^2	—	—	—	—	—	0.38	—
				parameter estimate	—	—	—	—	—	-0.11*	—
Large Fraction Spent	June	0.75	0.003	Partial R^2	—	—	—	—	0.75	—	—
				parameter estimate	—	—	—	—	0.17**	—	—
	July	0.54	0.12	Partial R^2	—	0.49	—	0.03	—	0.02	—
				parameter estimate	—	1.6*	—	0.05	—	-0.01	—

Table C-4
page 4 of 4

Dependent Variable	Month	R^2 for Model	P-value for Model	Type of Statistic	INDEPENDENT VARIABLES: Principal Component of Water Organic Substances	Beach Slope	Principal Component of Cobble Variables	Principal Component of Sediment Organic Substances	Principal Component of Grain Size Variables	Principal Component of Sediment Metals	Seston
Chromium in Tissue	August	0.52	0.04	Partial R^2	—	0.49	—	—	0.02	—	—
				parameter estimate	—	11.6*	—	—	-0.1	—	—
Iron in Tissue	August	0.73	0.04	Partial R^2	—	—	0.41	—	0.03	0.30	—
				parameter estimate	—	—	0.23**	—	-0.05	0.08+	—
Principal Component of Metals in Tissue	July	0.56	0.01	Partial R^2	—	—	—	—	—	0.22	0.34
				parameter estimate	—	—	—	—	—	0.8*	0.07*

Table C-5
page 1 of 2

Summary of final multiple regressions of biological variables against physical-chemical variables for August 1986. + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

				INDEPENDENT VARIABLES		
DEPENDENT VARIABLE	R^2 FOR MODEL	P-VALUE FOR MODEL	TYPE OF STATISTIC	PRINCIPAL COMPONENT OF GRAIN SIZE VARIABLES	COBBLE	BEACH SLOPE
Medium-large catch per unit effort	0.37	0.02	Partial R^2	0.02	0.28	0.07
			parameter estimate	-9.5	-1.9**	371.9
Large catch per unit effort	0.16	0.52	Partial R^2	0.11	0.0007	0.04
			parameter estimate	21.6	0.17	543.6
Medium-large Fraction Reproductive	0.18	0.25	Partial R^2	0.03	0.06	0.09
			Parameter estimate	0.03	0.003+	-0.96
Large Fraction Reproductive	0.1	0.7	Partial R^2	0.003	0.08	0.01
			Parameter estimate	-0.005	0.0007	-0.28
Medium-large Fraction Spent	0.16	0.31	Partial R^2	0.09	0.03	0.04
			Parameter estimate	-0.01	-0.0004	0.21
Large Fraction Spent	0.15	0.53	Partial R^2	0.15	0.0009	0.002
			Parameter estimate	0.009	-0.00008	0.04
Medium-large Fraction Partially Spent	0.3	0.06	Partial R^2	0.003	0.29	0.01
			parameter estimate	0.007	0.003*	0.36
Large Fraction Partially Spent	0.31	0.17	Partial R^2	0.09	0.21	0.008
			Parameter estimate	0.05*	0.003+	-0.22

Table C-5
page 2 of 2

Dependent Variable	R^2 for Model	P-value for Model	Type of Statistic	*Independent Variables* Principal Component of Grain Size Variables	Cobble	Beach Slope
Chromium in Tissue	0.07	0.64	Partial R^2	0.0008	0.07	0.0001
			Parameter estimate	-0.009	0.003	0.07
Iron in Tissue	0.03	0.86	Partial R^2	0.003	0.02	0.01
			Parameter estimate	-0.02	-0.003	1.1
Manganese in Tissue	0.08	0.6	Partial R^2	0.06	0.001	0.03
			Parameter estimate	-0.06	0.0009	1.4

Table C-6
page 1 of 2

Environmental data on cobble from the 1983 sand crab surveys. -- indicates that the datum was not available.

XLOCBCH (DISTANCE FROM SONGS IN METERS, NORTH < 0)	PRINCIPAL COMPONENT OF COBBLE VARIABLES (LARGER VALUES INDICATE MORE COBBLE)	% OF BEACH TERMED UNINHABITABLE (> 80% COBBLE)
JUNE 1983 RESULTS		
-115000	-1.05	0
-100000	-1.05	0
-79000	-0.71	52
-15500	1.50	0
-12000	-0.20	0
-65000	-1.02	0
-1500	1.29	0
-400	0.69	38
1500	0.22	0
6500	0.35	38
12000	-1.05	0
18000	-1.05	0
25000	-1.05	0
45000	-0.26	20
65000	-0.55	0
JULY 1983 RESULTS		
-115000	-1.05	0
-100000	-1.00	0
-79000	0.31	38
-15500	--	2
-12000	0.09	0
-6500	-1.05	0
-1500	0.25	44
-400	1.24	0
1500	1.92	0
6500	1.15	0
12000	-0.69	0
18000	-1.05	0
25000	-0.97	0
45000	--	11
65000	2.24	16

Table C-6

XLOCBCH (DISTANCE FROM SONGS IN METERS, NORTH < 0)	PRINCIPAL COMPONENT OF COBBLE VARIABLES (LARGER VALUES INDICATE MORE COBBLE)	% OF BEACH TERMED UNINHABITABLE (> 80% COBBLE)
AUGUST 1983 RESULTS		
-450000	-1.05	0
-115000	--	0
-100000	-1.05	0
-79000	-1.05	55
-15500	1.74	0
-12000	-1.05	0
-6500	-1.05	0
-1500	3.16	1
-400	--	72
1500	1.85	0
6500	4.97	0
12000	--	0
18000	-1.05	0
25000	-1.05	0
45000	-0.83	0
65000	-1.03	0

Table C-7

Percent of beach covered with cobble during the 1986 sand crab survey. GR indicates that gravel, rather than sand or cobble, was present.

XLOCBCH (DISTANCE FROM SONGS IN METERS, NORTH < 0)	% COBBLE COVER
-17500	10
-14000	GR
-12500	GR
-11500	1
-10500	GR
-8500	0
-7500	0
-6500	0
-5500	GR
-4500	40
-1500	50
-400	75
-400 (second visit)	85
0	0
500	75
1500	5
2500	80
3500	25
4500	0
5500	0
6500	15
7500	0
8500	0
9500	0
10500	0
45000	15
65000	0

Table C-8

Physical/chemical variables sampled at 0.4 km north of SONGS during 1986.

DATE	BEACH	% COBBLE COVER	BEACH SLOPE	% SILT/ CLAY	% COARSE SAND	GRAIN SIZE DISPERSION	GRAIN SIZE MEDIAN PHI	GRAIN SIZE SKEWNESS
8-11-86	0.4 K N	75	0.19	0	9.8	0.72	1.7	-0.22
8-29-86	0.4 K N	85	0.13	0.02	47.9	1.3	0.61	-0.05

Attachment 1: Example of final multiple regression output including information on residuals and influence of individual observations (see text).

DEP VARIABLE: LGPSPT
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB)F
MODEL	3	0.04378436	0.01459479	1.932	0.1744
ERROR	13	0.09822934	0.007556103		
C TOTAL	16	0.14201370			

ROOT MSE	0.08692585	R-SQUARE	0.3083
DEP MEAN	0.1318886	ADJ R-SQ	0.1487
C.V.	65.90853		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB)]T]	VARIABLE LABEL
INTERCEP	1	0.11801673	0.07822557	1.509	0.1553	INTERCEPT
BSLOPE	1	-0.22099712	0.58563584	-0.377	0.7120	BEACH SLOPE
COBBL	1	0.002743689	0.001440303	1.905	0.0791	PERCENT COBBLE COVER (GR=GRAVEL)
PCGS1	1	0.05241899	0.02250589	2.329	0.0366	PRINCIPAL COMPONENT FOR GRAIN SIZE

OBS	ID	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
1	-17500	.	0.1221	0.0261	.	.	.		.
2	-14000	.	0.1212	0.0268	.	.	.		.
3	-12500	0.0323	0.0942	0.0298	-0.0619	0.0817	-0.7585	] *]]	0.019
4	-11500	0.3022	0.2077	0.0393	0.0945	0.0776	1.2181	]]**]	0.095
5	-10500	0.0225	0.0375	0.0478	-0.0150	0.0726	-0.2071	]]]	0.005
6	-9500	.	.	.	.	.	.		.
7	-8500	0.2655	0.2022	0.0383	0.0633	0.0780	0.8119	]]*]	0.040
8	-7500	0.0424	0.1707	0.0416	-0.1283	0.0763	-1.6810	] ***]]	0.209
9	-6500	0.0847	0.1023	0.0299	-0.0176	0.0816	-0.2160	]]]	0.002
10	-5500	0	0.1045	0.0483	-0.1045	0.0723	-1.4452	] **]]	0.233
11	-4500	.	0.1501	0.1201	.	.	.		.
12	-3500	.	.	.	.	.	.		.
13	-2500	.	.	.	.	.	.		.
14	-1500	.	0.2543	0.0897	.	.	.		.
15	-400	.	0.2066	0.0775	.	.	.		.
16	0	.	0.0240	0.0526	.	.	.		.
17	500	0.1392	0.1500	0.0580	-0.0108	0.0647	-0.1668	]]]	0.006
18	1500	.	0.1454	0.0269	.	.	.		.
19	2500	0.1250	0.1573	0.0621	-0.0323	0.0608	-0.5319	] *]]	0.074
20	3500	0.1000	0.0571	0.0413	0.0429	0.0765	0.5611	]]*]	0.023
21	4500	.	0.1598	0.0268	.	.	.		.
22	5500	0	0.1287	0.0416	-0.1287	0.0763	-1.6870	] ***]]	0.212

OBS	ID	ACTUAL	PREDICT VALUE	STD ERR PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
23	6500	0.2251	0.0764	0.0461	0.1487	0.0737	2.0169	]]****]	0.397
24	7500	0.1840	0.1224	0.0251	0.0617	0.0832	0.7410	]]*]	0.012
25	8500	0.1935	0.1601	0.0372	0.0334	0.0785	0.4258	]]]	0.010
26	9500	0.1257	0.1641	0.0283	-0.0384	0.0822	-0.4668	]]]	0.006
27	10500	0.1639	0.0937	0.0288	0.0702	0.0820	0.8559	]]*]	0.023
28	12000	.	.	.	.	.	.		.
29	45000	.	0.2947	0.0744	.	.	.		.
30	65000	0.2360	0.2131	0.0515	0.0229	0.0700	0.3277	]]]	0.015

SUM OF RESIDUALS 1.88738E-15
SUM OF SQUARED RESIDUALS 0.09822934
PREDICTED RESID SS (PRESS) 0.1705194

OBS	ID	RESIDUAL	RSTUDENT	HAT DIAG H	COV RATIO	DFFITS	INTERCEP DFBETAS	BSLOPE DFBETAS	COBBL DFBETAS	PCGS1 DFBETAS
1	-17500	.	.	.	.	.	.	.	.	.
2	-14000	.	.	.	.	.	.	.	.	.
3	-12500	-0.0619	-0.7455	0.1177	1.3025	-0.2723	0.0208	-0.1189	0.1353	0.1109
4	-11500	0.0945	1.2434	0.2039	1.0655	0.6293	0.0455	-0.0511	0.3174	0.5016
5	-10500	-0.0150	-0.1993	0.3029	1.9500	-0.1314	-0.0666	0.0251	0.1086	0.1140
6	-9500	.	.	.	.	.	.	.	.	.
7	-8500	0.0633	0.8006	0.1946	1.3888	0.3935	-0.0244	0.0292	0.1948	0.3131
8	-7500	-0.1283	-1.8256	0.2286	0.6699	-0.9937	0.5517	-0.6527	-0.3490	-0.5631
9	-6500	-0.0176	-0.2079	0.1185	1.5402	-0.0762	-0.0551	0.0320	0.0473	0.0388
10	-5500	-0.1045	-1.5156	0.3081	0.9881	-1.0114	-0.9756	0.8090	0.5120	0.4382
11	-4500	.	.	.	.	.	.	.	.	.
12	-3500	.	.	.	.	.	.	.	.	.
13	-2500	.	.	.	.	.	.	.	.	.
14	-1500	.	.	.	.	.	.	.	.	.
15	-400	.	.	.	.	.	.	.	.	.
16	0	.	.	.	.	.	.	.	.	.
17	500	-0.0108	-0.1604	0.4455	2.4630	-0.1438	-0.0080	0.0140	-0.0855	-0.0105
18	1500	.	.	.	.	.	.	.	.	.
19	2500	-0.0323	-0.5167	0.5105	2.5767	-0.5276	0.0330	-0.0044	-0.3472	-0.0740
20	3500	0.0429	0.5457	0.2259	1.6130	0.2948	0.1266	-0.0483	-0.1469	-0.2388
21	4500	.	.	.	.	.	.	.	.	.
22	5500	-0.1287	-1.8339	0.2293	0.6652	-1.0002	0.6231	-0.8231	-0.0529	-0.1853
23	6500	0.1487	2.3378	0.2809	0.4269	1.4610	-0.7971	1.1694	-0.2448	-0.4441
24	7500	0.0617	0.7275	0.0832	1.2642	0.2192	-0.0105	0.0805	-0.0549	-0.0114
25	8500	0.0334	0.4120	0.1836	1.5949	0.1953	0.1641	-0.1472	-0.0158	0.0266
26	9500	-0.0384	-0.4523	0.1063	1.4404	-0.1560	0.0128	-0.0354	-0.0389	-0.0851
27	10500	0.0702	0.8466	0.1036	1.2265	0.2970	0.0141	0.0958	-0.1643	-0.1371
28	12000	.	.	.	.	.	.	.	.	.
29	45000	.	.	.	.	.	.	.	.	.

OBS	ID	RESIDUAL	RSTUDENT	HAT DIAG H	COV RATIO	DFFITS	INTERCEP DFBETAS	BSLOPE DFBETAS	COBBL DFBETAS	PCGS1 DFBETAS
30	65000	0.0229	0.3161	0.3511	2.0533	0.2325	0.1531	-0.1617	0.0581	0.1142

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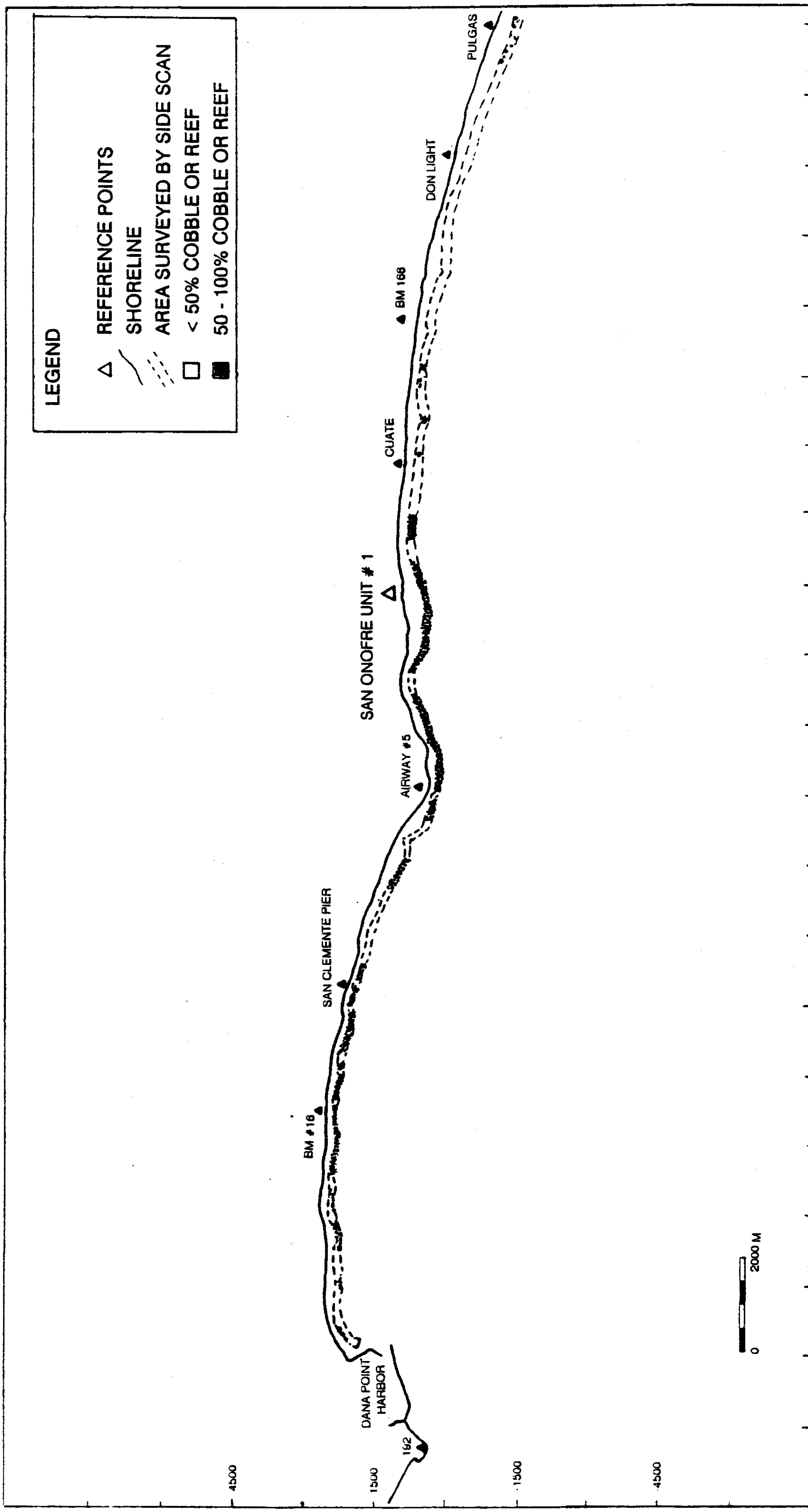
Figure C-1: Results of shallow subtidal survey for cobble. Survey was done on 1/23/87. Coordinates are from the standard MRC coordinate system. Outcrops on beach were visually sited during the survey and from aerial photos.



LEGEND
REFERENCE POINTS
SHORELINE
AREA SURVEYED BY SIDE SCAN
< 50% COBBLE OR REEF
50 - 100% COBBLE OR REEF
PULGAS
DON LIGHT
BM 168
CUATE
SAN ONOFRE UNIT # 1
AIRWAY #5
SAN CLEMENTE PIER
BM #16
DANA POINT HARBOR
192
2000 M
0
10500
7500
4500
1500
-1500
-4500
-7500
-10500
-13500
-16500

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APPENDIX D: ABBREVIATED SURVEYS AND REPRODUCTIVE SYNCHRONY IN SAND CRABS

D.1. Introduction

Reports of abnormal reproduction among sand crabs in the vicinity of SONGS (Wenner 1982; Siegel and Wenner 1984), motivated the MRC to further investigate several traits associated with egg production (see Barnett and Green 1984). Of special concern was the prevalence near SONGS of female crabs bearing allegedly "abnormal" egg masses in which all egg cases were ruptured (spent), a condition which has been attributed to disruption in the normal brooding of eggs (Siegel and Wenner 1984). The significance of these ruptured egg masses is not clear, however, because information on the reproductive cycle of *Emerita analoga* in relation to the spent condition is limited. In this chapter, we attempt to clarify whether reproductive patterns near the generating station were indeed highly atypical, and whether the elevated incidence of the spent condition previously reported from sites near the generating station was still evident in 1983 and 1984. By assessing a number of traits potentially related to egg production, these studies will also increase our general understanding of the sand crab reproductive cycle.

The condition of a female bearing a clutch of spent egg cases is not necessarily abnormal, in and of itself. Females could be carrying masses of ruptured egg cases simply because their eggs have recently hatched. Information on how long females retain empty egg cases on their pleopods following hatching is scant, although it has been claimed that they are removed or sloughed off within several days (Siegel and Wenner 1984). Two processes might contribute to naturally high proportions of crabs in this condition, without involving abnormal disruption of the reproductive cycle: (1) Synchronous hatching within local populations could periodically lead to high proportions of females bearing completely spent egg masses, which would be detected if beaches were sampled at the end of an egg production cycle; (2) Females might tend to retain their empty egg masses for longer times towards the end of the reproductive season, as there would be no need for clean pleopods before deposition of a new batch of eggs. Such differences in the timing of the reproductive cycle could lead to differences in the reproductive characteristics of sand crabs sampled from different beach sites at the same time. Consequently, sites sampled on a monthly basis (approximately the duration of a brood cycle: Cox and Dudley 1968; Fusaro 1980) could exhibit consistent differences in the proportions of crabs in different reproductive states simply because populations from the various beaches are assessed during different stages of their reproductive cycle.

Earlier MRC studies of sand crab reproductive variables did not reveal whether patterns in the prevalence of the spent egg condition among beaches might be due to among-site variability in the timing and duration of the reproductive cycle. In the main text of this volume, we simply tested for "location effects", i.e. systematic trends with distance from SONGS in the proportions of female sand crabs carrying all intact eggs, spent eggs, or partially-spent egg masses, on beaches at varying distances from the generating station. We also investigated the possibility of an association between the first two of these reproductive variables and the magnitude of the discharge volumes from SONGS (Main text, Results). Those sets of analyses could provide circumstantial evidence for an effect of SONGS, but would not clarify the potential mechanisms giving rise to those patterns. We report here on two studies aimed at clarifying the etiology of this potential indicator of disrupted egg production.

The first study, done in 1983, addressed two primary questions. First, sites were sampled from late August to mid-October, to determine whether females might tend to retain their spent egg cases towards the end of the reproductive season. Second, the study supplements the three comprehensive surveys taken during the summer of 1983, by continuing to assess the commonness of the spent egg condition at beach sites over a broad geographic range. This would further clarify whether levels of the spent condition in the region about SONGS are anomalously high, or within the range encountered at other beaches along the southern California coast.

The second study, done in 1984, was designed primarily to investigate whether sand crab populations exhibit synchronous reproduction. From July to September, data were collected on detailed aspects of sand crab reproduction and shell morphology using an approximately weekly sampling interval, from three sites near SONGS, and a site at La Jolla Beach, 65 km south of the generating station. These data, with such a short time interval between sampling surveys, will help clarify how duration of reproductive season, and timing of egg release and development, vary within and among local populations of female crabs, and how these factors might influence patterns in the prevalence of the spent egg condition.

D.2. Methods

D.2.1. 1983: abbreviated surveys

Five abbreviated surveys, consisting only of collections of sand crabs, with no accompanying data on the physical environment, were done on selected beaches from late August through mid-October, 1983. Sand crabs were sampled opportunistically using a shovel. Only crabs from sieve size 5 or larger (>6.3 mm in carapace length) were retained for analyses (see Barnett and Green 1984 for details).

Data on the percentage of females with intact egg masses (100 * number of individuals with intact eggs / total number of female crabs) and the percentage of females with spent eggs (100 * number of individuals with only spent eggs / total number of female crabs) were plotted in two ways and visually examined for trends. Totals from within-site patches were pooled before calculating these values, to avoid overweighting estimates from sparse patches. The first set of plots consists of the values for each of the variables from all sites, depicted along an axis of longshore distances from SONGS for each survey. The second set of plots is of the relative change in the percentage of reproductive individuals with spent eggs (100 * number of individuals with spent eggs / total number of individuals with spent or intact eggs) against time, at each of the sites surveyed through September. These plots include values from the three earlier comprehensive surveys (see main text). Percentages were only calculated from samples totalling more than five individuals.

D.2.2. 1984: studies of reproductive synchrony

Field and laboratory methods

Sampling of several characteristics relating to sand crab reproduction and molt cycle was done at approximately weekly intervals on four beaches, including three in the vicinity of SONGS, and La Jolla (65 km south of the generating station). We will restrict our discussion here primarily to the sites 6.5 and 0.4 km north, and 65 km south of SONGS, since the beach 1.5 km north of the generating station was sampled on only three occasions. The site at 1.5 km North was sampled because it was believed that this beach might have to substitute for the original choice of 0.4K North, since it appeared as though 0.4K north might not provide a sufficient number of crabs for analyses. This turned out not to be the case, so further sampling at 1.5K North was abandoned. Observations were collected from the height of the breeding season in early July, until late August, 1984. Additional surveys were conducted at La Jolla until early October, to document any changes in reproductive variables at the end of the breeding season for that site.

For each survey, approximately 100-200 female sand crabs were collected by shovel from at least three different patches (where possible) at a given site, and then sorted by size using a sieving method. A subsample of approximately half of the females from two size classes (7-10 and 10-13 mm in carapace length), was then classified into different categories relating to reproduction and molt cycle.

External reproductive condition of individual female crabs was evaluated. The presence or absence of eggs was noted, and if eggs were present, the egg mass was categorized into one of three color levels--bright orange, burnt orange, or gray, representing sequentially later stages of egg development. The presence and prevalence of the spent egg condition was also evaluated for each individual, with categories of intact egg masses (<15% spent egg cases within the egg mass), partially spent egg masses (15-85% of egg cases in the spent condition), and totally spent egg masses (>85% of egg cases in the spent condition). The total number of reproductive females is defined as the sum of the number of intact, spent and partially spent individuals. The proportions of the reproductive population in the spent, partially spent, and intact egg mass conditions were calculated by dividing the individual totals for each condition by the total number of reproductive females, and then expressed as percentages. In all cases, proportions were calculated after pooling the numbers from patch subsamples.

Two additional characters were documented. Internal reproductive state was evaluated by dissecting specimens and examining their ovaries, which were classified as having developed or undeveloped oocytes. Carapaces were classified into three conditions--hard, semi-hard, or soft, with a softer shell being evidence of more recent molting.

Analytical methods

The data were plotted through time separately for each site, and the plots were visually examined for distinct modes or other temporal patterns. Strong peaks in values of the variables through time among a population of crabs would be evidence for their reproductive synchrony. Unimodal or monotonic patterns in the values would potentially indicate seasonal trends in reproduction, while polymodal patterns could indicate both local synchrony in the cycling of the relevant variable, and the possibility of multiple brood production within a season.

We employed two statistical tests to augment our interpretations of any patterns in the plots of the data. Together we use these tests to evaluate whether the reproductive structure of the populations changed through time, and whether such changes were gradual and systematic in contrast with random and uncorrelated values through time. A sequence of uncorrelated values is what might occur if changes through time were due solely to variations in factors such as sampling efficiency (perhaps because of a short term change in behavior by crabs in response to high surf, for example).

Multiway contingency analyses were run to test for effects of time, location, and "time-by-location" interactions on the levels of each of the variables. For each variable, the numbers of crabs within each level of the variable were classified into cells representing site and survey combinations. Survey dates were categorized into one of 12 time intervals for these analyses. A log-linear analysis (using maximum likelihood estimation) was then used to test whether the proportions associated with each cell deviated from the marginal probabilities of the overall matrix of values (SAS 1985). A significant time effect indicates changes through time that were common to all the populations sampled. A significant time-by-location interaction indicates changes through time that were unique to one or more of the populations.

We used the Durbin-Watson test for serial correlation in order to differentiate slow and systematic changes from one survey to the next, from fluctuations arising from random variability uncorrelated in time, perhaps due to responses to short-term events. Positive serial correlation among adjacent residuals, after factoring out the overall mean level for the site, would be evidence for slow and systematic dynamics. The data were tested for serial correlations within each level of a variable (e.g. the proportions of crabs in each egg color category), and across all sites simultaneously, to provide sufficient sample sizes. In order to determine probability levels for the results, the null distribution of the Durbin-Watson statistic was approximated using the most accurate of the three methods given in Stewart-Oaten (1986).

D.3. Results

D.3.1. The 1983 study

The abbreviated surveys documented patterns in reproduction among sites towards the end of the reproductive season. The two major findings of these studies were: (1) females with completely spent egg masses sometimes constituted a high proportion of the population at beaches far removed from SONGS; and (2) the prevalence of this spent condition appears to be related to reproductive season, with elevated levels occurring later in the season at all sites (Figs. D-1 - D-3). The data also provide evidence that the reproductive season ends at different times on different beaches.

Female crabs bearing only completely spent eggs were observed at every site sampled on all abbreviated surveys prior to October (Table D-1; Figs. D-4 - D-6). At least 10% of the females were in this condition at some time over the duration of the study at every site. There was an indication that fewer crabs had spent eggs at the three most southerly beaches, where the proportions in this condition never rose above 14%, while the other sites all exceeded 32% with spent eggs for at least one of the surveys (Table D-1; Figs. D-4 - D-6). Substantial proportions of females with completely spent egg cases were documented from populations at all the northerly sites, however, and not just those in the vicinity of SONGS. In fact the highest proportion with spent eggs observed at any of the sites over all the surveys was 51%, at the site 100 km north of SONGS during early September (Fig. D-4). Levels of the spent egg condition were greater than 10% from both 100K North and 115K North on all of the abbreviated surveys. This is in contrast with the claim that such levels of the spent condition do not occur at beaches far from SONGS (Siegel and

Wenner 1984). More recently, Wenner (1988) has also reported high values from beaches north of Los Angeles. Proportions with spent eggs at sites in the vicinity of SONGS (within 10 km) were roughly similar to one another (Fig. D-5).

At the four northerly sites, no crabs with intact clutches of eggs were collected during the last two surveys (Table D-1). While catch per unit effort was not measured during the abbreviated surveys, crabs were obtained in lower numbers and with greater difficulty at all sites on consecutively later surveys in September, and were absent from the two most southerly sites (45 and 65 km south of SONGS) assessed in October (Table D-1). Thus, these surveys appear to have documented the termination of the reproductive season in 1983. The reproductive season may have ended later among sand crabs on the two most southerly sites, as they were the only two beaches where females with intact egg cases were collected on the September surveys (Table D-1). This percentage was low at 45K South during early September (3%: Fig. D-4) and had declined to 0% by September 23 (Fig. D-5), while the population at 65K South had a moderate proportion with intact eggs during the final two surveys of September (27% and 24%, respectively; Figs. D-5 - D-6). By October, however, sand crabs were not found at either of these southerly sites (Table D-4).

Females carrying intact egg cases were rarer than might be expected if such a condition were representative of "normal" reproduction during the time period of the abbreviated surveys. The absence of females carrying clutches of intact eggs at more northerly sites was not restricted to beaches in the region of SONGS, but included the populations from beaches 100 and 115 km north of the generating station. Females with intact egg masses were absent from all four sites ranging from 100 km north to 1.5 km south of SONGS in early September (Table D-1; Fig. D-4), and remained absent from sites over a similar geographical range (115 km north to 6.5 km south of SONGS: Figs. D-5 - D-6) on subsequent surveys taken during mid- and late September.

While the proportions of the female population bearing eggs fluctuated considerably over the entire set of surveys from 1983 (including the three comprehensive surveys of June, July and early August (main text); and the abbreviated surveys from late August to early October, focused on here), examination of the relative prevalence of females with spent as opposed to intact (non-spent) egg cases over this entire period indicates that the spent condition tended to reach or match seasonal highs later in the season (Figs. D-1 - D-3). This pattern was not as clear at sites where females with intact clutches of eggs were never common (e.g., 115K North and 6.5K North). At those sites the spent condition was prevalent early in the season as well as on later surveys at those sites, becoming slightly less common during the height of reproduction in July and August. At all sites, however, the percent of reproductive individuals in the spent egg condition tended to be at, or near, the highest values late in the season (Figs. D-1 - D-3).

D.3.2. The 1984 study

Measures of a number of traits potentially related to the egg production cycle provided evidence for reproductive synchrony within local populations of crabs. Statistical tests revealed that values for the different characters were often varying in a systematic fashion from survey to survey, indicative of long-term processes, rather than simply erratic and random fluctuations. These sustained patterns were generally more pronounced in the larger size class of crabs. Evidence for reproductive synchrony also varied on different beaches, with crabs at 0.4K North appearing quite strongly synchronized, while crabs at 65K South showed minimal indications of synchrony. Below we describe the results for each of the variables assessed.

Carapace condition

Carapace condition was measured because the entire process of egg production and brooding must occur within a molt cycle. Thus, synchrony in molting could lead to reproductive synchrony, especially if the period of the egg production cycle approximates the duration of the molt interval. Here, a soft carapace is evidence that molting has recently occurred. The results suggest that there is marked synchrony in the molt cycle within some populations, and that the timing of the molt cycle differs among populations.

Sand crabs exhibiting semi-hard or hard shells, together, typically accounted for greater than 90% of the individuals on a beach, while crabs with soft carapaces almost always comprised only a small proportion (<10%) of the individuals, and were frequently altogether absent from samples. (Figs. D-7 - D-9). We eliminated the soft-shelled category from the contingency analyses, due to its general sparseness.

The prevalence of the hard and semi-hard carapace conditions changed through time, and did so differently from beach to beach ($P<0.0005$ for effects of time and time-by-site interactions in both size classes of crabs [Table D-2]). For the smaller individuals, the general levels of the two shell hardnesses were also affected by site ($P<0.0005$), while for the larger size class, differences between sites were not as evident ($P<0.10$; Table D-2). Since both time and the interactions of time with site were significant in both size classes, these results not only indicate that there were changes in the relative levels of shell hardness through time, but that the patterns of these temporal changes differed from beach to beach. As it is likely that the temporal effect arises from either seasonal factors or localized synchrony in molting, the significant interaction terms for both size classes emphasize that populations from different beaches are not all in phase with one another.

Changes through time in the proportions of crabs with hard or semi-hard carapaces also did not appear to simply be due to random fluctuations. Longer, more systematic trends in the changing levels of shell types were indicated by positive serial correlations among the residuals from successive surveys for larger crabs (Durbin-Watson test, $P<0.05$ for each of the three carapace hardnesses). Tests for positive serial correlation in the 7-10 mm size class were nearly significant for the hard and semi-hard carapace types (Durbin-Watson test, $P<0.10$). Examination of the plots reveals long-term (seasonal trends). The soft carapace condition was more prevalent in earlier surveys, and hard carapaces tended to dominate later in the season (Figs. D-7 - D-9).

Ovarian condition

The ovarian cycle appears to be related to egg production in some crustaceans (Haefner 1977), so we examined data on the presence of developed or undeveloped oocytes within the ovaries to provide another possible assay for reproductive synchrony (Figs. D-10 - D-12). Over the duration of this study, populations did not appear to be randomly fluctuating about the mean levels for these two conditions, but showed trends indicating both seasonal changes and possible synchrony in ovarian condition. There was a marked tendency for the proportions of crabs with developed oocytes to decline as the season progressed--

evidence for a reduction in the production of broods as the season progressed (Figs. D-10 - D-12).

Levels of developed and undeveloped oocytes not only varied through time, but also varied among sites, and showed different temporal patterns at different sites. Strong evidence for an *increase* to a peak value, *followed* by a marked *decline*, was found only at the 0.4K North site (Fig. D-11). The proportion of 7-10 mm females in this category increased monotonically from 14% on July 5 to a maximum of 52% with developed oocytes by July 19, followed by monotonic declines to below 1% by August 16. Proportions of females with developed oocytes in the 10-13 mm size category at 0.4K North were also generally much higher in July than August (Fig. D-11). No conspicuous peaks were evident in data from the remaining sites (Figs. D-10, D-12). The levels of crabs with developed oocytes tended to be higher at the 65K South and 6.5K North sites than at 0.4K North--ranging roughly from 50-80% for most of the surveys (Figs. D-10, D-12). In contrast, the prevalence of developed oocytes among 7-10 mm females at 0.4K North peaked at 52%, with the other surveys ranging from 0 to 33%; and while 10-13 mm females at 0.4K North did exhibit up to 80% with developed oocytes, most of the surveys showed values below 40% (Fig. D-11).

Statistical support for the patterns discussed above follows. Levels of developed and undeveloped oocytes differed significantly from site to site for larger crabs, and from survey to survey for both sizes of females ($P<0.0001$ for effect of site on oocyte levels in large females; $P<0.0001$ for effect of time on both sizes of females; Table D-2). The highly significant interaction terms show that these temporal patterns differed on various beaches ($P<.0001$ for both size classes). Furthermore, these patterns might result from systematic changes in ovarian condition, such as would arise from a seasonal trend or synchrony in reproductive cycling, rather than erratic fluctuations due to, e.g., sampling error (Durbin-Watson tests for positive serial correlation: $P<0.0001$ for large crabs; $P<0.05$ for smaller crabs). Temporal patterns in ovarian development, together with the statistically significant time by location interactions suggest that egg production might have started later at the 0.4 K North site, than at the other sites.

Egg color

Distinct peaks or systematic changes in the prevalence of crabs with different egg colors would indicate the existence of at least moderate amounts of reproductive synchrony. However, it should be emphasized that the durations of the three egg color stages are not known, precluding rigorous interpretation of trends in the data. It is believed that eggs exhibit the bright orange coloration for the longest duration, followed by the burnt-orange color, only briefly occurring in the gray color phase just prior to hatching (see Barnett and Green 1984).

Patterns in the prevalence of the different egg colors were suggestive of both seasonal trends, as well as local reproductive synchrony. The levels of the different egg color stages did not vary significantly from site to site ($P>0.25$ for both size classes; Table D-2), although more developed egg stages (burnt-orange and gray) appeared to be more prevalent among larger crabs from 65 km south of SONGS, compared with the other sites (Figs. D-13 - D-15). This might reflect greater brooding success among the crabs at that site. (Our failure to detect a significant site effect might result from the overall scarcity of crabs in the well developed categories, leading to a relatively small contribution to the statistical results.)

The values for the various egg colors varied through time among the larger females, as indicated by the multiway contingency analyses ($P < 0.0001$; Table D-2), although time had little effect on egg color levels in small females ($P > 0.50$). Among the larger crabs, no site-by-time interaction was detected, suggesting that temporal changes affected the different sites in similar fashion ($P > 0.50$ for the interaction term; Table D-2). Differences in patterns of temporal change between sites among the smaller crabs were indicated by the statistically significant for site-by-time interaction ($P < 0.0001$; Table D-2).

Fluctuations in the levels of bright-orange eggs among larger females were indicative of long-term patterns, such as might be expected from reproductive synchrony or a strong seasonal component in egg production (Durbin-Watson test for positive serial correlation, $P < 0.0001$). Fluctuations in levels of burnt-orange and gray eggs showed no indications of serial correlations for either size class. Both of these egg-color categories were often absent on surveys (probably because of their short duration (Siegel and Wenner 1984)), and almost always much less common than the levels for bright-orange eggs (Figs. D-13 - D-15). It is possible that the lack of serial correlation for these stages of egg development stems from the shorter duration of these stages in comparison with the bright-orange stage (e.g. Siegel and Wenner 1984).

The generally low levels for the burnt-orange and gray egg categories make it possible that reproductive synchrony will be manifested as strong peaks in the data, rather than as systematic trends. On two occasions the patterns in the succession of peaks for the different color stages were consistent with the developmental sequence of eggs: at 6.5K North for larger crabs, and 0.4K North for smaller crabs, peaks in bright-orange eggs were followed consecutively by peaks in burnt-orange and then gray eggs (Figs. D-13 - D-14). There was a pronounced peak in the prevalence of gray eggs among smaller females at the 65K South site--potentially indicative of reproductive synchrony, as gray eggs were absent on the preceding and subsequent surveys (Fig. D-15). The large crabs at 0.4K North also showed separate modes in the prevalence of the burnt-orange and gray eggs, but it was not possible to discern whether they were arrayed through time in the proper developmental sequence, due to a lack of information from earlier in the season (Fig. D-14).

Completely spent, partially spent, and intact egg mass conditions

Several conclusions emerge from the analyses of patterns in the overall prevalence of reproductive individuals, and the relative prevalences of females bearing intact egg masses, egg masses with some ruptured eggs (partially spent), and egg masses with completely ruptured eggs (completely spent). There appears to be a strong seasonal component to reproduction, egg production increasing from July to mid-August (Figs. D-16 - D-18), then decreasing from September onward for the site sampled through October (Fig. D-18). The relative prevalence of the completely spent egg condition also showed a seasonal tendency, with increasing representation during later surveys at sites where it initially appeared in low levels (Figs. D-19 - D-21). The completely spent condition varied widely in commonness from site to site, however, being the predominant reproductive state over the duration of the surveys for one of the sites (Fig. D-19). Still, at all three sites, the spent egg condition constituted the majority of reproductive females for at least one survey (Figs. D-19 - D-21).

Patterns in the prevalence of reproductive individuals, i.e., females bearing any type of egg mass--with or without ruptured eggs, were significantly affected by beach site, as well as time ($P < 0.01$, and $P < 0.0001$, for effects of site on proportions of reproductive females in the small and larger size classes, respectively; and $P < 0.0001$ for effect of time on reproductive proportions in both size classes; Table D-2). There were also strong indications that changes in the prevalence of reproductive individuals through time were different on different beaches (interaction of time with site, $P < .0001$ for both size classes; Table D-2). Site-specific differences in the effects of time could arise from events varying on a local scale (for example, a patch of plankton-rich water passing a beach, as well as other local oceanographic conditions such as wave-wash intensity), and might influence the onset of egg production, or egg development rate among the sand crabs on a beach (Wenner *et al.* 1987). The difference in timing of reproductive patterns from site to site is particularly obvious when contrasting 65K South with the other sites. At 65K South, extremely high proportions of large female individuals were bearing eggs in early July, and continued to do so until September (Fig. D-18). At the other sites, and for small females at 65K South, percentages of reproductive females increased markedly from July through mid-August (Figs. D-16 - D-18).

The significant effects of time revealed by the multiway contingency analysis may not simply reflect differences due to random fluctuations, but variability arising from more long-term trends, especially in the larger females (Durbin-Watson test for positive serial correlation; $P < 0.0001$ for 10-13 mm females, $P < 0.15$ for 7-10 mm females). In conjunction with the significant interaction terms from the multiway contingency analyses, these results and examination of the plots indicate that the long term trends probably reflect seasonality in egg production, which appears to vary from beach to beach: continually high egg production among large individuals at 65K South, peaks in reproduction during mid-August for both size classes at 0.4K North, and increasing representation of reproductive females through August 23, the last date assessed for 6.5K North (Figs. D-16 - D-18).

Surveys at La Jolla (65K South) were continued into October, and appeared to document the end of the reproductive season: smaller crabs became extremely sparse on the beach; and the proportions of larger crabs with eggs declined. The minimum percentage of large reproductive individuals on surveys prior to September being 90%, while the maximum value from the last three surveys (for which there were sufficient numbers of crabs to make the calculation) was 75% (Figs. D-18).

We next consider patterns in the relative prevalence of reproductive females categorized by characteristics of their egg masses (Figs. D-19 - D-21): intact (<15% ruptured eggs), partially spent (15-85% of eggs ruptured), and completely spent (>85% ruptured eggs). Unfortunately, the frequent scarcity of reproductive individuals precluded using a multiway contingency analysis to test for the effects of site and time on these patterns, so we primarily rely on examination of the plotted results (Figs. D-19 - D-21). Still, the data reveal that the completely spent egg condition can become quite prevalent at sites far removed from the vicinity of SONGS, and appears to do so later in the season (bottom half of Fig. D-21). The spent egg condition may thus represent a population retaining ruptured egg cases after producing a final brood for that reproductive season. General levels of the completely spent egg condition varied widely from site to site, however.

The proportional representation of females with intact eggs relative to the other two egg mass types was usually lowest at the 6.5 km North beach, with a maximum value of 20% on one occasion (found in the larger crabs), and most of the other values well below 10% (Fig. D-19). The majority of reproductive females in both size classes at 6.5K North always had completely spent egg cases. On the other hand, females with intact eggs were generally in the majority at 65K South, for both size classes (Fig. D-21). Late in the season, the proportion with intact egg masses appeared to decline amongst the larger size class at 65K South. The pattern for smaller females at this site could not be determined late in the season due to their scarcity (Fig. D-21).

The tendency for the relative proportion of reproductive females with intact egg cases to decline later in the season is also reflected in the patterns for both size classes of females at 0.4K North (Fig. D-20). There is a concomitant rise in the relative proportions of crabs bearing spent egg cases at 0.4 km North with both size classes showing values of around 80% or higher on the final survey of August 23. The late season declines in the relative prevalence of intact egg cases at the 65K South were also matched by increases in females carrying completely and partially spent egg masses. The relative prevalence of the completely spent condition peaked at 68% on September 21 for the larger females at 65 km South, and was generally high for the three final surveys from that site (Fig. D-21). There were no obvious temporal trends in the relative prevalences of the different egg case types at the site 6.5 km North of SONGS (Fig. D-19).

The relative abundances of reproductive females with partially spent egg masses ranged widely, but were generally highest at 0.4K North (Figs. D-19 - D-21). This potentially "abnormal" condition, however, was documented from all sites, and on two occasions greater than 40% of the individuals collected from La Jolla (65K South) had partially spent egg masses (Fig. D-21).

The proportional representation of the intact, partially-spent and completely spent egg cases conditions did not fluctuate randomly from survey to survey. Systematic or long-term trends were evident in the patterns for the intact and completely spent conditions among larger crabs (Durbin-Watson test for positive serial correlation: $P<.0005$). For smaller crabs, only the completely spent condition showed significant positive serial correlation among residuals from consecutive surveys ($P<0.05$). This failure to detect serial correlation may reflect the scarcity of data values for analysis of the smaller crabs (i.e, low power), and not the lack of real patterns. (Power analyses were not done because standard methods for calculating power for this type of analysis are not available, and the issue at stake did not warrant the substantial effort of developing estimates of power through simulation procedures.) However, the plot for small females from 0.4K North, for example, is highly suggestive of a decline in the intact egg condition, and a late season increase the prevalence of the completely spent condition (Fig. D-20).

D.4. Discussion

We draw several conclusions from the results. First, moderate to high levels of females carrying masses of completely ruptured egg cases were commonly observed at sites far removed from SONGS. The levels of completely spent egg cases documented from sites near SONGS are not so high as to be outside the range found on other beaches within the southern California bight, and so are not "anomalous" or "abnormal" to the extent that they might be if similar levels could not be found elsewhere. Second, the prevalence of the spent condition appears to vary seasonally, its occurrence becoming more common later in the reproductive season. Since we also found evidence that sand crab populations on different beaches might conclude their reproductive seasons at different times, comparisons among beaches in the prevalence of the spent egg condition may lead to spurious conclusions if the potential effect of a seasonal component is not considered. Natural variability in environmental factors, such as food supply, can dramatically affect local patterns in reproduction (Wenner, *et al.* 1987), and contribute to site-specific differences in the timing of the onset and conclusion of the reproductive season. Care is needed to document whether elevated levels of the spent egg condition simply indicate the end of the reproductive season on that beach.

Examination of temporal patterns in several traits related to egg production indicate that local populations may be in reproductive synchrony. This possibility recommends caution when interpreting patterns in reproductive variables documented from surveys taken at monthly intervals. If a pulse of food can induce synchrony in molting (Siegel 1984), it might also tend to synchronize the egg production cycle. Samples from a particular beach may capture a population that is in a different phase of its reproductive cycle than populations at other beaches. When surveys are done at monthly intervals, populations may be repetitively sampled in the same phase of their reproductive cycles, since this duration approximates a normal brood cycle (Cox and Dudley 1968; Fusaro 1980). This could lead to consistent differences in populations from different beaches purely because of artifacts due to the sampling regime.

The abbreviated surveys revealed that the prevalence of the spent egg condition could become quite common among females on beach sites far removed from SONGS. The claim of "abnormally" high levels of the spent condition in the region near the generating station must be re-considered since roughly equivalent levels in this condition do indeed occur elsewhere. Of course, the prevalence of spent egg cases at these other sites could result from perturbations affecting the populations in those regions. The abbreviated surveys also revealed apparent peaks in reproductive activity, during which the prevalence of crabs bearing intact egg cases was extremely high, occasionally accounting for greater than 80% of the female population on the southernmost beaches during some of the earlier comprehensive surveys (Main text, Results). The proportions of females with clutches of spent egg cases at the two southernmost sites were low during those early surveys, increasing later in the season as the proportions with intact egg cases declined. These results, as well as those from 100K North, support the hypothesis that the spent egg condition normally rises to higher levels towards the end of the reproductive season.

The 1984 study involved measuring aspects of ovarian condition, external reproductive condition and stage in the molt cycle of female sand crabs from beaches at approximately weekly intervals during the summer and fall of 1984. These measures provided indications that local populations (within a beach site) do indeed exhibit at least some reproductive synchrony, as well as a seasonal component in egg production. Similar to the results from 1983, the prevalence of the completely spent egg condition appeared to increase later in the reproductive season, reaching moderate to high levels on all beaches.

The evidence for reproductive synchrony stems from a number of sources. The regularity of patterns in the prevalence of the hard and semi-hard shell conditions suggests synchronous molting, which may correlate with synchronization of the reproductive cycle. Measures of ovarian and egg conditions are more directly related to the reproductive cycle of female crabs and also provided evidence of reproductive synchrony. A pronounced peak in the prevalence of small crabs with developed ovaries at 0.4 K North provides strong evidence for reproductive synchrony at that site. None of the other beaches showed strong modes, but rather indicated broader seasonal trends in oocyte development: the prevalence of crabs with developed ovaries decreased, and with undeveloped ovaries increased, later in the season.

Distinct peaks in the occurrence of crabs with different egg colors were sometimes observed, and provide support for the reproductive synchrony hypothesis. The degree of synchrony, however, did appear to vary substantially among the three sites. This may be due to local differences in environmental conditions entraining reproductive synchrony to varying degrees.

Overall patterns in the prevalence of reproductive individuals, i.e. females bearing all types of egg clutches, as well as patterns in the relative proportions of the females with intact, partially spent or completely spent egg masses, further supported earlier observations of seasonality in reproduction, and of increasing prevalence of the spent egg condition late in the season. Even the site 65 km south of SONGS showed moderate to high levels of both the completely and partially spent conditions in the larger crabs on the final surveys in late September and October.

In principle, the information on ovarian development, and the proportions of the population carrying eggs of different colors, and clutches of spent eggs, and the proportion of crabs with hard or soft carapaces, could be combined to provide a description of the phenology of reproduction on each beach. However, because the connection between ovarian development and egg production, and the duration of the different egg color stages are not well documented any such attempt is admittedly speculative. Nonetheless, it is obvious that the phenology of reproduction differed among the beaches during the 1984 study. For example, the results at 0.4K North strongly suggest synchronized reproduction, with a peak of reproduction in August, and successful hatching and a sharp build up of crabs with spent eggs by September. In contrast, reproduction appears to be much less synchronized at La Jolla. The proportion of the larger crabs that were reproductive remained more constant, and the build up of crabs with spent eggs at the end of the reproductive season was more gradual. In contrast with either of these sites, the fraction spent remained high throughout the season at 6.5K North, and this probably indicates less successful reproduction at that site.

The studies examined in this report were devised because of concern that the reproductive patterns of sand crabs in the region of SONGS were abnormal (Siegel and Wenner 1984; Wenner 1982). The primary evidence for aberrant egg production was the finding that high proportions of females within 20 km of the generating station were bearing completely spent egg cases. It was suggested that this was evidence for disruption of egg production, i.e., premature rupturing of eggs, although abortion of developing eggs was not directly observed (Siegel and Wenner 1984).

The results from the studies described in this chapter thus have direct implications for the interpretation of other data collected for the MRC on reproductive variables in sand crabs. Since the duration of the reproductive season can vary from site to site, samples from single points in time, or even several surveys over the summer, may fail to accurately characterize the reproductive characteristics of the populations during that year. Crabs on some beaches could be past their peak of egg production, while others are currently at maximum production. Variability in the prevalence of the spent egg condition may also simply be reflections of these differences in the timing and duration of reproductive season from site to site.

Reproductive synchrony would also affect patterns in the prevalence of traits related to egg production. Ideally, we need observations from all sites, taken over the duration of the reproductive season, with a sampling regime that is frequent enough to avoid the pitfalls of sampling over an interval approximating the duration of a brood cycle. Such a sampling regime would prevent the confounding of differences in timing of the reproductive season between sites with "location effects" of greater interest.

Past MRC studies involved comparing patterns in reproductive variables from sites sampled a few times at monthly intervals, or even sampled only once over the entire reproductive season. Clearly, certain types of conclusions regarding differences in the reproductive performance of crabs from different beaches sites, made on the bases of such sparse sampling regimes, must be regarded with caution. With regard to potential impacts of SONGS, overall conclusions regarding the importance of differences in sand crab reproduction among sites rests on their repeated occurrence over a number of different years, and in their temporal association with events that can be linked to SONGS.

Table D-1

Summary of patterns in the prevalence of the intact and completely spent egg conditions during the abbreviated surveys of 1983. Values for the intact and completely spent entries represent percentages of the total female population. Values for the percent reproductive with spent eggs is 100 * (completely spent/sum of intact and completely spent). A blank indicates site was not sampled. -- indicates no crabs were found.

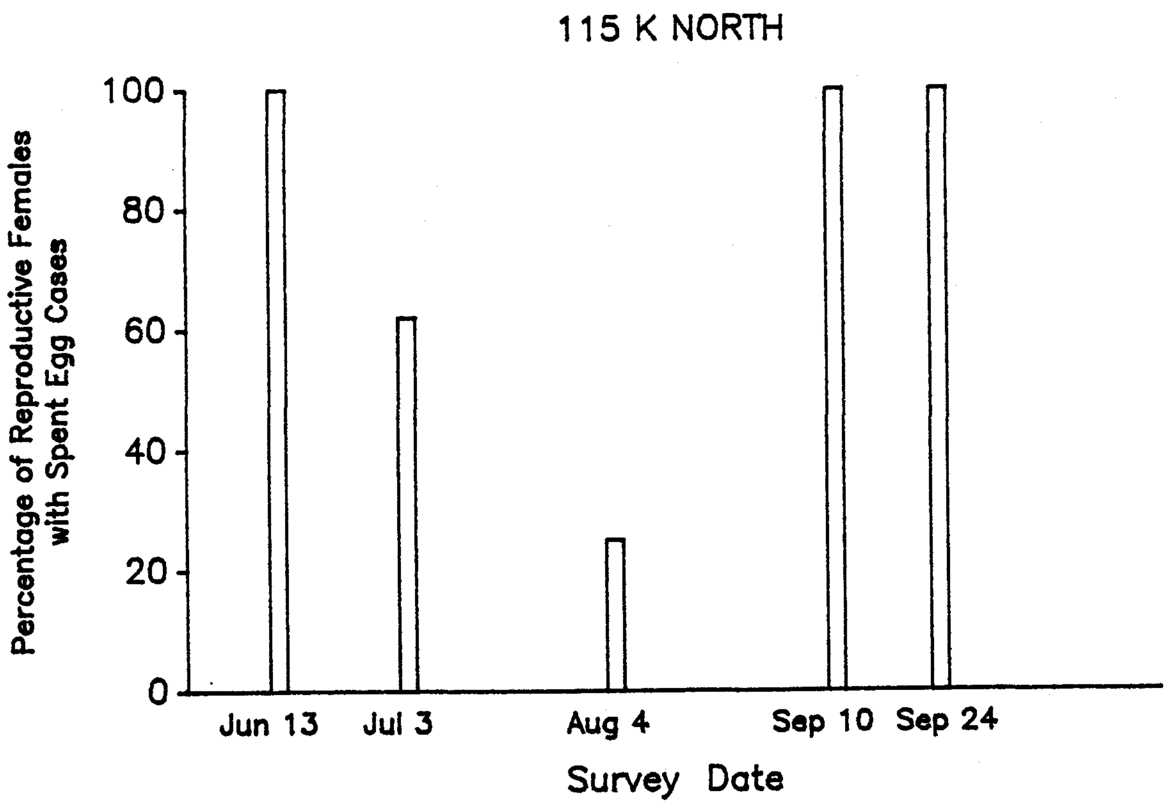
SURVEY DATE	CONDITION OF EGG MASS (%)	STUDY SITE 115K N	100K N	6.5K N	6.5K S	45K S	65K S
Aug. 30 - Sept. 3	% Intact		0	0		2.8	
	% Completely spent		51.8	25.5		7.7	
	% Reproductive with spent eggs		100	100		73.6	
Sept. 9 - Sept. 10	% Intact	0	0	0	0	3.3	27.4
	% Completely spent	32.4	11.9	36.6	12.0	13.3	11.1
	% Reproductive with spent eggs	100	100	100	100	80.1	28.8
Sept. 23 - Sept. 24	% Intact	0	0	0	0	0	23.9
	% Completely spent	20.9	10.5	10.2	6.0	1.6	7.0
	% Reproductive with spent eggs	100	100	100	100	100	22.7
Oct. 5	% Intact					--	--
	% Completely spent					--	--
	% Reproductive with spent eggs					--	--
Oct. 19	% Intact					--	
	% Completely spent					--	
	% Reproductive with spent eggs					--	

Table D-2

Effects of time, site, and time by site interactions on the proportions of sand crabs exhibiting different levels for characters related to egg production in 1984. Results are χ^2 values from multiway contingency analyses. * indicates $p < 0.05$. ** indicates $p < 0.005$.

		SMALLER CRABS (7-10 MM)			LARGER CRABS (10-13 MM)		
TRAIT	TREATMENT	χ^2	d.f.	P	χ^2	d.f.	P
CARAPACE	time	77.09	10	0.0001**	492.09	11	0.0001**
HARDNESS	site	17.39	2	0.0002**	5.74	2	0.06
(semi-hard	time x site	135.63	14	0.0001**	127.50	14	0.0001**
or hard)	intercept	0	1	0.99	5.14	1	0.02*
OOCYTE	time	114.46	10	0.0001**	372.05	11	0.0001**
DEVELOPMENT	site	0.63	2	0.73	21.46	2	0.0001**
(developed or	time x site	101.49	14	0.0001**	289.00	14	0.0001**
undeveloped)	intercept	1.96	1	0.98	0.03	1	0.87
EGG COLOR	time	7.43	16	0.96	72.99	24	0.0001**
(bright orange,	site	0	4	1.0	4.92	4	0.30
burnt orange	time x site	176.01	15	0.0001**	19.41	26	0.82
or gray)	intercept	0	2	1.0	0	2	1.0
REPRODUCTIVE	time	157.23	10	0.0001**	321.98	12	0.0001**
STATE	site	9.16	2	0.01*	31.24	2	0.0001**
(presence or	time x site	150.41	14	0.0001**	230.57	14	0.0001**
absence of eggs)	intercept	0	1	0.99	22.60	1	0.99

Figure D-1: Changes through time in the percentages of reproductive crabs that had completely spent egg cases at the sites 115 and 100 km north of SONGS. Data are from both the comprehensive surveys and the abbreviated surveys of 1983.


115 K NORTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
Jun 13
Jul 3
Aug 4
Sep 10
Sep 24
Survey Date

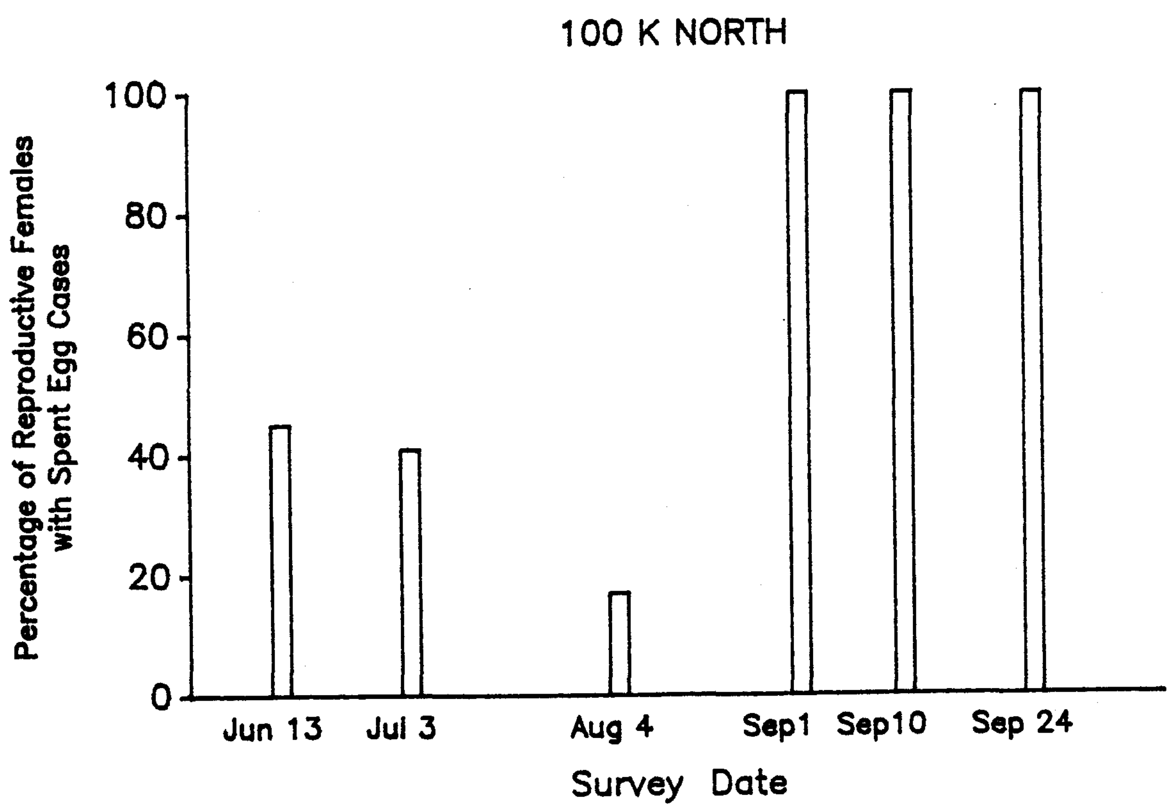
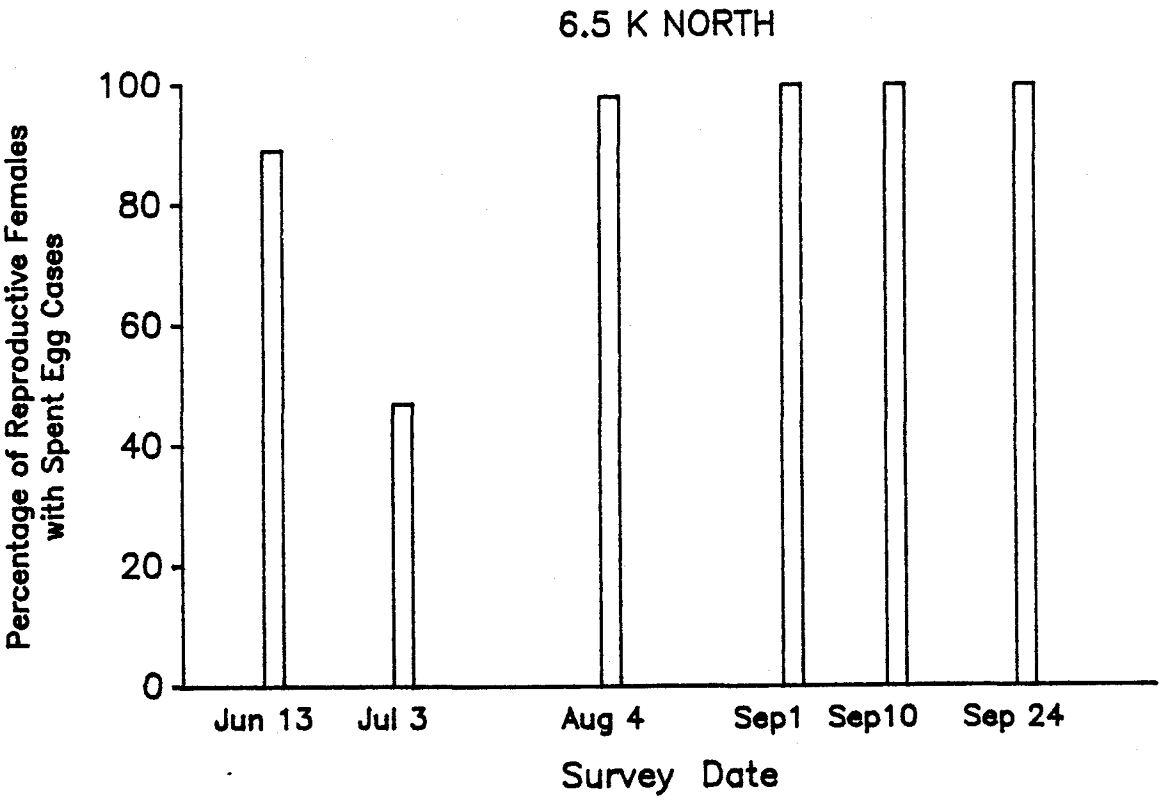

100 K NORTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
Jun 13
Jul 3
Aug 4
Sep1
Sep10
Sep 24
Survey Date

Figure D-2: Changes through time in the percentages of reproductive crabs that had completely spent egg cases at the sites 6.5 km north, and 6.5 km south of SONGS. Data are from both the comprehensive surveys and the abbreviated surveys of 1983.


6.5 K NORTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
Jun 13
Jul 3
Aug 4
Sep1
Sep10
Sep 24
Survey Date

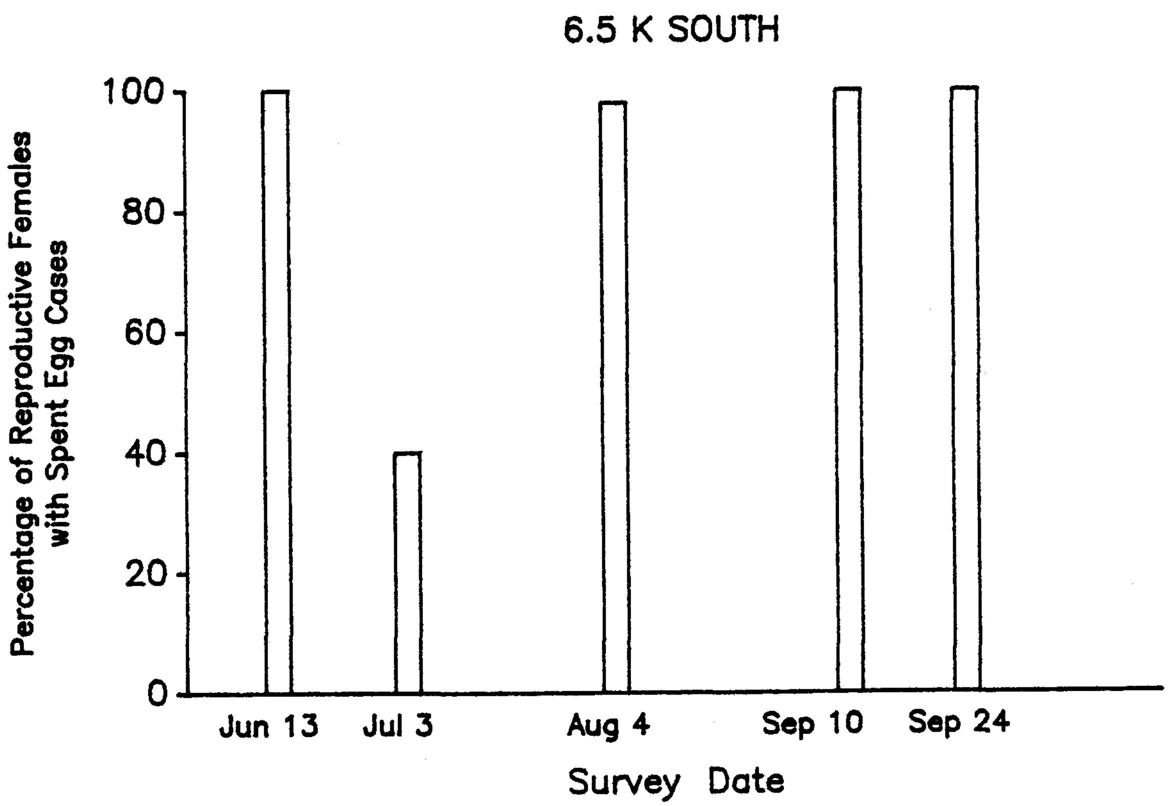
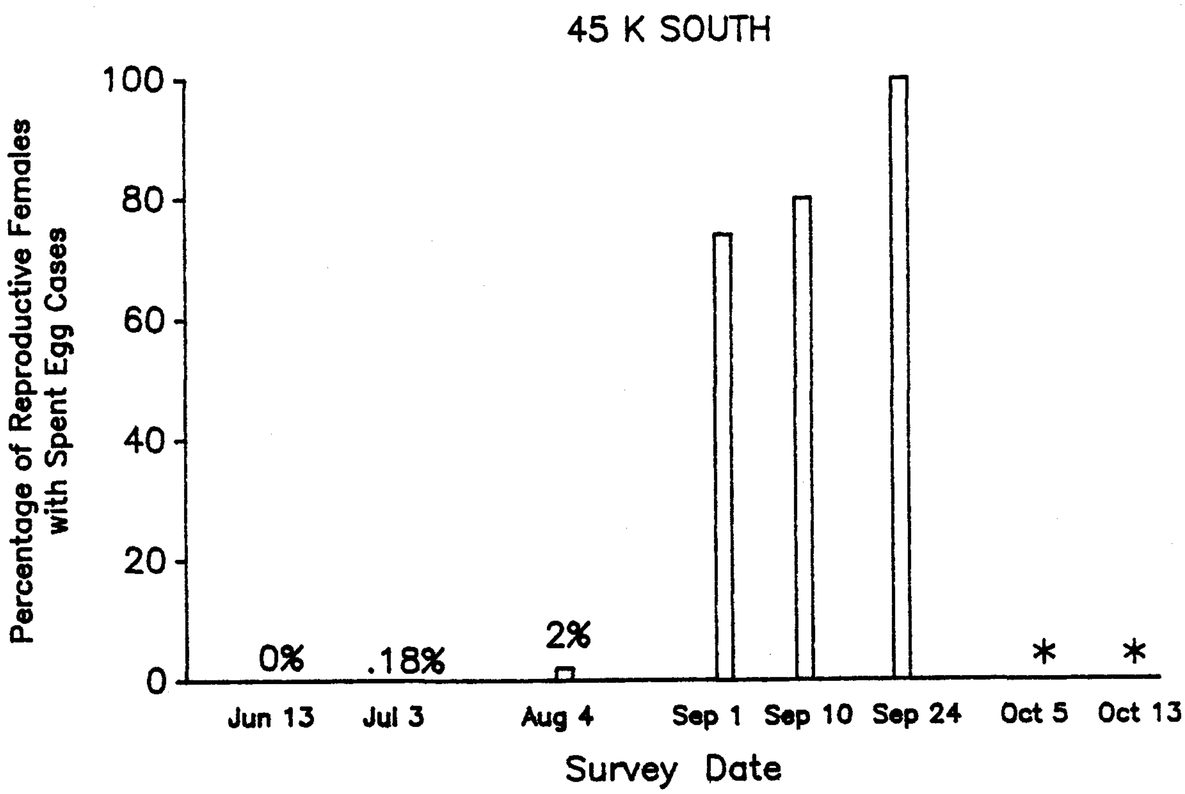

6.5 K SOUTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
Jun 13
Jul 3
Aug 4
Sep 10
Sep 24
Survey Date

Figure D-3: Changes through time in the percentages of reproductive crabs that had completely spent egg cases at the sites 45 and 65 km south of SONGS. Data are from both the comprehensive surveys and the abbreviated surveys of 1983. * indicates that site was sampled, but no crabs were found.


45 K SOUTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
0%
.18%
2%
*
*
Jun 13
Jul 3
Aug 4
Sep 1
Sep 10
Sep 24
Oct 5
Oct 13
Survey Date

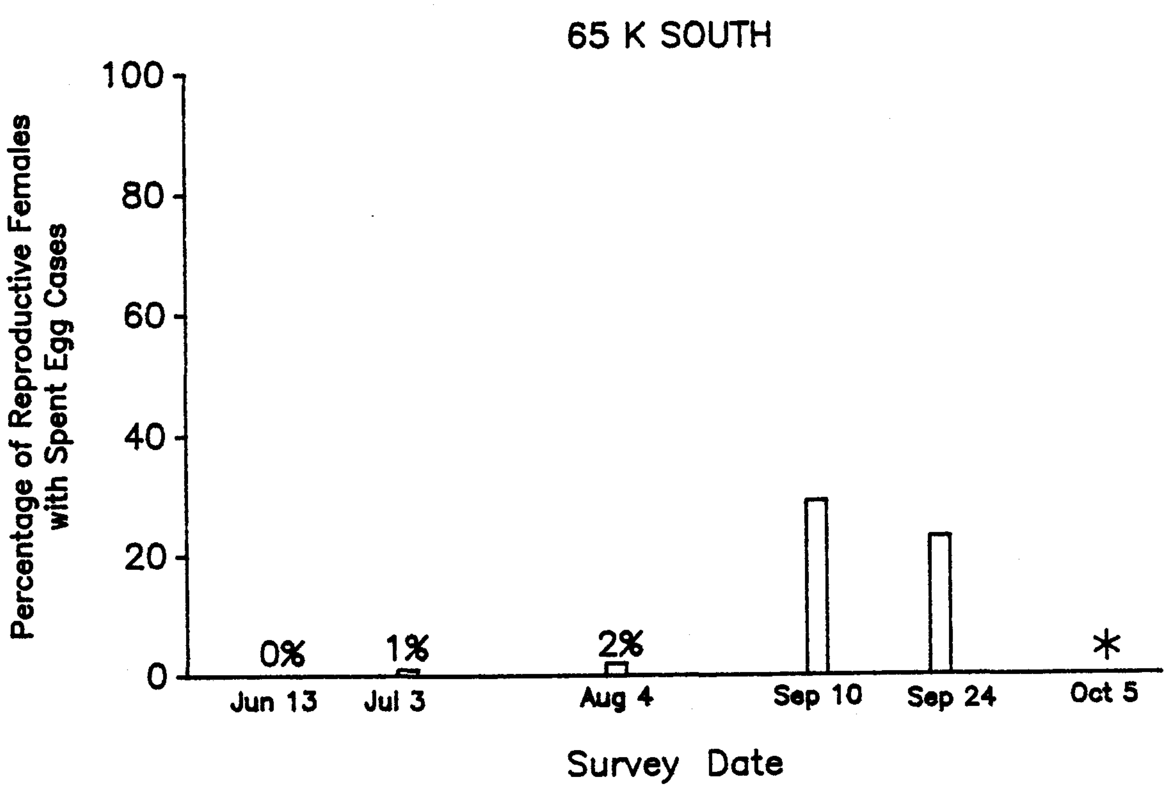
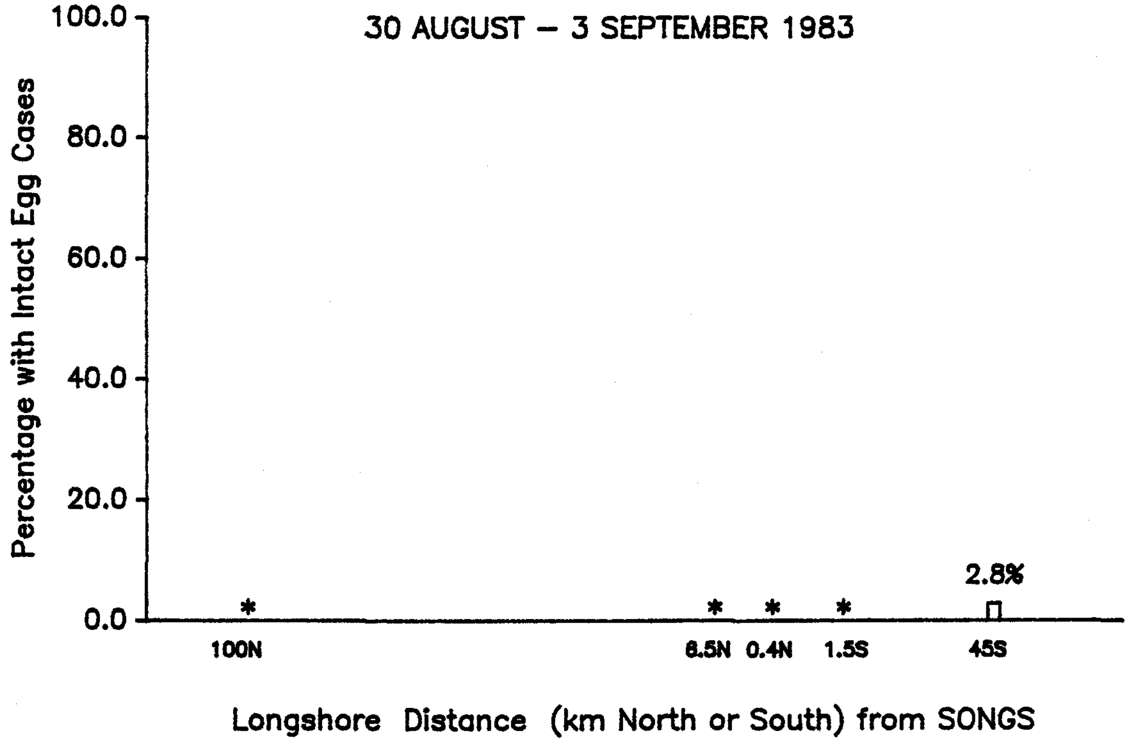
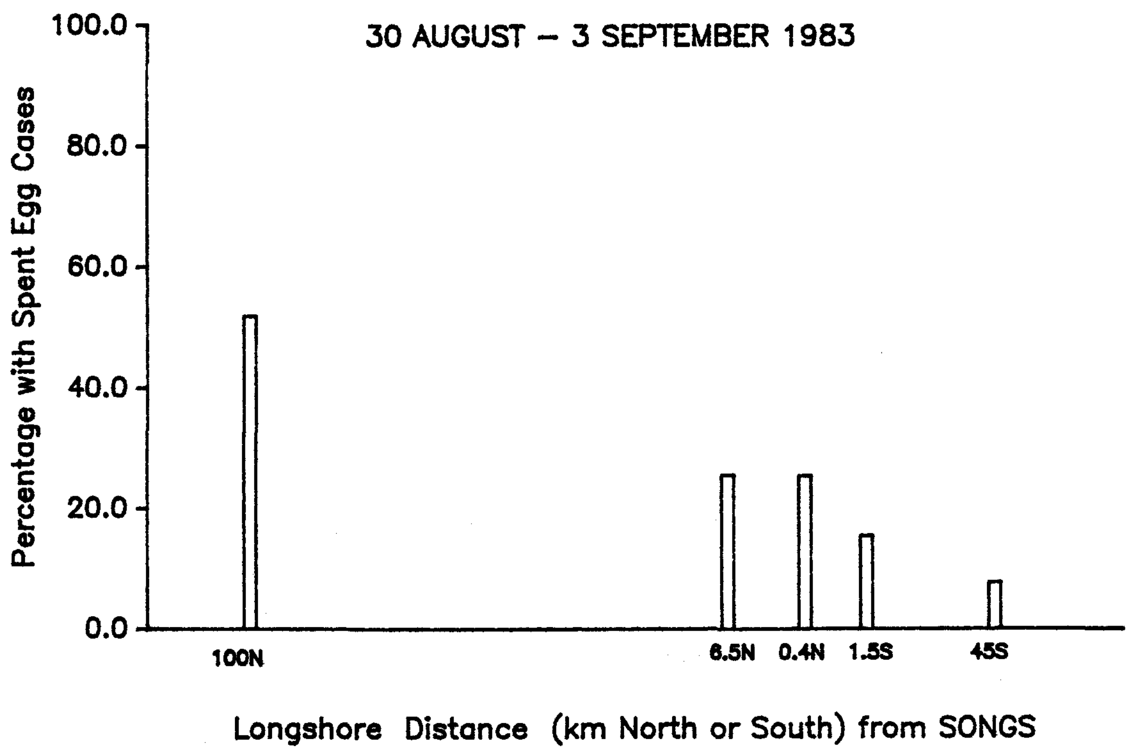

65 K SOUTH
Percentage of Reproductive Females with Spent Egg Cases
100
80
60
40
20
0
0%
1%
2%
*
Jun 13
Jul 3
Aug 4
Sep 10
Sep 24
Oct 5
Survey Date

Figure D-4: Percentages of crabs with intact or completely spent egg cases during the first abbreviated survey of 1983. * indicates a zero value for that site.

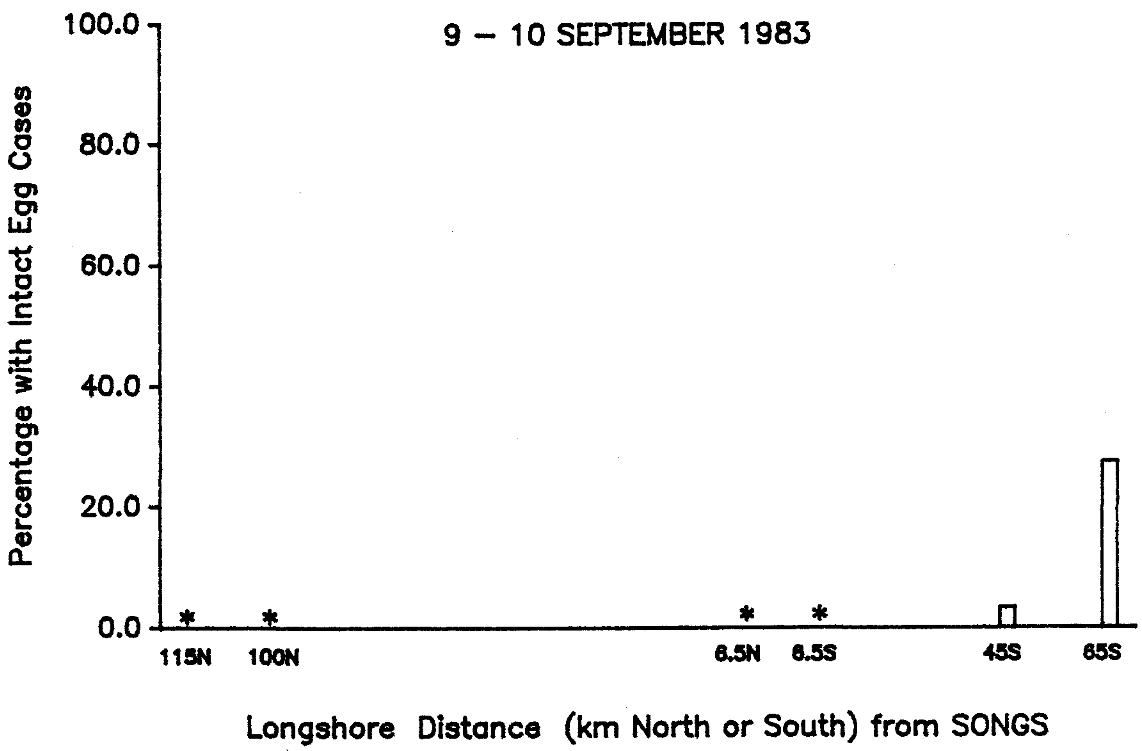


30 AUGUST – 3 SEPTEMBER 1983
Percentage with Intact Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
2.8%
*
100N
6.5N
0.4N
1.5S
45S
Longshore Distance (km North or South) from SONGS



30 AUGUST – 3 SEPTEMBER 1983
Percentage with Spent Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
100N
6.5N
0.4N
1.5S
45S
Longshore Distance (km North or South) from SONGS

Figure D-5: Percentages of crabs with intact or completely spent egg cases during the second abbreviated survey of 1983. * indicates a zero value for that site.


9 – 10 SEPTEMBER 1983
Percentage with Intact Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
115N
100N
6.5N
6.5S
45S
65S
Longshore Distance (km North or South) from SONGS

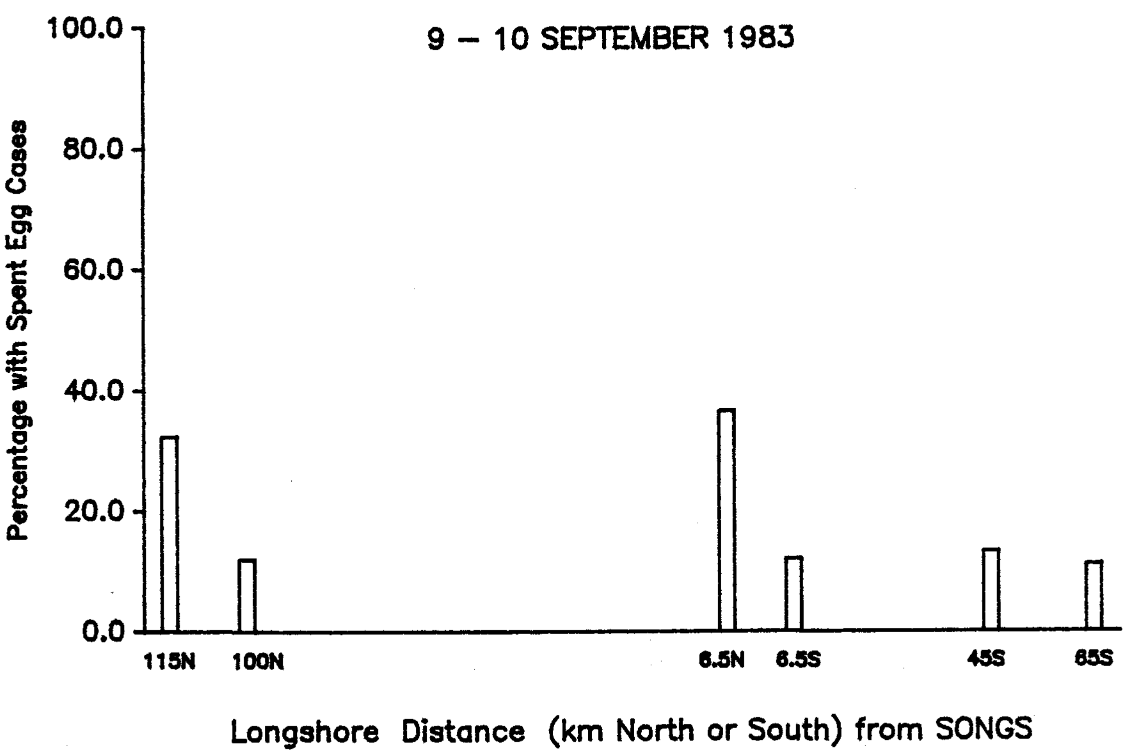
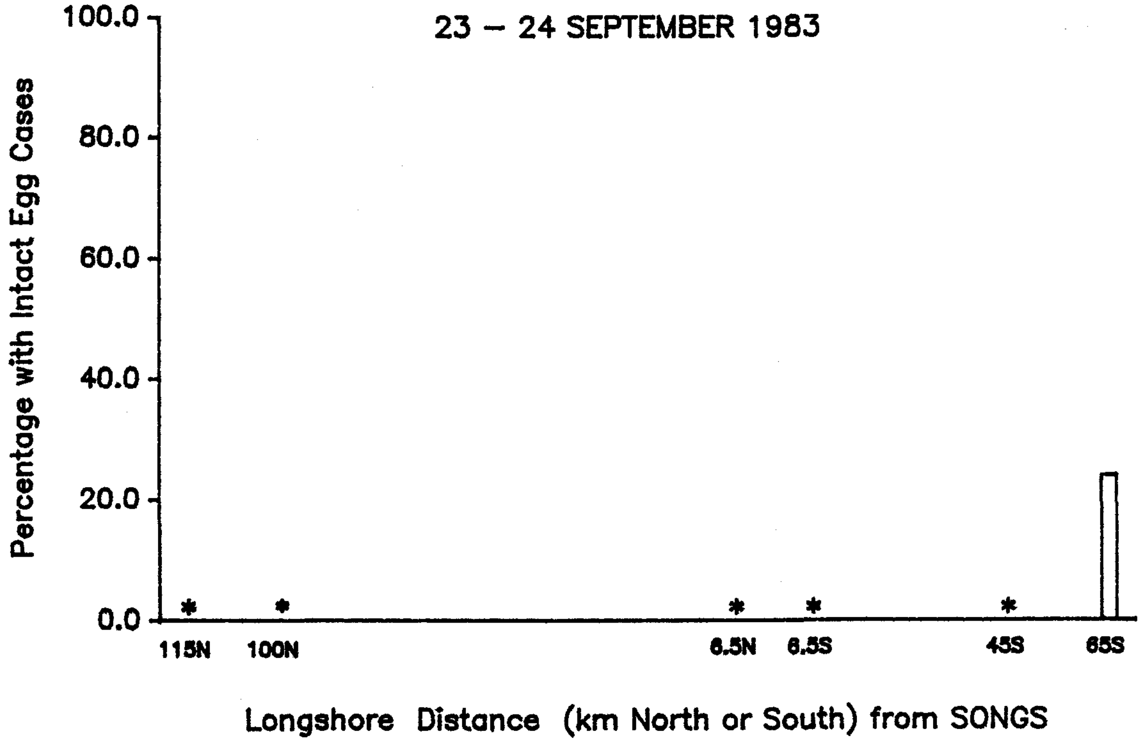

9 – 10 SEPTEMBER 1983
Percentage with Spent Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
115N
100N
6.5N
6.5S
45S
65S
Longshore Distance (km North or South) from SONGS

Figure D-6: Percentages of crabs with intact or completely spent egg cases during the third abbreviated survey of 1983. * indicates a zero value for that site.


23 – 24 SEPTEMBER 1983
Percentage with Intact Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
115N
100N
6.5N
6.5S
45S
65S
Longshore Distance (km North or South) from SONGS

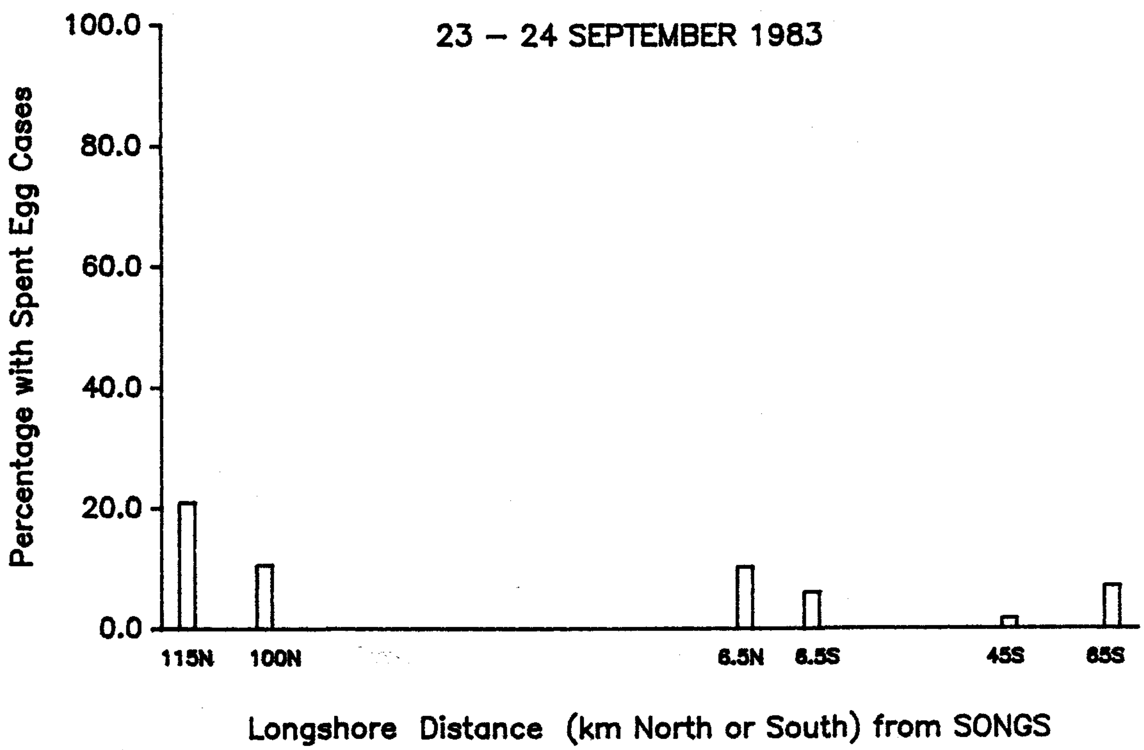
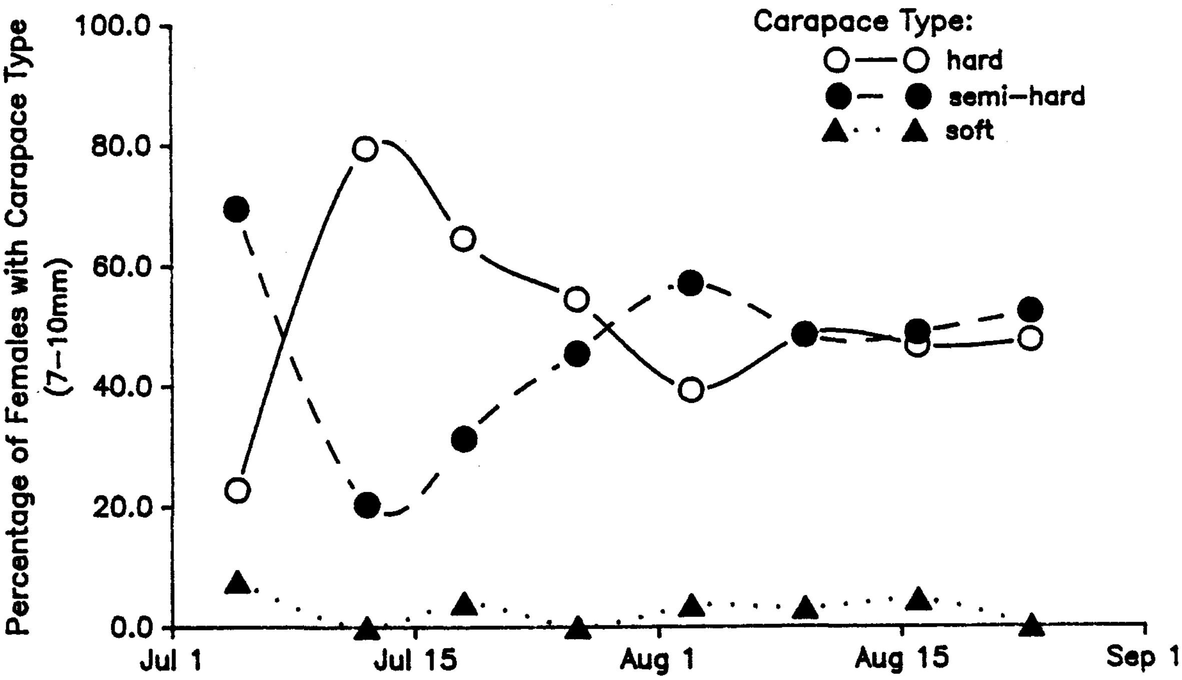
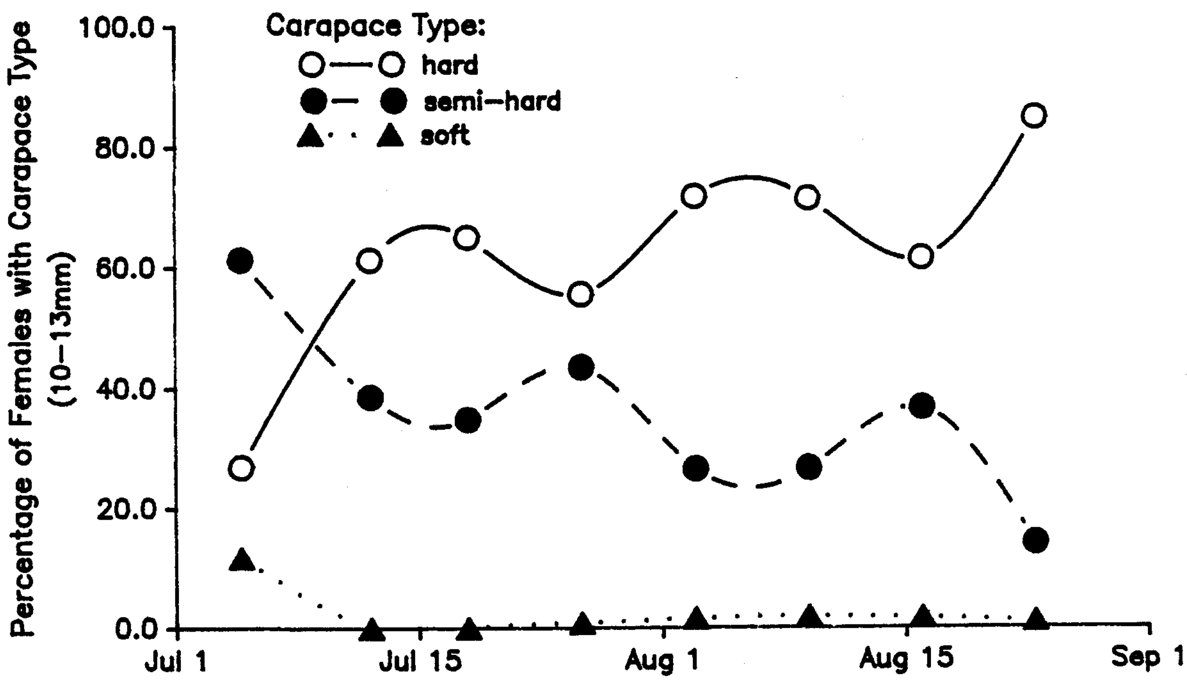

23 – 24 SEPTEMBER 1983
Percentage with Spent Egg Cases
100.0
80.0
60.0
40.0
20.0
0.0
115N
100N
6.5N
6.5S
45S
65S
Longshore Distance (km North or South) from SONGS

Figure D-7: Changes through time in the percentages of females with different carapace types from the site 6.5 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.

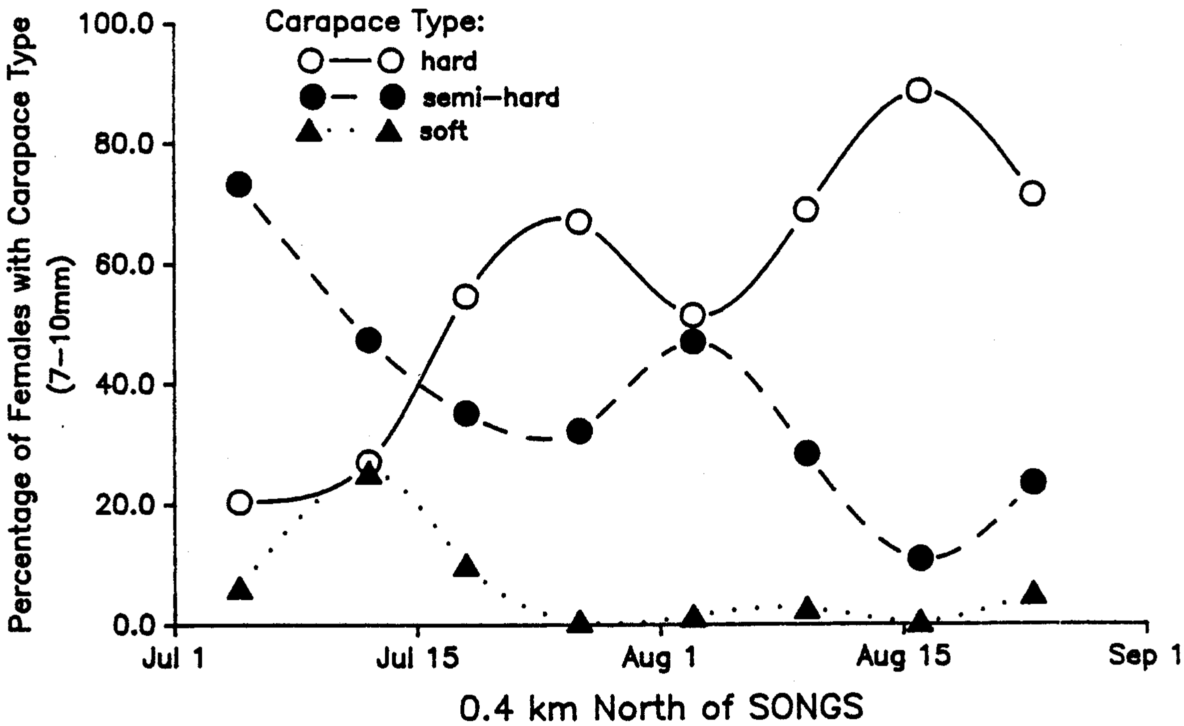


6.5 km North of SONGS



6.5 km North of SONGS

Figure D-8: Changes through time in the percentages of females with different carapace types from the site 0.4 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.


Carapace Type:
hard
semi-hard
soft
Percentage of Females with Carapace Type (7–10mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

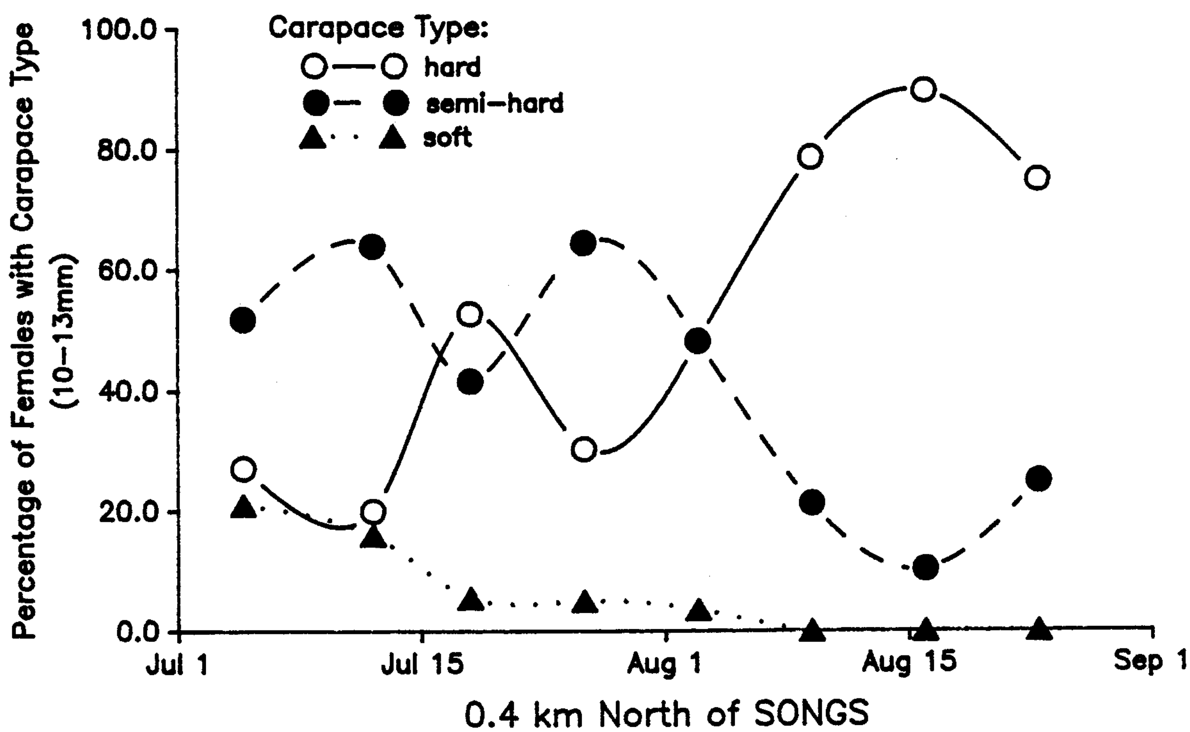
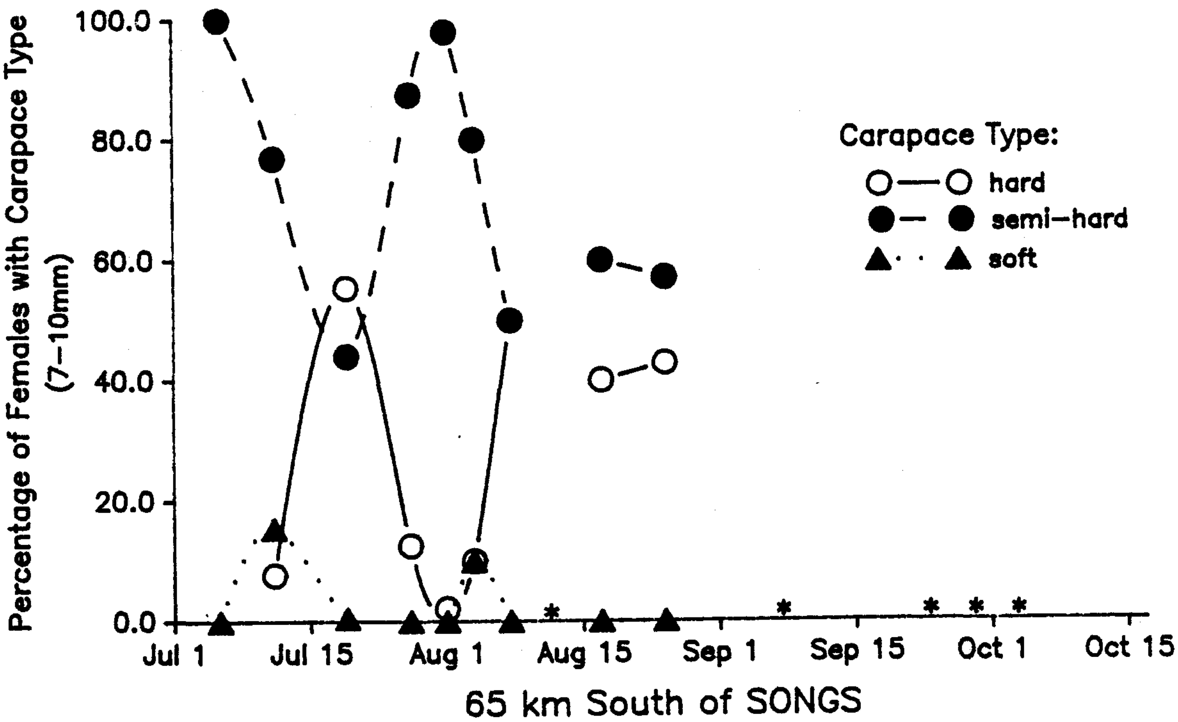
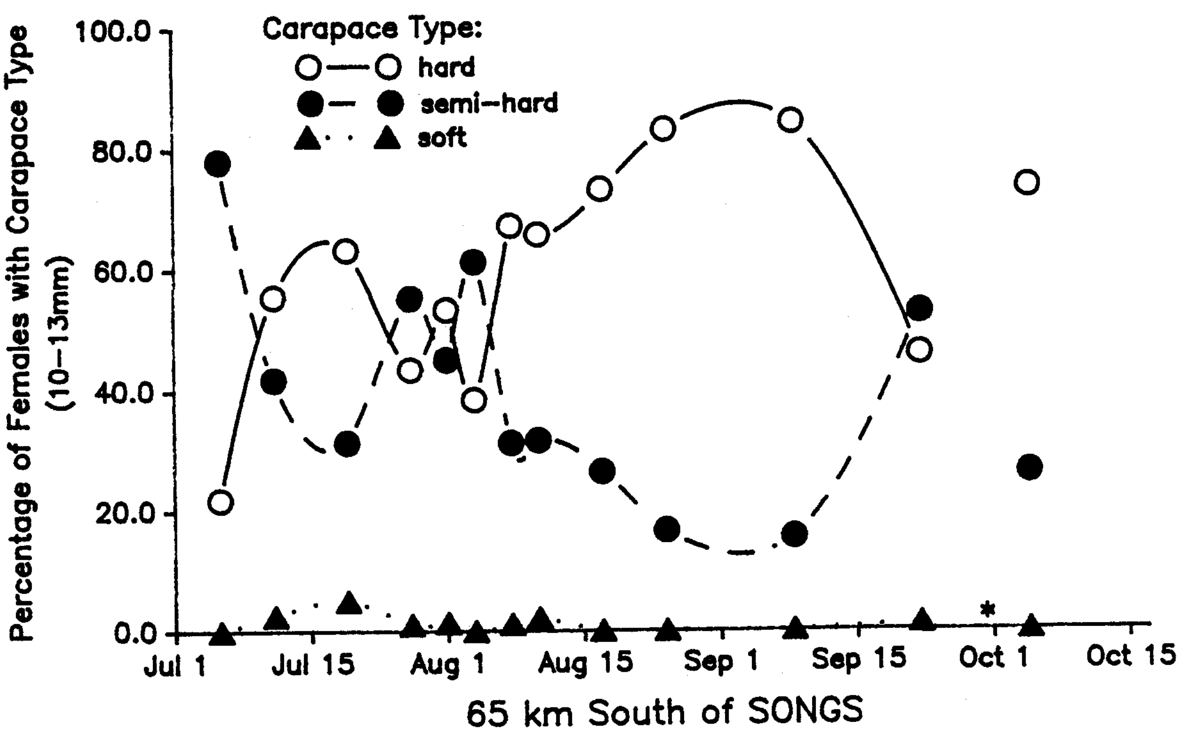

Carapace Type:
hard
semi-hard
soft
Percentage of Females with Carapace Type (10–13mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

Figure D-9: Changes through time in the percentages of females with different carapace types from the site 65 km south of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates an insufficient number of crabs was collected, so no percentages were calculated.

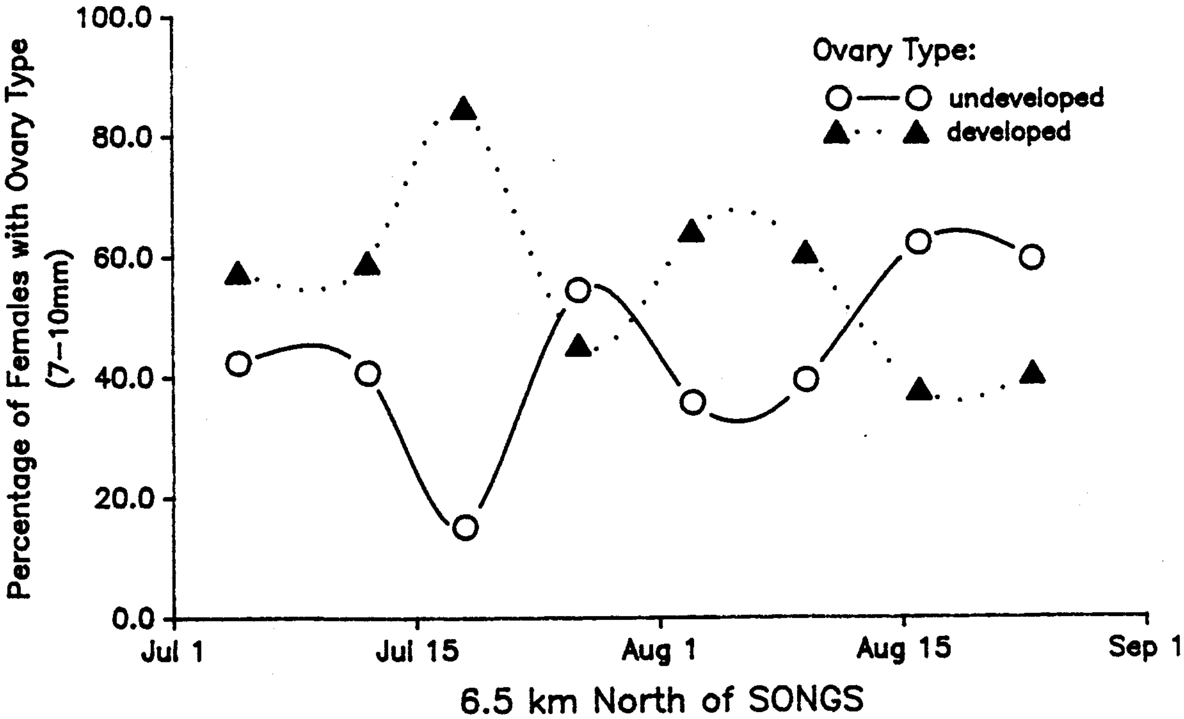


Percentage of Females with Carapace Type (7–10mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS
Carapace Type:
hard
semi-hard
soft



Percentage of Females with Carapace Type (10–13mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS
Carapace Type:
hard
semi-hard
soft

Figure D-10: Changes through time in the percentages of females with different oocyte types from the site 6.5 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Females with Ovary Type
(7–10mm)
Ovary Type:
undeveloped
developed
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

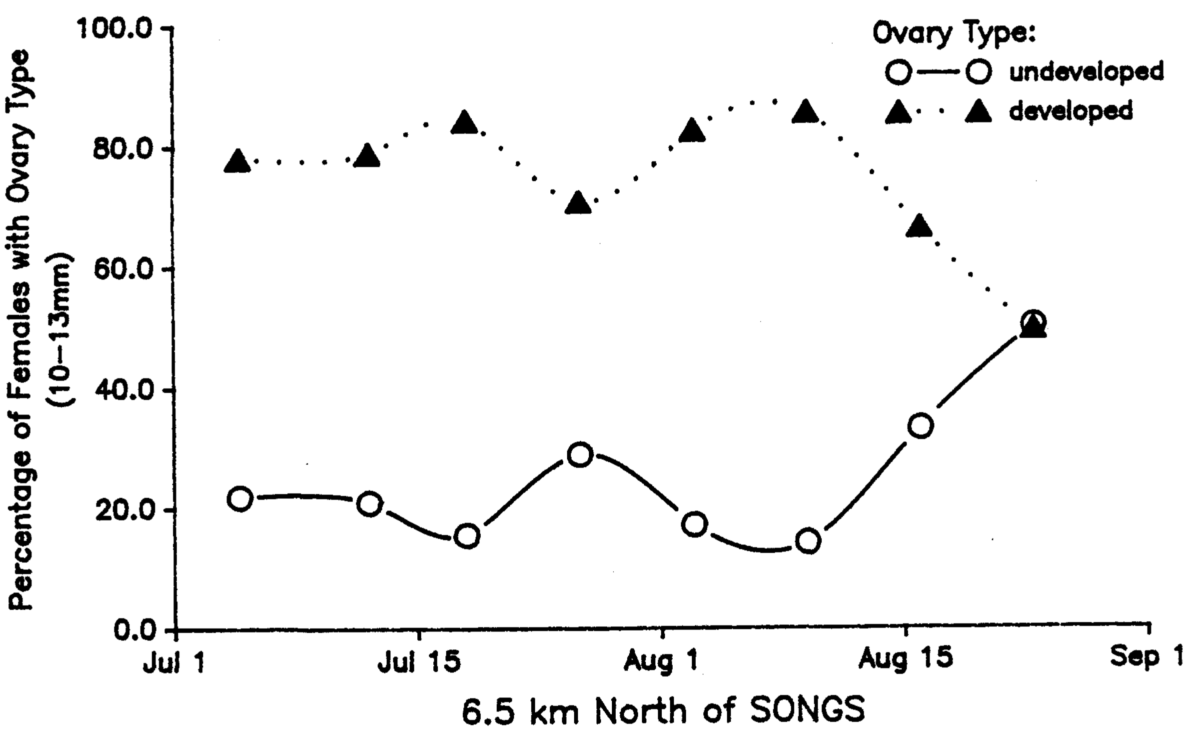
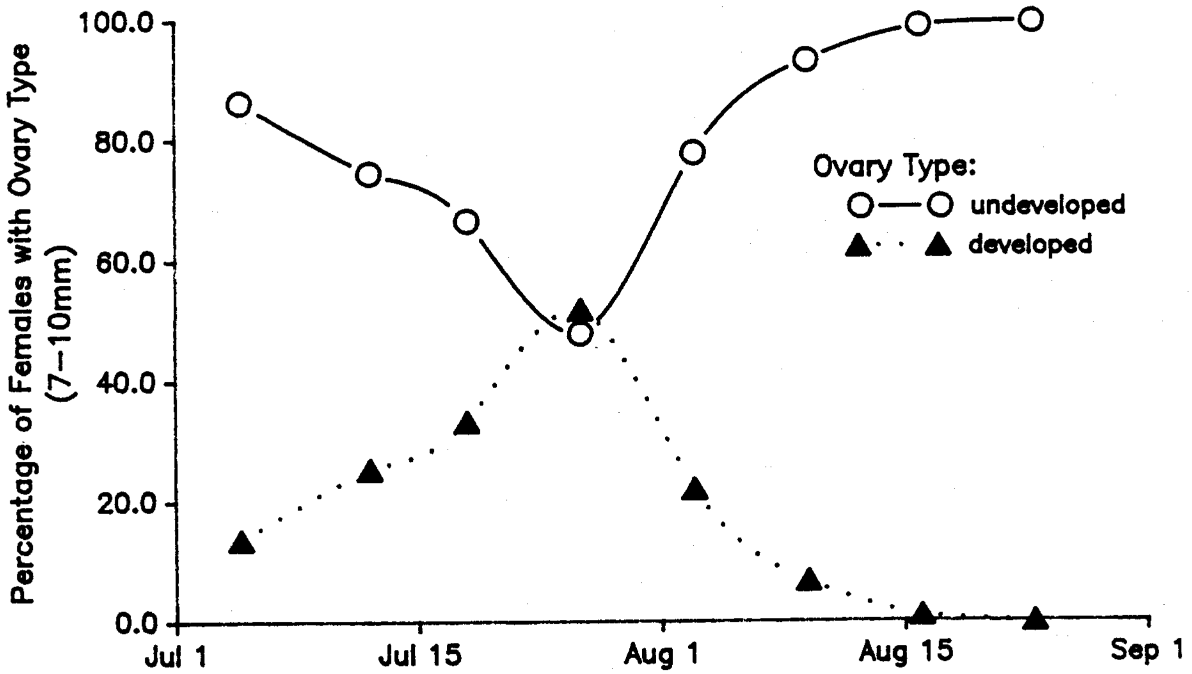
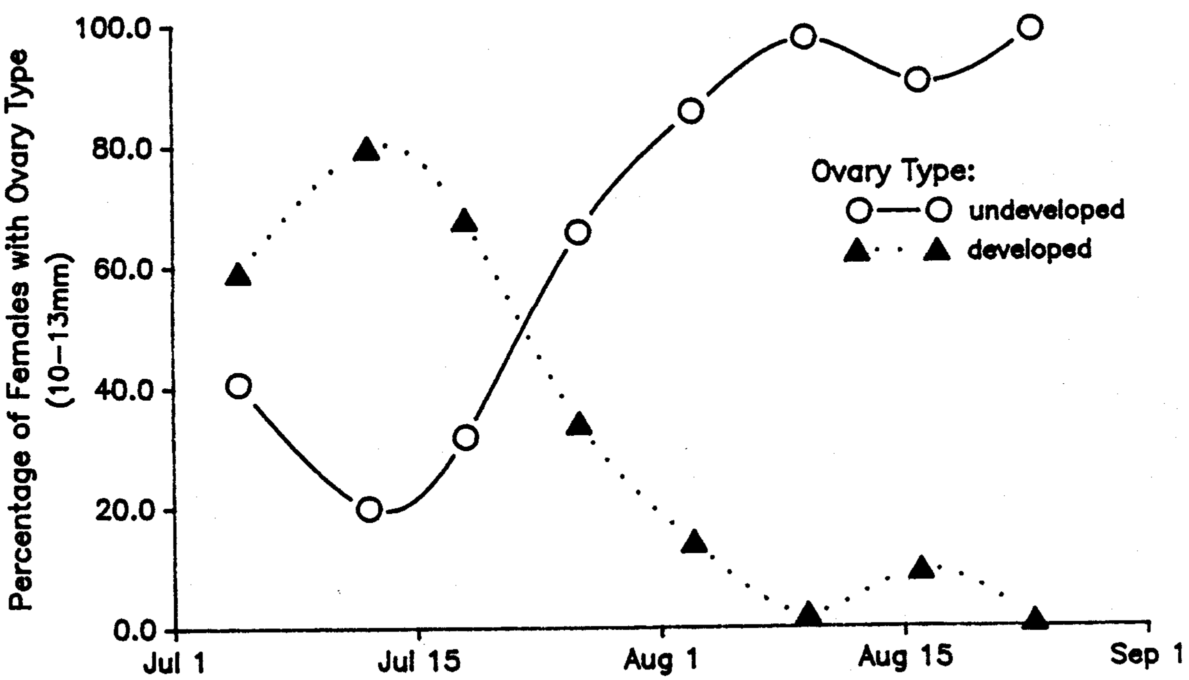

100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Females with Ovary Type
(10–13mm)
Ovary Type:
undeveloped
developed
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

Figure D-11: Changes through time in the percentages of females with different oocyte types from the site 0.4 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.

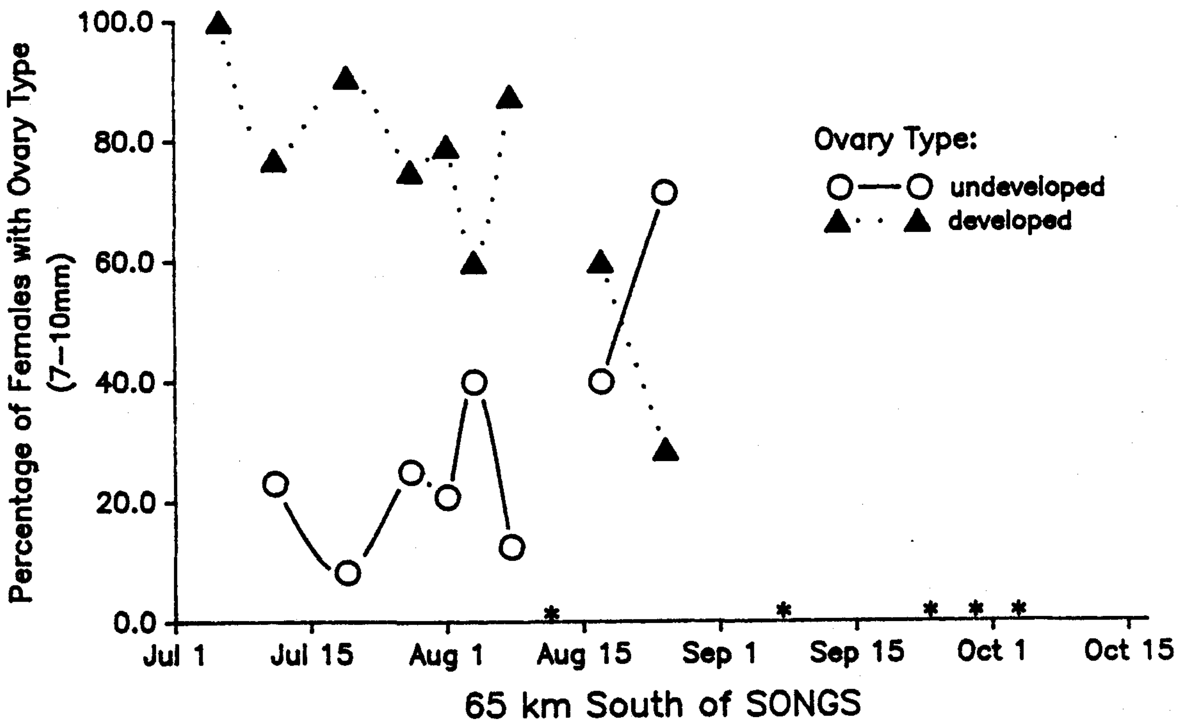


0.4 km North of SONGS



0.4 km North of SONGS

Figure D-12: Changes through time in the percentages of females with different oocyte types from the site 65 km south of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.


Percentage of Females with Ovary Type (7–10mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
Ovary Type:
undeveloped
developed
65 km South of SONGS

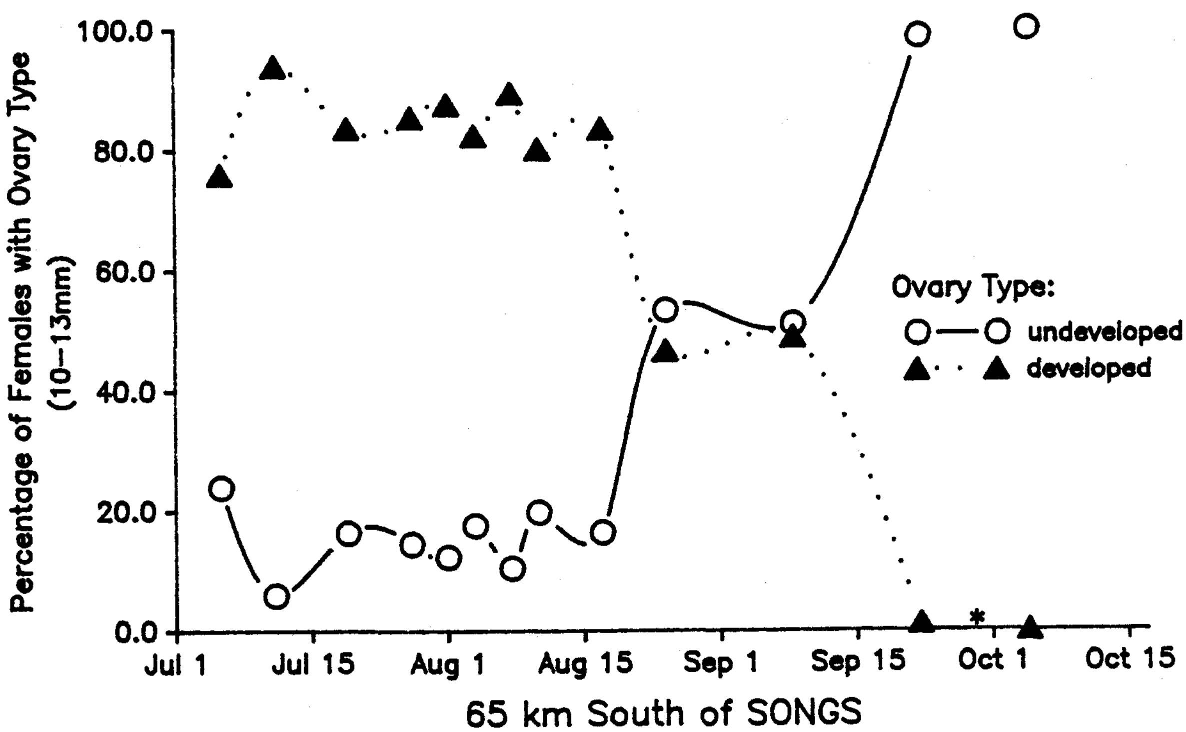
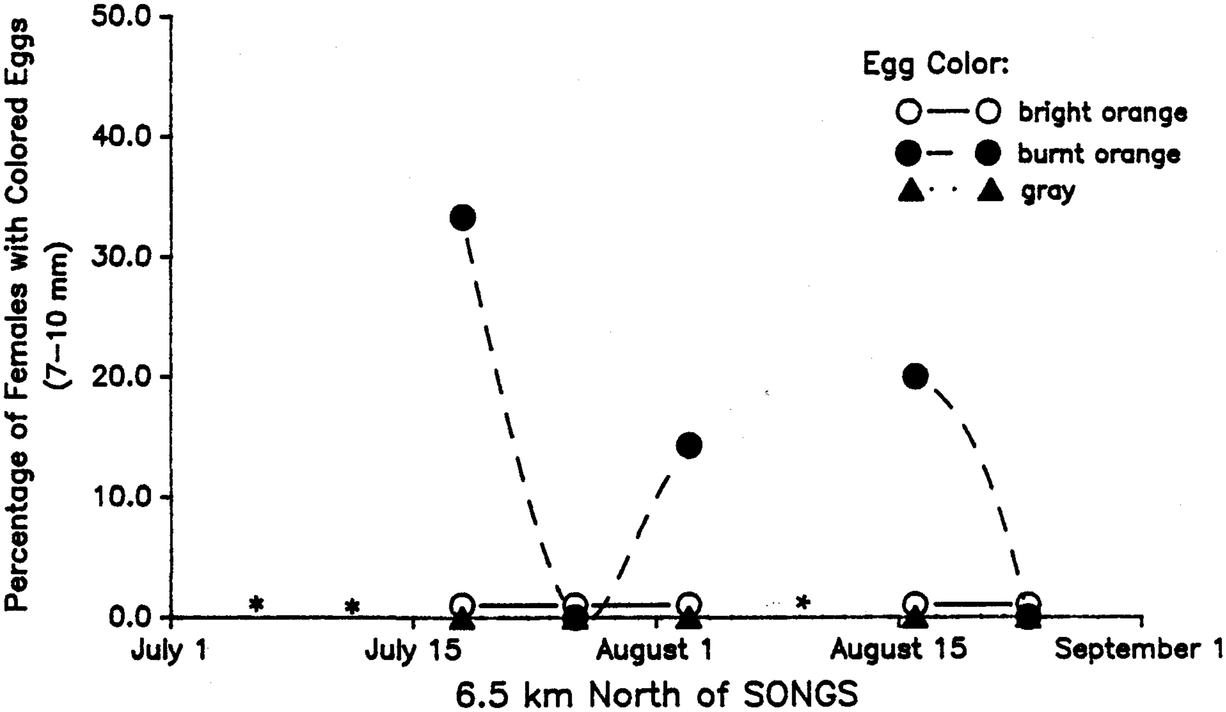

Percentage of Females with Ovary Type (10–13mm)
100.0
80.0
60.0
40.0
20.0
0.0
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
Ovary Type:
undeveloped
developed
65 km South of SONGS

Figure D-13: Changes through time in the percentages of females with different egg color types from the site 6.5 km north of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.


50.0
40.0
30.0
20.0
10.0
0.0
Percentage of Females with Colored Eggs
(7–10 mm)
Egg Color:
bright orange
burnt orange
gray
*
July 1
July 15
August 1
August 15
September 1
6.5 km North of SONGS

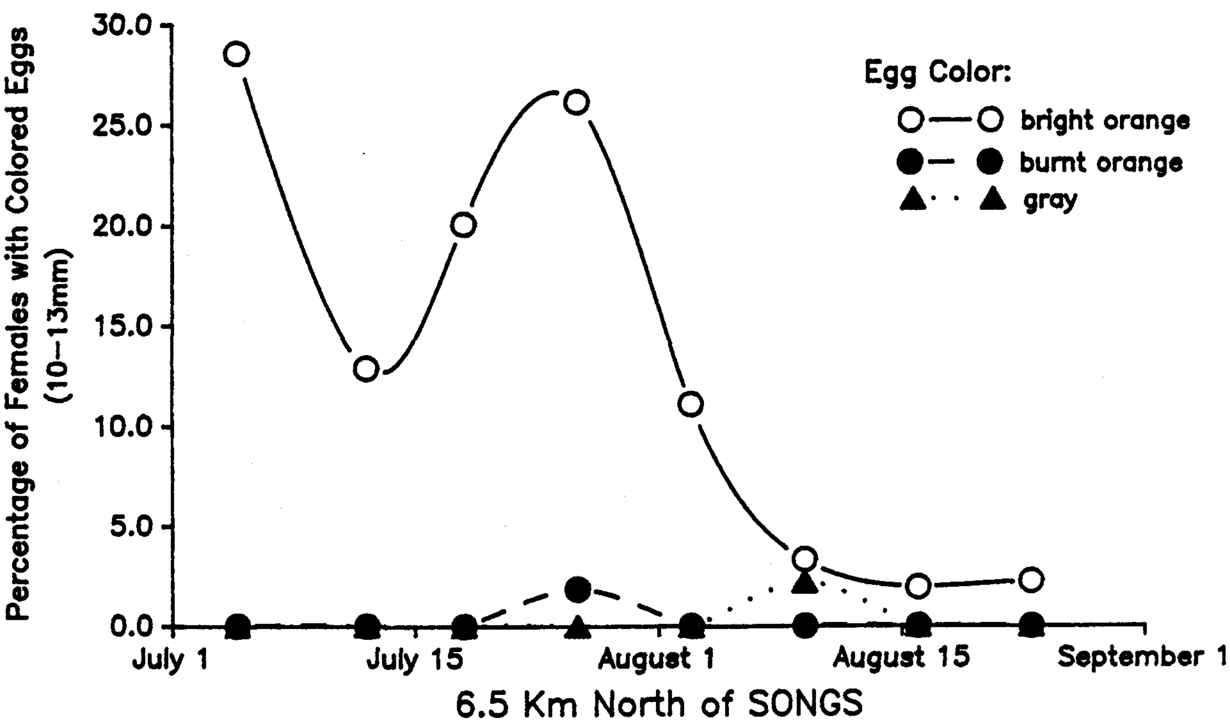
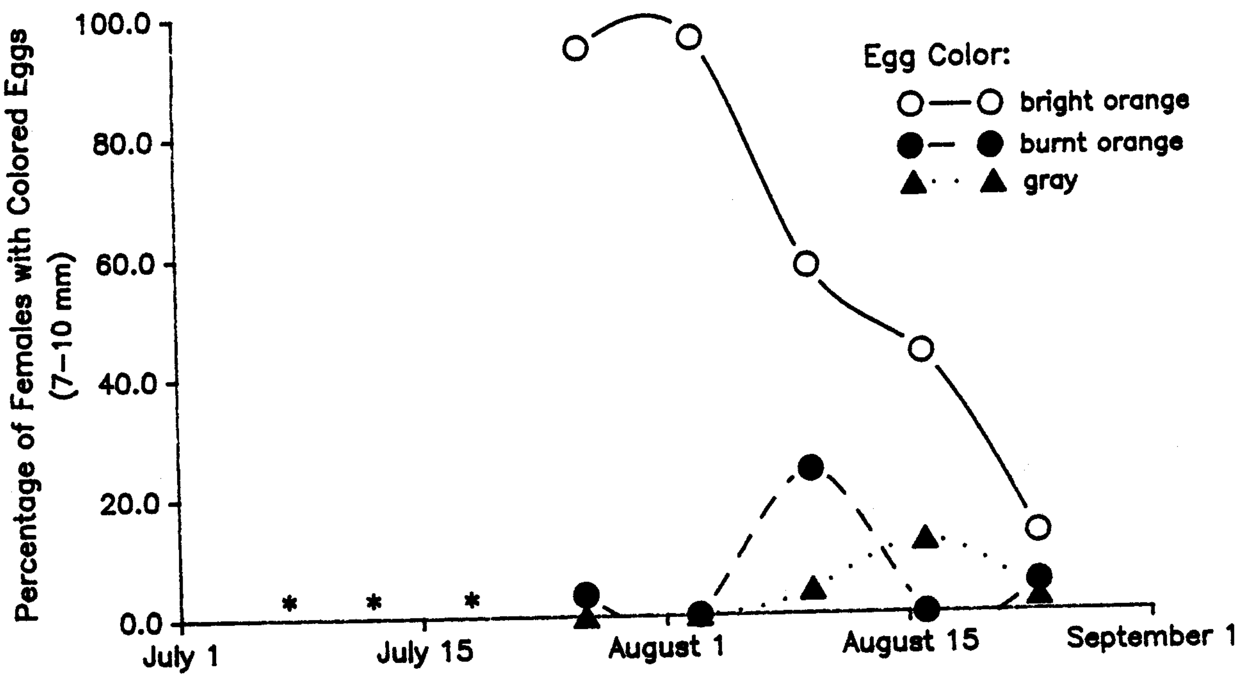
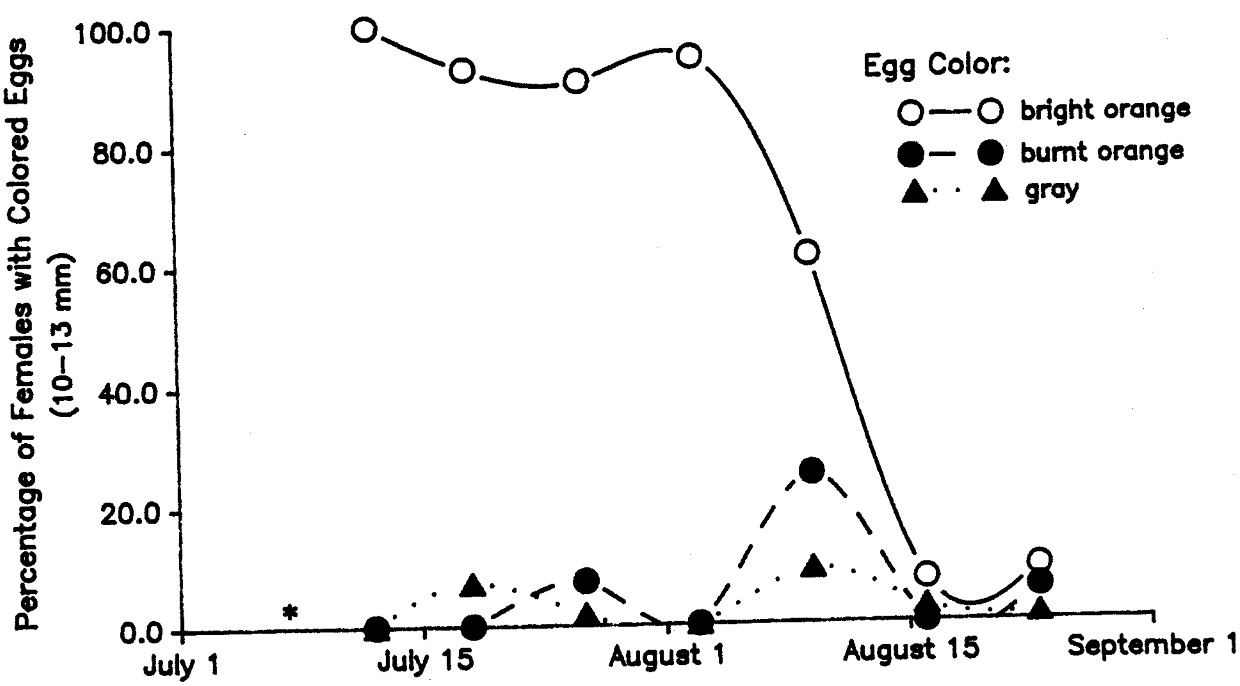

30.0
25.0
20.0
15.0
10.0
5.0
0.0
Percentage of Females with Colored Eggs
(10–13mm)
Egg Color:
bright orange
burnt orange
gray
July 1
July 15
August 1
August 15
September 1
6.5 Km North of SONGS

Figure D-14: Changes through time in the percentages of females with different color types from the site 0.4 km north of SONGS, during the 1984 surveys. The two size classes are presented separately, * indicates that an insufficient number of crabs was collected, so no percentages were calculated.

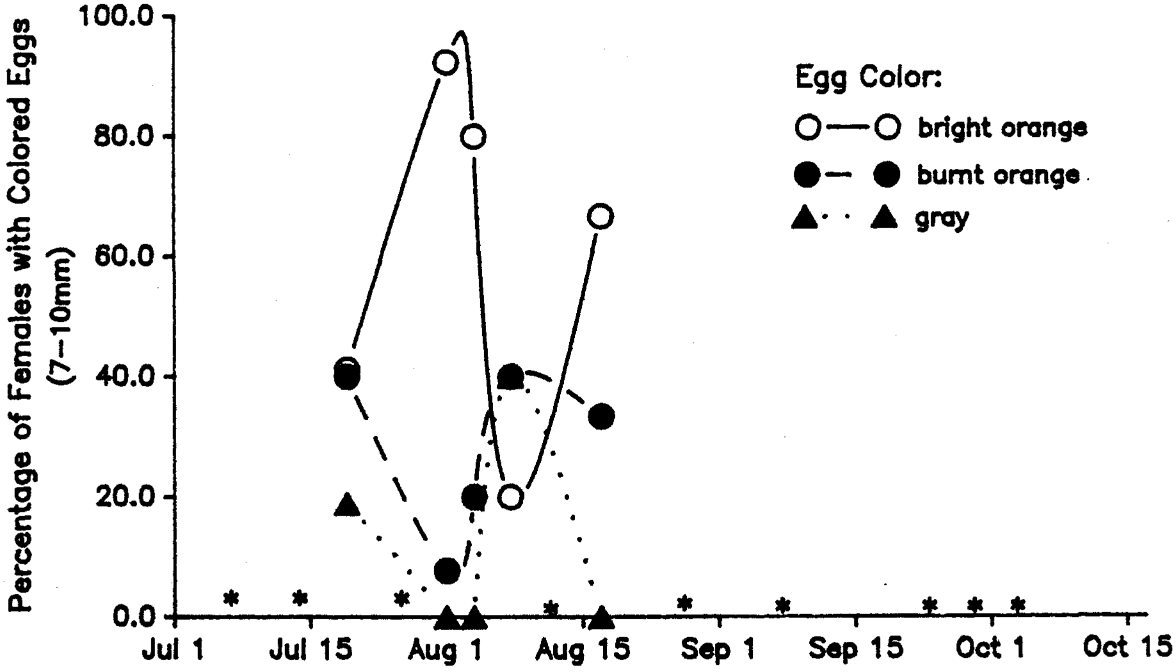


0.4 Km North of SONGS

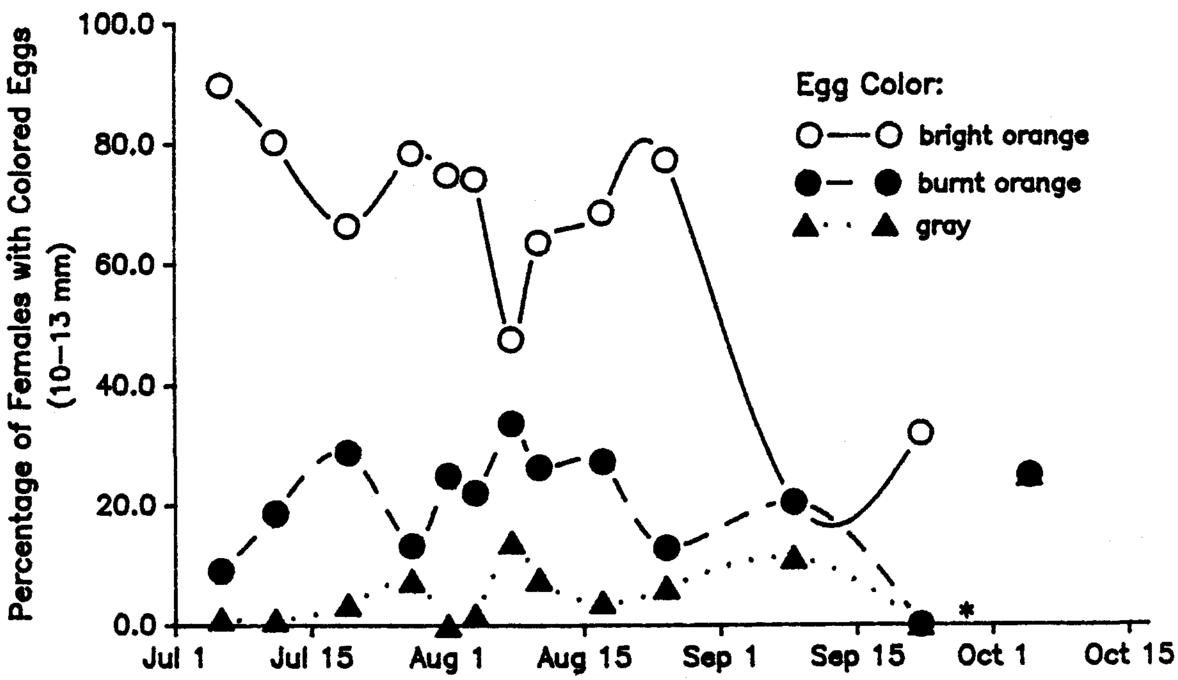


0.4 Km North of SONGS

Figure D-15: Changes through time in the percentages of females with different egg color types from the site 65 km south of SONGS, during the 1984 surveys. The tow size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.

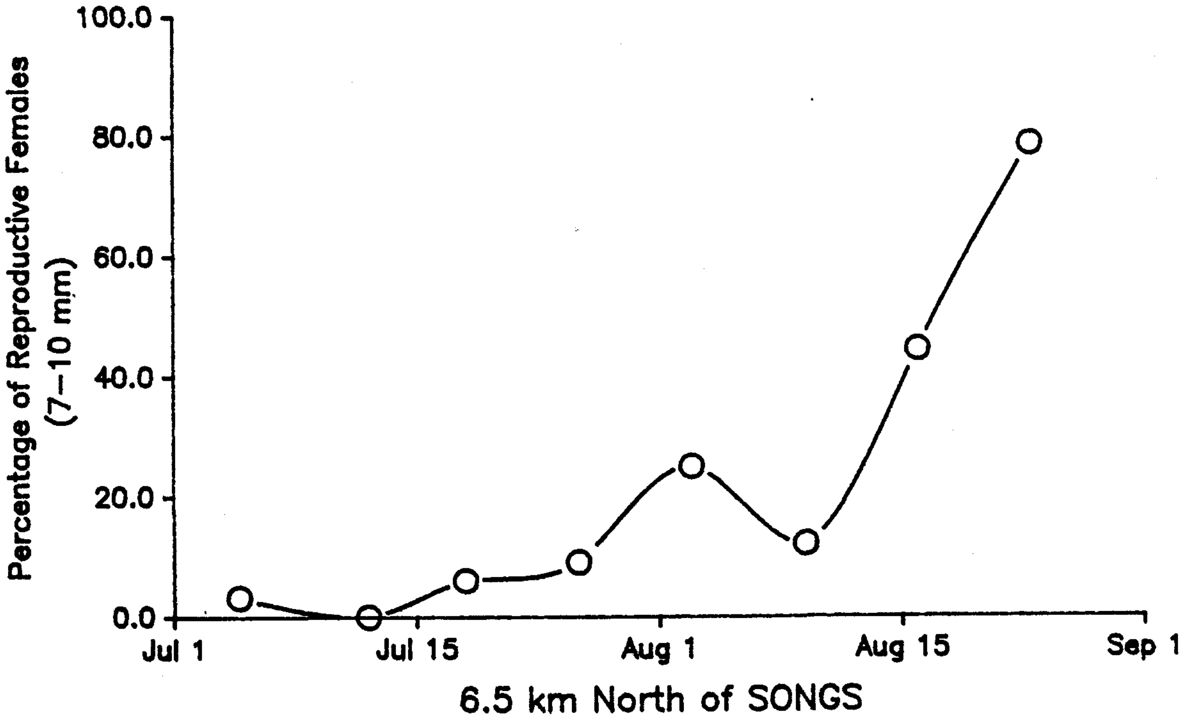


65 km South of SONGS



65 km South of SONGS

Figure D-16: Changes through time in the percentages of reproductive females from the site 6.5 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(7–10 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

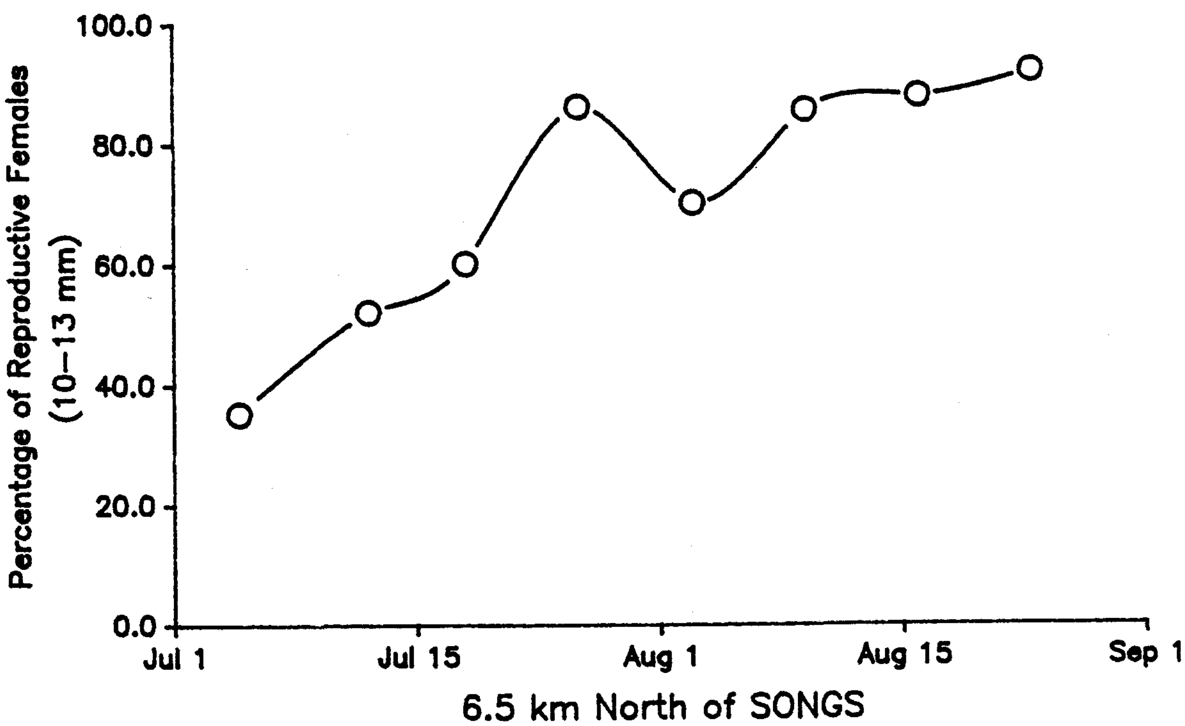
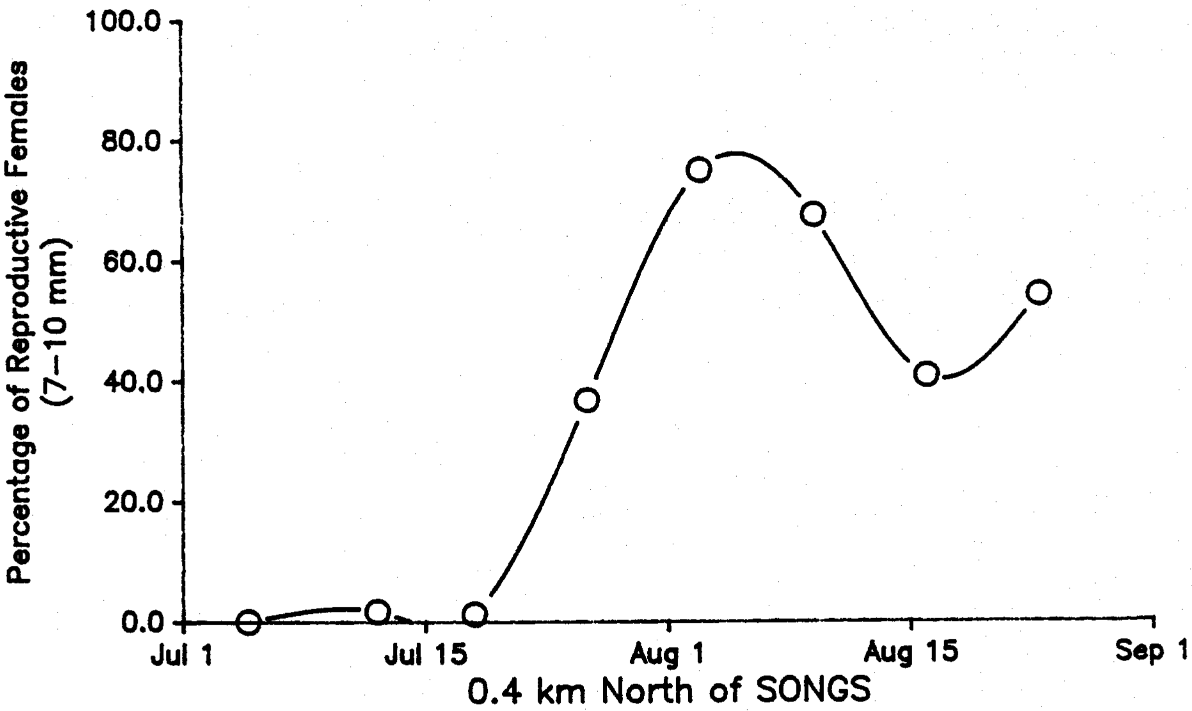

100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(10–13 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

Figure D-17: Changes through time in the percentages of reproductive females from the site 0.4 km north of SONGS, during the 1984 surveys. The two size classes are presented separately.


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(7–10 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

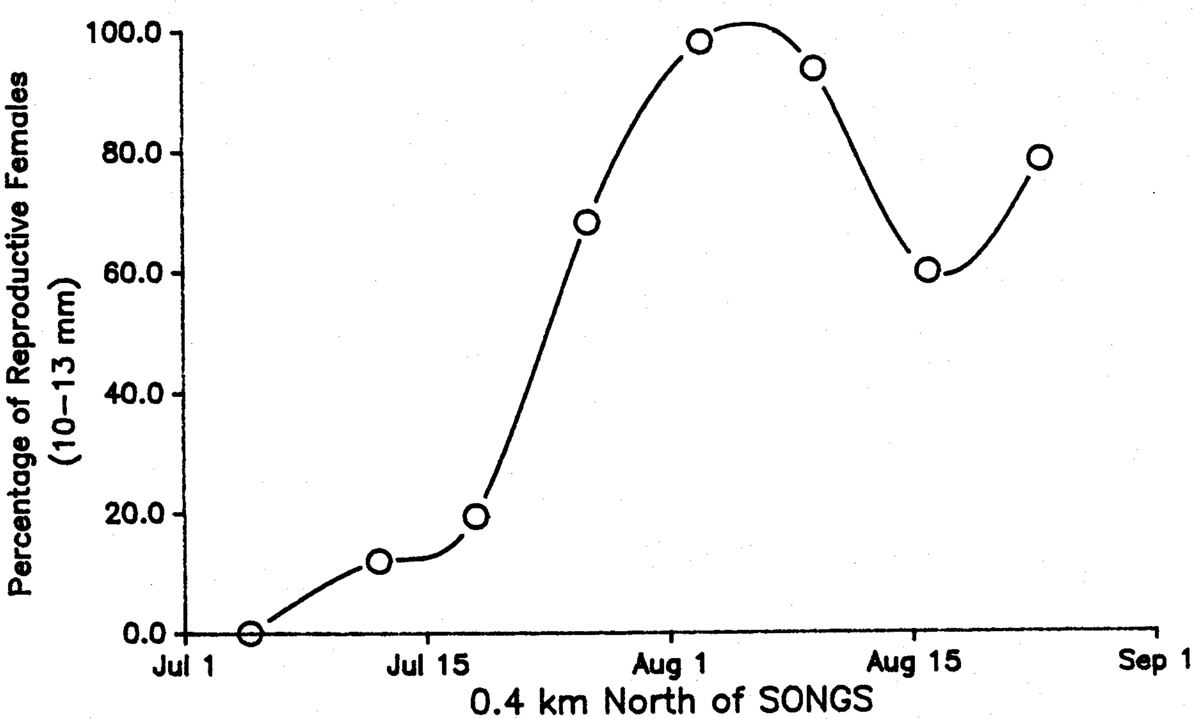
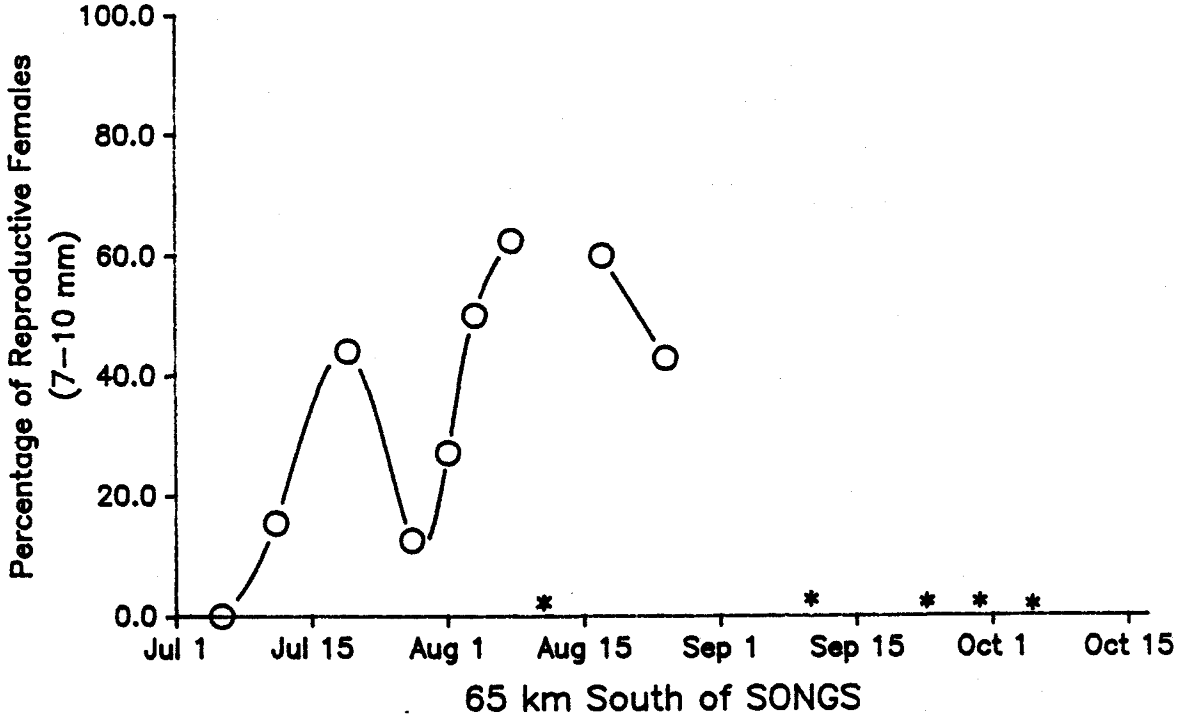
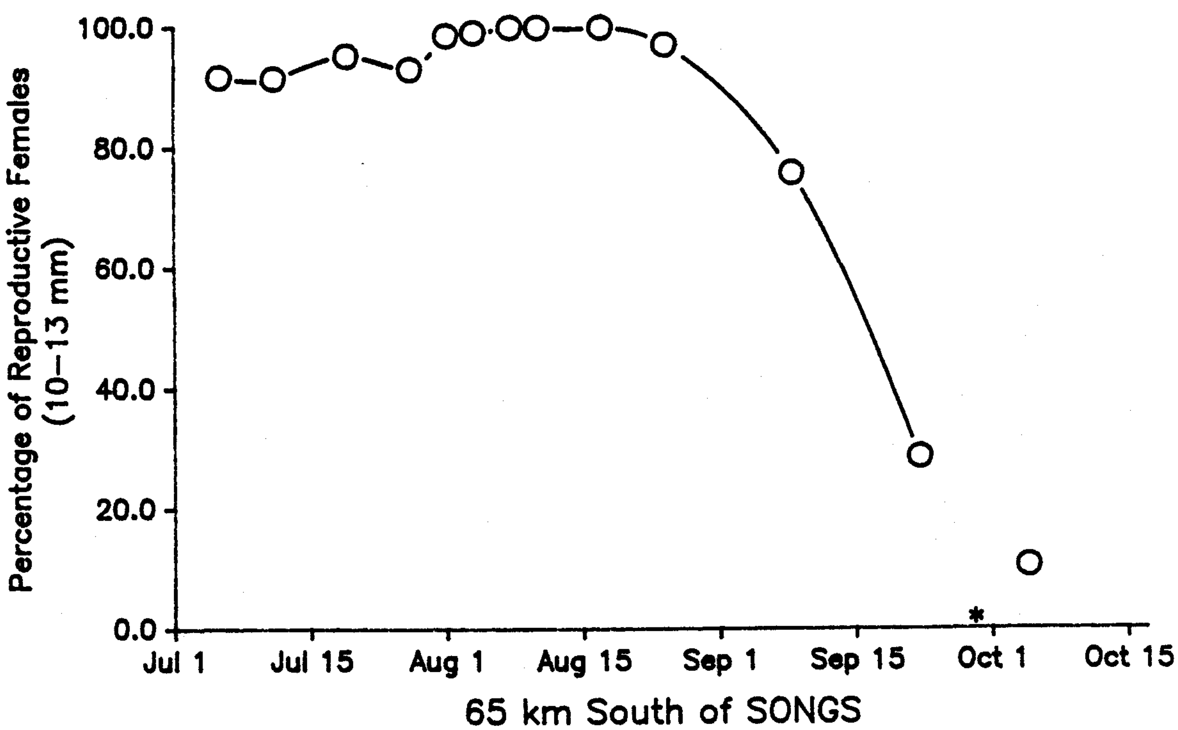

100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(10–13 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

Figure D-18: Changes through time in the percentages of reproductive females from the site 65 km south of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.

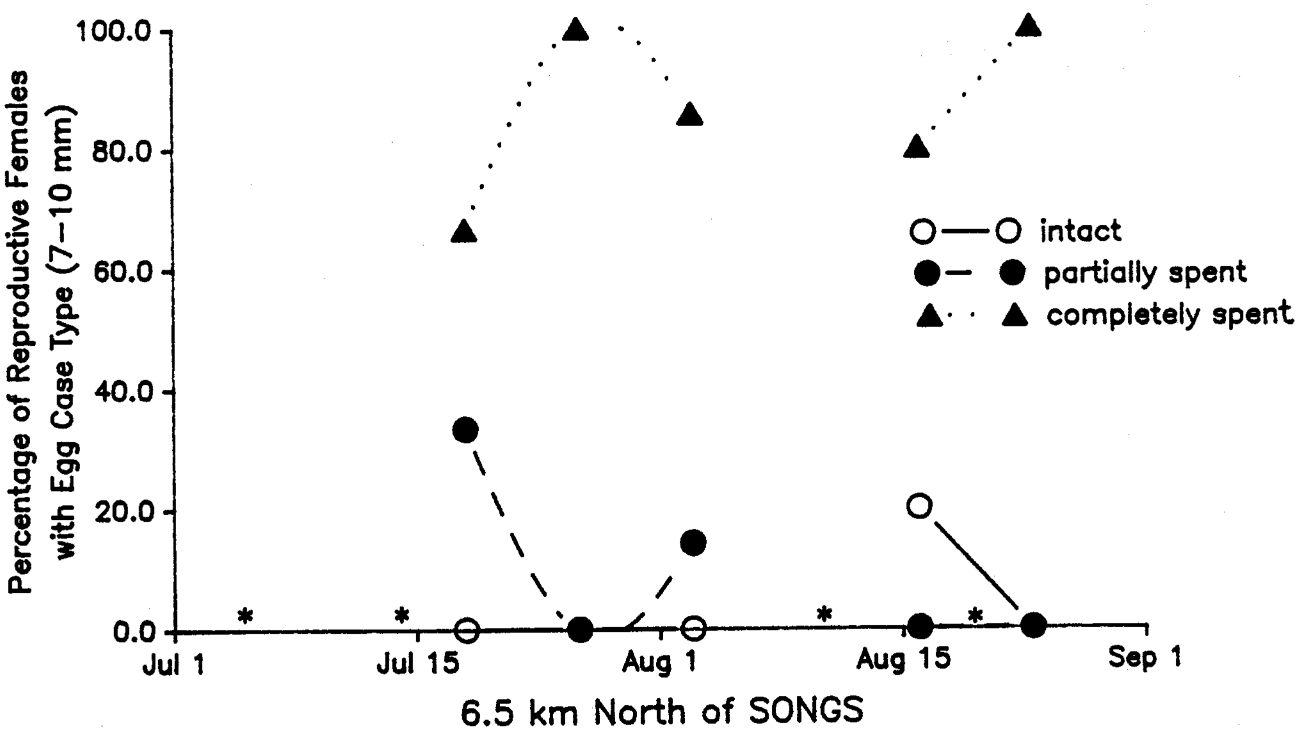


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(7–10 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS



100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females
(10–13 mm)
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS

Figure D-19: Changes through time in the percentages of females with intact, partially spent, or completely spent egg cases from the site 6.5 km north of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.


Percentage of Reproductive Females with Egg Case Type (7–10 mm)
100.0
80.0
60.0
40.0
20.0
0.0
intact
partially spent
completely spent
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

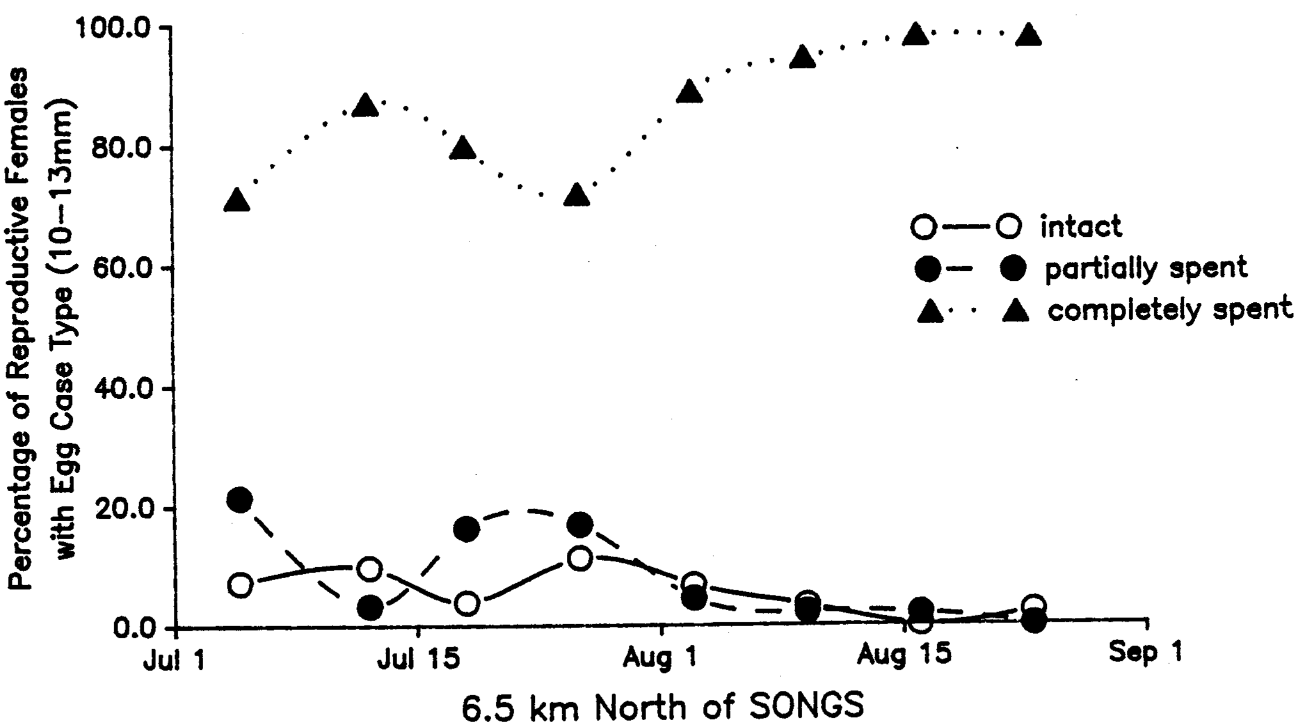
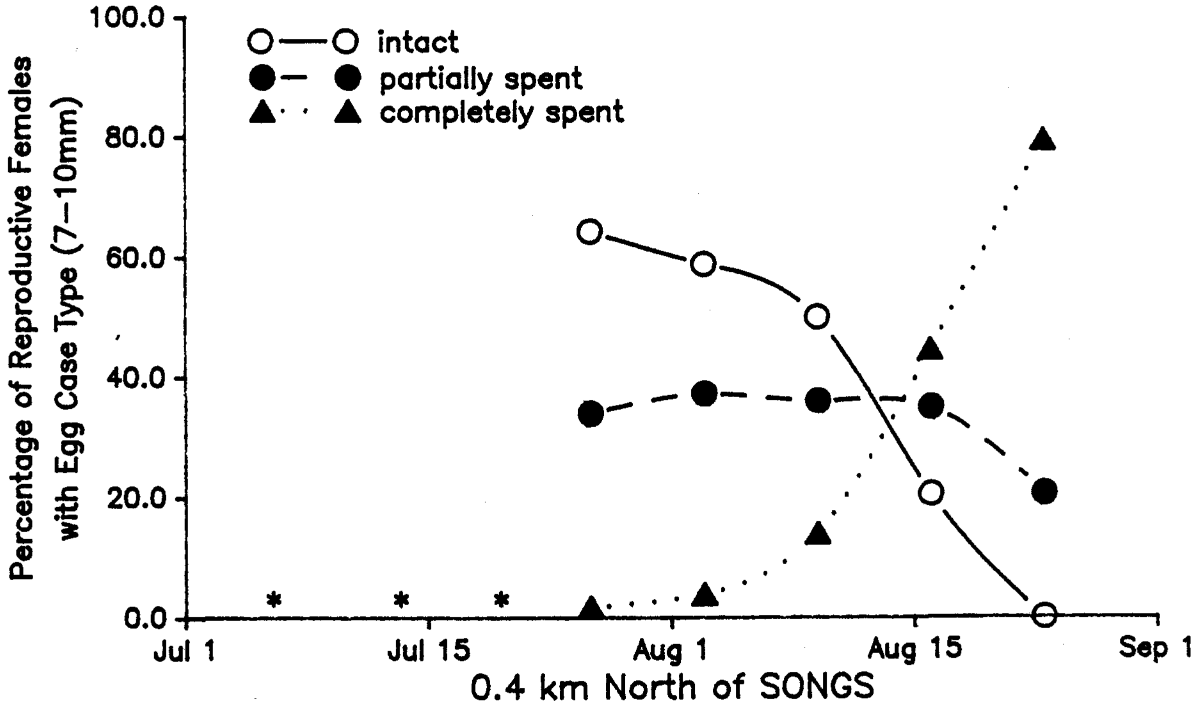

Percentage of Reproductive Females with Egg Case Type (10–13mm)
100.0
80.0
60.0
40.0
20.0
0.0
intact
partially spent
completely spent
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
6.5 km North of SONGS

Figure D-20: Changes through time in the percentages of females with intact, partially spent, or completely spent egg cases from the site 0.4 km north of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females with Egg Case Type (7–10mm)
intact
partially spent
completely spent
*
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

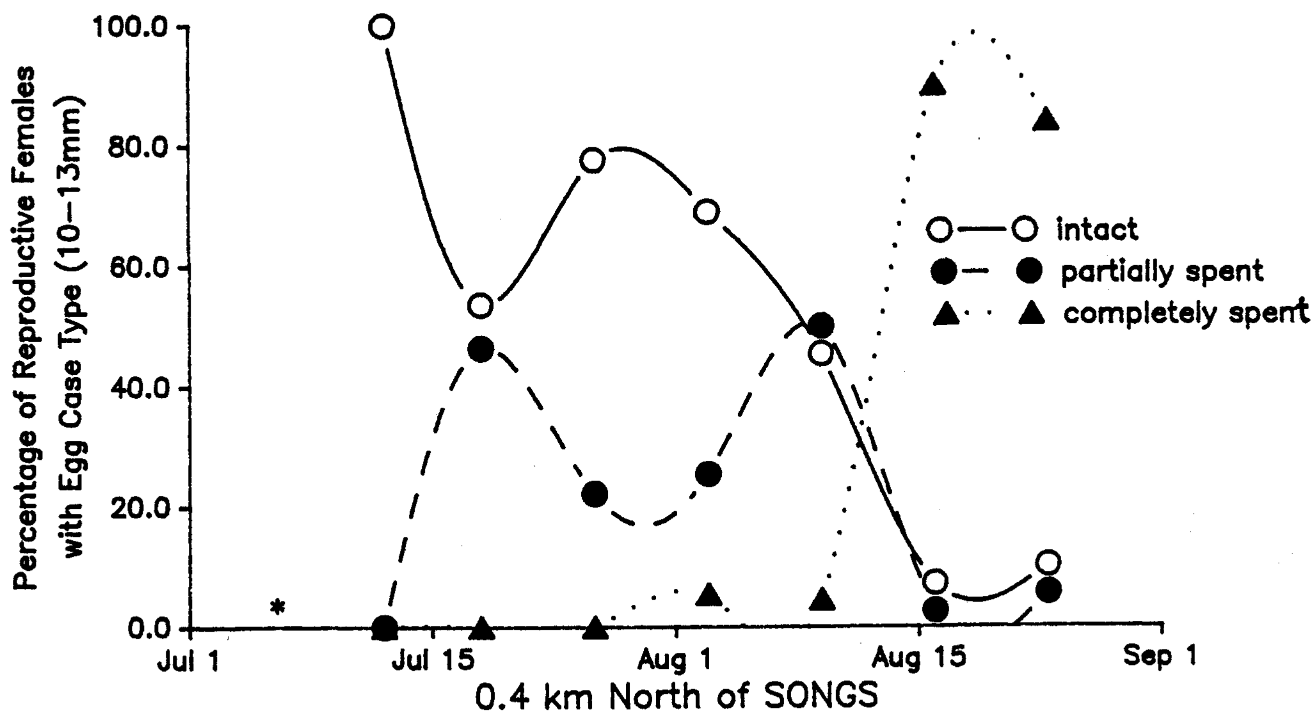
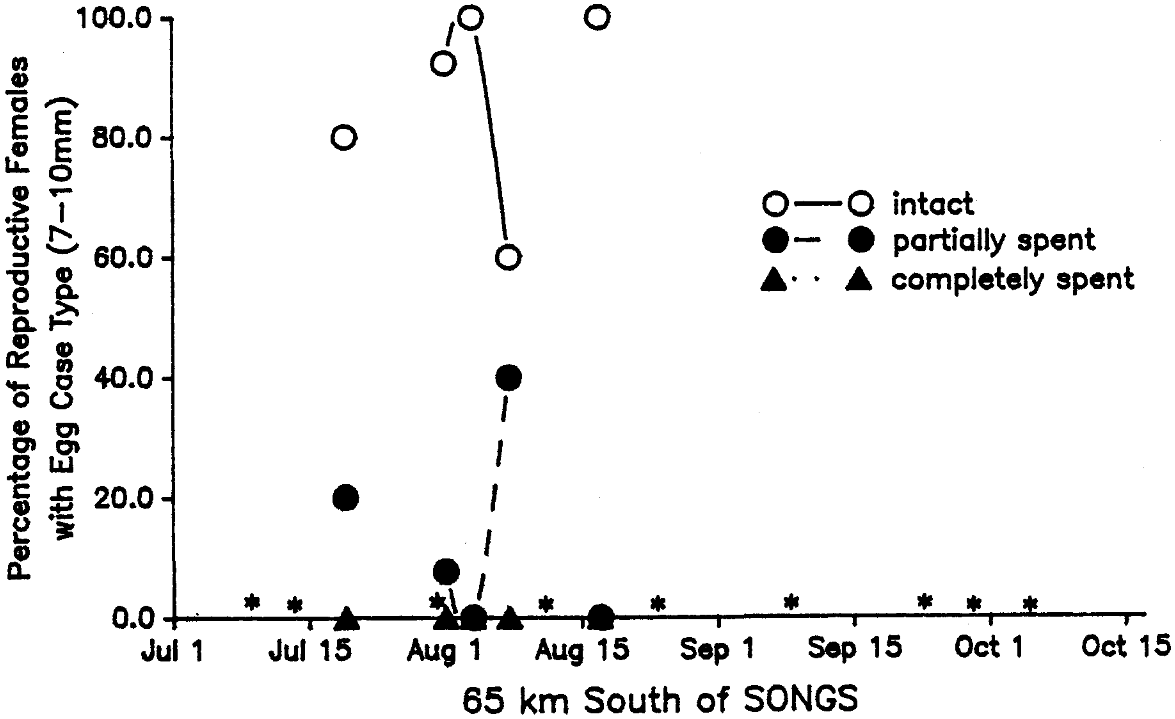
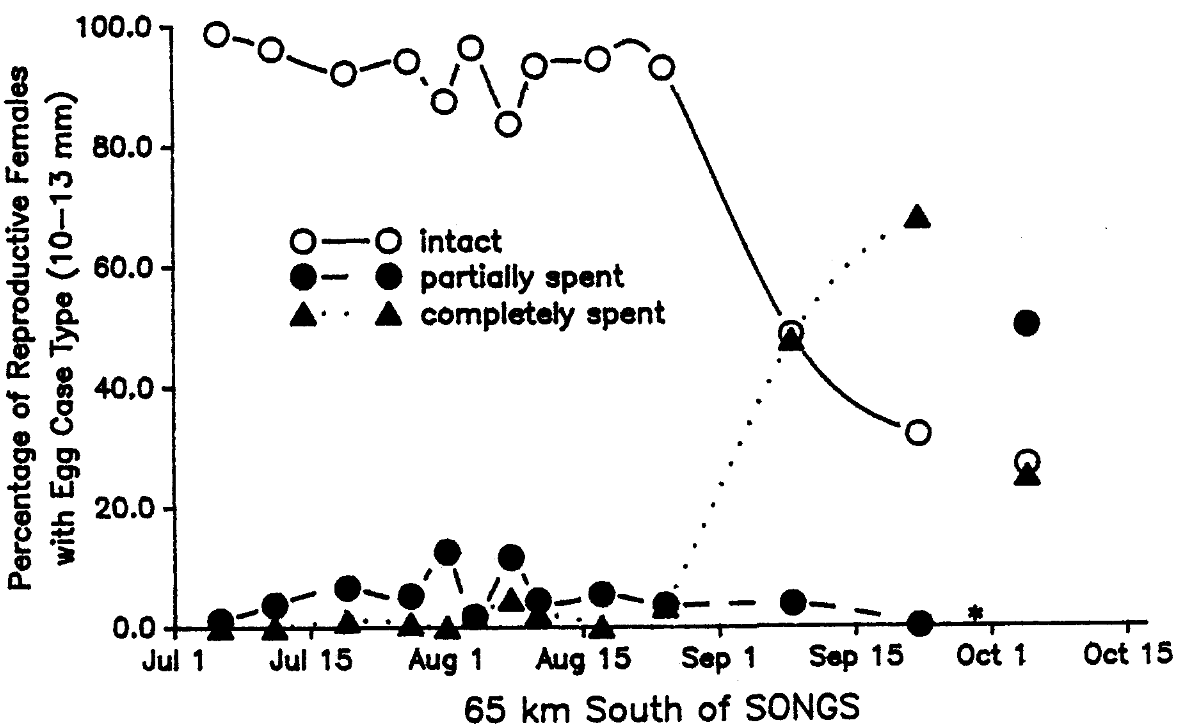

100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females with Egg Case Type (10–13mm)
intact
partially spent
completely spent
*
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
0.4 km North of SONGS

Figure D-21: Changes through time in the percentages of females with intact, partially spent, or completely spent egg cases from the site 65 km south of SONGS, during the 1984 surveys. The two size classes are presented separately. * indicates that an insufficient number of crabs was collected, so no percentages were calculated.


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females with Egg Case Type (7–10mm)
intact
partially spent
completely spent
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS


100.0
80.0
60.0
40.0
20.0
0.0
Percentage of Reproductive Females with Egg Case Type (10–13 mm)
intact
partially spent
completely spent
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
65 km South of SONGS

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APPENDIX E. MONTH BY MONTH RESULTS OF PRIMARY TESTS FOR LOCATION EFFECTS

Table E-1
page 1 of 8

Pearson product-moment correlation coefficients of sand crab catch per unit effort versus distance from SONGS in 1976-1978. -- indicates no crabs were collected at any site. Data from sites 6.5 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50% of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Male	-0.04	5	0.94	0.06
Oct 76	Male	0.36	5	0.55	0.06
Nov 76	Male	0.61	5	0.28	0.05
Dec 76	Male	--	5	--	--
Jan 77	Male	--	5	--	--
Feb 77	Male	--	5	--	--
Mar 77	Male	--	5	--	--
Apr 77	Male	-0.70	5	0.19	0.06
May 77	Male	-0.83	5	0.08	0.20
Jun 77	Male	-0.32	5	0.60	0.07
Jul 77	Male	0.64	5	0.25	0.06
Oct 77	Male	-0.29	5	0.64	0.06
Nov 77	Male	-0.35	5	0.57	0.06
Dec 77	Male	0.52	5	0.37	0.05
Jan 78	Male	0.75	5	0.14	0.06
Feb 78	Male	0.59	5	0.30	0.05
Mar 78	Male	0.88	5	0.051	0.06

Table E-1

DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Megalopa	0.39	5	0.52	0.06
Oct 76	Megalopa	0.53	5	0.36	0.05
Nov 76	Megalopa	--	5	--	--
Dec 76	Megalopa	--	5	--	--
Jan 77	Megalopa	--	5	--	--
Feb 77	Megalopa	--	5	--	--
Mar 77	Megalopa	--	5	--	--
Apr 77	Megalopa	-0.67	5	0.21	0.24
May 77	Megalopa	-0.38	5	0.53	0.09
Jun 77	Megalopa	0.20	5	0.75	0.06
Jul 77	Megalopa	0.95	5	0.01*	0.11
Oct 77	Megalopa	0.40	5	0.50	0.05
Nov 77	Megalopa	-0.33	5	0.59	0.05
Dec 77	Megalopa	-0.18	5	0.77	0.06
Jan 78	Megalopa	0.55	5	0.33	0.05
Feb 78	Megalopa	0.44	5	0.45	0.05
Mar 78	Megalopa	0.20	5	0.75	0.05

Table E-1
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DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Small Females	-0.44	5	0.46	0.07
Oct 76	Small Females	-0.06	5	0.92	0.06
Nov 76	Small Females	0.61	5	0.28	0.05
Dec 76	Small Females	--	5	--	--
Jan 77	Small Females	--	5	--	--
Feb 77	Small Females	--	5	--	--
Mar 77	Small Females	--	5	--	--
Apr 77	Small Females	-0.79	5	0.11	0.06
May 77	Small Females	-0.83	5	0.08	0.13
Jun 77	Small Females	-0.55	5	0.33	0.06
Jul 77	Small Females	0.83	5	0.08	0.07
Oct 77	Small Females	-0.27	5	0.66	0.05
Nov 77	Small Females	-0.29	5	0.64	0.05
Dec 77	Small Females	0.17	5	0.79	0.05
Jan 78	Small Females	-0.27	5	0.66	0.05
Feb 78	Small Females	0.44	5	0.45	0.05
Mar 78	Small Females	0.61	5	0.27	0.05

Table E-1

DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Medium-small Females	-0.45	5	0.45	0.06
Oct 76	Medium-small Females	0.09	5	0.88	0.05
Nov 76	Medium-small Females	0.61	5	0.28	0.05
Dec 76	Medium-small Females	--	5	--	--
Jan 77	Medium-small Females	--	5	--	--
Feb 77	Medium-small Females	--	5	--	--
Mar 77	Medium-small Females	--	5	--	--
Apr 77	Medium-small Females	-0.02	5	0.96	0.07
May 77	Medium-small Females	0.38	5	0.53	0.07
Jun 77	Medium-small Females	0.01	5	0.99	0.06
Jul 77	Medium-small Females	0.23	5	0.71	0.1
Oct 77	Medium-small Females	-0.68	5	0.21	0.06
Nov 77	Medium-small Females	-0.33	5	0.59	0.05
Dec 77	Medium-small Females	-0.09	5	0.89	0.05
Jan 78	Medium-small Females	-0.04	5	0.94	0.06
Feb 78	Medium-small Females	0.24	5	0.70	0.05
Mar 78	Medium-small Females	0.93	5	0.02*	0.07

DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Medium-large Females	0.30	5	0.62	0.06
Oct 76	Medium-large Females	0.75	5	0.14	0.05
Nov 76	Medium-large Females	0.61	5	0.28	0.05
Dec 76	Medium-large Females	--	5	--	--
Jan 77	Medium-large Females	--	5	--	--
Feb 77	Medium-large Females	--	5	--	--
Mar 77	Medium-large Females	--	5	--	--
Apr 77	Medium-large Females	0.96	5	0.01*	0.10
May 77	Medium-large Females	0.85	5	0.07	0.06
Jun 77	Medium-large Females	0.82	5	0.09	0.07
Jul 77	Medium-large Females	0.82	5	0.09	0.07
Oct 77	Medium-large Females	0.28	5	0.64	0.06
Nov 77	Medium-large Females	0.19	5	0.76	0.06
Dec 77	Medium-large Females	0.51	5	0.38	0.05
Jan 78	Medium-large Females	0.97	5	0.01*	0.12
Feb 78	Medium-large Females	0.56	5	0.32	0.05
Mar 78	Medium-large Females	0.78	5	0.12	0.06

Date (Mo. Yr.)	Class	r	N	P	Power
Sep 76	Large Females	0.59	5	0.29	0.06
Oct 76	Large Females	0.97	5	0.005*	0.09
Nov 76	Large Females	--	5	--	--
Dec 76	Large Females	--	5	--	--
Jan 77	Large Females	--	5	--	--
Feb 77	Large Females	--	5	--	--
Mar 77	Large Females	--	5	--	--
Apr 77	Large Females	0.83	5	0.08	0.06
May 77	Large Females	0.88	5	0.047*	0.06
Jun 77	Large Females	-0.20	5	0.74	0.05
Jul 77	Large Females	0.74	5	0.15	0.05
Oct 77	Large Females	0.51	5	0.38	0.05
Nov 77	Large Females	0.56	5	0.33	0.05
Dec 77	Large Females	0.61	5	0.28	0.05
Jan 78	Large Females	0.86	5	0.06	0.06
Feb 78	Large Females	0.58	5	0.31	0.05
Mar 78	Large Females	0.89	5	0.04*	0.06

Table E-1

DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	Very large Females	0.87	5	0.053	0.08
Oct 76	Very large Females	0.89	5	0.04*	0.06
Nov 76	Very large Females	0.61	5	0.28	0.05
Dec 76	Very large Females	--	5	--	--
Jan 77	Very large Females	--	5	--	--
Feb 77	Very large Females	--	5	--	--
Mar 77	Very large Females	--	5	--	--
Apr 77	Very large Females	0.70	5	0.19	0.05
May 77	Very large Females	0.89	5	0.049*	0.06
Jun 77	Very large Females	0.78	5	0.12	0.06
Jul 77	Very large Females	0.90	5	0.04*	0.06
Oct 77	Very large Females	0.61	5	0.28	0.05
Nov 77	Very large Females	0.61	5	0.28	0.05
Dec 77	Very large Females	--	5	--	--
Jan 78	Very large Females	--	5	--	--
Feb 78	Very large Females	0.61	5	0.28	0.05
Mar 78	Very large Females	0.96	5	0.01*	0.07

Table E-1
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DATE (MO. YR.)	CLASS	r	N	P	POWER
Sep 76	TOTAL	-0.16	5	0.80	0.06
Oct 76	TOTAL	0.30	5	0.62	0.06
Nov 76	TOTAL	0.61	5	0.28	0.05
Dec 76	TOTAL	--	5	--	--
Jan 77	TOTAL	--	5	--	--
Feb 77	TOTAL	--	5	--	--
Mar 77	TOTAL	--	5	--	--
Apr 77	TOTAL	-0.72	5	0.17	0.08
May 77	TOTAL	-0.81	5	0.09	0.21
Jun 77	TOTAL	-0.39	5	0.51	0.07
Jul 77	TOTAL	0.69	5	0.20	0.07
Oct 77	TOTAL	-0.35	5	0.56	0.06
Nov 77	TOTAL	-0.32	5	0.60	0.05
Dec 77	TOTAL	0.37	5	0.54	0.05
Jan 78	TOTAL	0.79	5	0.11	0.06
Feb 78	TOTAL	0.53	5	0.35	0.05
Mar 78	TOTAL	0.89	5	0.04*	0.07

Table E-2

Pearson product-moment correlation coefficients of mean maximum size of female sand crabs versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	r	N	P	POWER
SEP 76	0.49	4	0.51	0.10
OCT 76	0.64	4	0.36	0.10
APR 77	0.14	6	0.79	0.13
MAY 77	0.54	5	0.35	0.84
JUN 77	-0.34	6	0.51	1.0
JUL 77	-0.38	6	0.46	0.74
AUG 77	-0.54	6	0.26	0.86
OCT 77	0.81	5	0.10	0.93
NOV 77	0.85	4	0.15	1.0
JAN 78	0.79	4	0.21	0.33
FEB 78	0.46	3	0.70	0.16
MAR 78	0.77	3	0.44	1.0
JUL 80	-0.46	4	0.54	0.17
APR 81	-0.98	3	0.13	1.0
MAY 81	0.56	5	0.33	0.21
JUL 81	0.55	5	0.34	0.13
AUG 81	0.47	5	0.43	0.13
SEP 81	0.66	4	0.34	0.10
OCT 81	0.94	3	0.22	0.18
JUN 83	0.13	5	0.84	0.10
JUL 83	-0.34	9	0.37	0.99
AUG 83	0.02	7	0.96	0.98

Table E-3

Pearson product-moment correlation coefficients of mean maximum size of male sand crabs versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	r	N	P	POWER
SEP 76	0.74	5	0.15	0.31
OCT 76	0.83	5	0.09	0.43
APR 77	0.49	6	0.33	1.0
MAY 77	0.14	6	0.79	1.0
JUN 77	0.12	6	0.82	1.0
JUL 77	-0.33	6	0.53	0.93
AUG 77	0.54	6	0.27	1.0
OCT 77	0.85	4	0.15	0.68
NOV 77	0.90	4	0.10	1.0
DEC 77	0.78	3	0.43	0.17
JAN 78	0.995	3	0.06	1.0
JUL 80	-0.04	4	0.96	1.0
APR 81	0.53	4	0.47	0.08
MAY 81	0.43	5	0.47	0.45
JUL 81	0.70	5	0.19	0.60
AUG 81	0.74	5	0.15	0.58
SEP 81	0.76	4	0.24	0.55
OCT 81	0.95	3	0.21	0.19
JUN 83	0.65	5	0.23	0.82
JUL 83	-0.34	8	0.41	1.0
AUG 83	0.29	6	0.58	1.0

Table E-4

T-tests comparing mean maximum size of female sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% difference (of the mean of beaches within 20 km of SONGS) between Near and Far beaches at the 0.05 level.

DATE	NEAR BEACHES			FAR BEACHES						
(MO. YR.)	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
APR 77	7.4	1.92	5	5.4	–	1	4.0	0.43	0.69	0.29
MAY 77	5.3	0.24	4	6.8	–	1	3.0	-2.81	0.07	1.0
JUN 77	6.6	0.22	5	5.5	0.09	2	5.0	2.86	0.04*	1.0
JUL 77	8.9	0.53	5	7.6	1.41	2	5.0	1.09	0.32	0.83
AUG 77	9.1	0.50	5	7.1	0.57	2	5.0	2.31	0.07	0.97
JUL 80	8.9	1.35	3	12.1	1.47	6	7.0	-1.39	0.21	0.36
AUG 80	13.4	–	1	11.9	0.69	3	2.0	1.12	0.38	1.0
MAY 81	8.1	0.70	5	9.1	–	1	4.0	-0.56	0.60	1.0
JUL 81	10.1	1.24	5	6.9	–	1	4.0	1.08	0.34	0.85
AUG 81	10.8	1.20	5	5.4	–	1	4.0	1.84	0.14	0.91
SEP 81	10.9	1.55	4	5.5	–	1	3.0	1.57	0.21	0.66
JUN 83	11.0	4.67	3	8.1	0.88	8	2.1	0.61	0.60	0.10
JUL 83	9.1	0.65	5	9.8	0.65	10	13.0	-0.68	0.51	0.98
AUG 83	11.2	0.86	4	11.7	0.81	9	11.0	-0.34	0.74	0.96

Table E-5

T-tests comparing mean maximum size of male sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% difference (of the mean of beaches within 20 km of SONGS) between Near and Far beaches at the 0.05 level.

DATE (MO. YR.)	NEAR BEACHES MEAN	SE	N	FAR BEACHES MEAN	SE	N	DF	T	P	POWER
APR 77	5.05	0.21	5	5.2	–	1	4.0	-0.2	0.85	1.0
MAY 77	5.0	0.12	5	5.2	–	1	4.0	-0.63	0.56	1.0
JUN 77	5.3	0.19	5	4.9	0.19	2	5.0	1.31	0.25	1.0
JUL 77	6.0	0.27	5	5.6	0.92	2	5.0	0.51	0.63	1.0
AUG 77	6.1	0.23	5	6.4	0.08	2	5.0	-0.92	0.40	1.0
JUL 80	6.0	0.09	3	6.5	0.32	6	5.7	-1.34	0.23	1.0
AUG 80	6.9	–	1	6.1	0.54	3	2.0	0.74	0.54	1.0
MAY 81	5.8	0.28	5	6.5	–	1	4.0	-0.89	0.42	1.0
JUL 81	6.1	0.30	5	5.4	–	1	4.0	0.93	0.40	1.0
AUG 81	6.6	0.35	5	5.4	–	1	4.0	1.44	0.22	1.0
SEP 81	6.9	0.31	4	5.2	–	1	3.0	2.47	0.09	1.0
JUN 83	6.7	0.87	3	6.6	0.38	8	9.0	0.07	0.94	1.0
JUL 83	6.8	0.18	5	6.8	0.27	9	12.0	0.0008	0.99	1.0
AUG 83	7.5	0.34	4	7.6	0.35	9	11.0	-0.23	0.82	1.0

Table E-6

Month by month tests for location effects on molt increments of female sand crabs.

Pearson product-moment correlation coefficients of molt increment of female sand crabs versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
SEP 76	Small	0.53	5	0.35	0.20
OCT 76	Small	-1.0	3	0.0001*	1.0
APR 77	Small	0.27	4	0.73	0.45
MAY 77	Medium-small	0.74	5	0.15	0.68
	Small	0.84	6	0.03*	1.0
JUN 77	Medium-small	-0.28	6	0.59	0.67
	Small	-0.66	6	0.15	0.98
JUL 77	Medium-small	0.58	6	0.23	0.96
	Small	0.53	6	0.28	0.60
AUG 77	Medium-small	0.91	6	0.01*	0.84
	Small	-0.58	4	0.42	0.43

T-tests comparing the molt increment of female sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% (of the mean of beaches within 20 km of SONGS) difference between Near and Far beaches at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	NEAR BEACHES MEAN	SE	N	FAR BEACHES MEAN	SE	N	DF	T	P	POWER
APR 77	Small	0.819	0.094	3	0.876	–	1	2	-0.30	0.79	0.64
MAY 77	Medium-small	0.849	0.071	4	1.2	–	1	3	-2.21	0.11	1.0
	Small	0.755	0.023	5	0.872	–	1	4	-2.09	0.1	1.0
JUN 77	Medium-small	1.01	0.075	5	1.05	0.312	2	5	-0.23	0.83	0.47
	Small	0.882	0.043	5	0.754	0.064	2	5	1.58	0.17	0.99
JUL 77	Medium-small	0.787	0.054	5	1.06	0.226	2	5	-1.81	0.13	0.57
	Small	0.656	0.045	5	0.95	0.05	2	5	-3.65	0.01*	0.94
AUG 77	Medium-small	0.673	0.09	5	1.19	0.017	2	5	-3.43	0.02*	0.52
	Small	0.612	0.073	3	0.525	–	1	2	0.59	0.61	0.57

Table E-7

Month by month tests for location effects on molt increments of male sand crabs.

Pearson product-moment correlation coefficients of molt increment of male sand crabs versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
SEP 76	Small	0.21	5	0.74	0.22
OCT 76	Small	0.93	4	0.08	0.15
APR 77	Small	0.36	4	0.64	0.25
MAY 77	Small	0.54	6	0.27	0.57
JUN 77	Small	-0.58	5	0.30	0.43
JUL 77	Small	0.94	6	0.006*	0.77
AUG 77	Small	0.82	6	0.048*	0.74

T-tests comparing the molt increment of male sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% (of the mean of beaches within 20 km of SONGS) difference between Near and Far beaches at the 0.05 level.

DATE	SIZE	NEAR BEACHES			FAR BEACHES						
(MO. YR.)	CLASS	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
APR 77	Small	0.53	0.088	3	0.64	–	1	2	-0.61	0.61	0.42
MAY 77	Small	0.54	0.062	5	0.68	–	1	4	-0.90	0.42	0.91
JUN 77	Small	0.69	0.093	4	0.62	0.044	2	4	0.52	0.63	0.43
JUL 77	Small	0.44	0.021	5	0.78	0.275	2	1	-1.21	0.44	0.07
AUG 77	Small	0.52	0.062	5	0.68	0.100	2	5	-1.43	0.21	0.50

Table E-8
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Pearson product-moment correlation coefficients of the fraction of female sand crabs that were reproductive versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50% of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
SEP 76	Medium-large	-0.94	4	0.06	0.07
	Medium-small	-0.61	5	0.28	0.05
APR 77	Large	0.50	3	0.67	0.05
MAY 77	Large	-0.50	3	0.67	0.05
JUN 77	Medium-large	-0.57	4	0.43	0.05
	Medium-small	-0.57	6	0.24	0.06
JUL 77	Large	0.87	3	0.33	0.22
	Medium-large	-0.94	6	0.006*	0.74
	Medium-small	-0.77	6	0.07	0.13
AUG 77	Medium-large	-0.55	5	0.34	0.12
	Medium-small	-0.89	6	0.02*	0.25
	Small	-0.42	6	0.41	0.05
JUL 80	Large	-0.77	3	0.44	0.05
	Medium-large	-0.41	4	0.59	0.06
	Medium-small	0.24	4	0.76	0.05
MAY 81	Large	-0.93	4	0.08	0.07
	Medium-large	-0.54	5	0.35	0.05
	Medium-small	-0.54	5	0.35	0.05
JUL 81	Large	-0.71	4	0.29	0.05
	Medium-large	-0.61	5	0.27	0.05
	Medium-small	-0.57	5	0.31	0.05

Table E-8
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DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
AUG 81	Large	-0.96	3	0.18	0.06
	Medium-large	-0.44	5	0.46	0.06
	Medium-small	-0.85	5	0.07	0.06
SEP 81	Large	-0.69	4	0.31	0.05
	Medium-large	-0.83	4	0.17	0.05
	Medium-small	-0.39	4	0.61	0.05
JUN 83	Large	0.98	3	0.12	0.09
	Medium-large	1.0	3	0.0001*	1.0
JUL 83	Large	0.91	5	0.03*	0.20
	Medium-large	0.68	8	0.06	0.12
	Medium-small	-0.15	9	0.69	0.07
AUG 83	Large	0.83	4	0.17	0.06
	Medium-large	0.46	8	0.25	0.08
	Medium-small	0.47	8	0.24	0.07
AUG 86	Large	-0.14	16	0.61	0.99
	Medium-large	0.004	22	0.98	0.98

Table E-9
page 1 of 2

T-tests comparing the fraction of female sand crabs that were reproductive between Near (impact) and Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% difference (of the mean of beaches within 20 km of SONGS) between Near and Far beaches at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	NEAR BEACHES MEAN	NEAR BEACHES SE	NEAR BEACHES N	FAR BEACHES MEAN	FAR BEACHES SE	FAR BEACHES N	DF	T	P	POWER
JUN 77	Medium-small	0.048	0.029	5	0	0	2	5.0	0.97	0.38	0.06
JUL 77	Large	0.899	0.043	3	1.000	–	1	2.0	-1.16	0.36	1.0
	Medium-large	0.787	0.074	5	0.166	0.075	2	5.0	4.78	0.005*	0.55
	Medium-small	0.202	0.063	5	0	0	2	5.0	1.93	0.11	0.10
AUG 77	Medium-small	0.562	0.135	5	0.022	0.022	2	5.0	2.38	0.06	0.14
	Small	0.004	0.004	5	0	0	2	5.0	0.6	0.58	0.05
JUL 80	Large	0.397	0.168	3	0.846	0.053	5	6.0	-3.18	0.02*	0.22
	Medium-large	0.075	0.056	3	0.225	0.086	6	7.0	-1.14	0.29	0.06
	Medium-small	0.001	0.001	3	0.002	0.001	6	7.0	-0.47	0.65	0.07
AUG 80	Large	0.954	–	1	0.955	0.022	3	2.0	-0.03	0.98	1.0
	Medium-large	0.915	–	1	0.813	0.035	3	2.0	1.47	0.28	1.0
	Medium-small	0.375	–	1	0.087	0.035	3	2.0	4.11	0.055	1.0
MAY 81	Large	0.369	0.184	4	0.808	–	1	3.0	-1.07	0.36	0.11
	Medium-large	0.120	0.120	5	0	–	1	4.0	0.41	0.70	0.07
	Medium-small	0.004	0.004	5	0	–	1	4.0	0.41	0.70	0.07

Table E-9
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DATE (MO. YR.)	SIZE CLASS	NEAR BEACHES MEAN	SE	N	FAR BEACHES MEAN	SE	N	DF	T	P	POWER
JUL 81	Large	0.199	0.167	4	0.962	–	1	3.0	-2.04	0.13	0.07
	Medium-large	0.177	0.133	5	0.827	–	1	4.0	-2.00	0.11	0.08
	Medium-small	0.084	0.072	5	0.035	–	1	4.0	0.28	0.79	0.07
AUG 81	Large	0.381	0.20	3	1.000	–	1	2.0	-1.55	0.26	0.09
	Medium-large	0.277	0.077	5	0.412	–	1	4.0	-0.72	0.51	0.28
	Medium-small	0.041	0.019	5	0	–	1	4.0	0.88	0.43	0.13
SEP 81	Medium-large	0.146	0.090	4	0.200	–	1	3.0	-0.27	0.81	0.09
	Medium-small	0.056	0.032	4	0	–	1	3.0	0.79	0.49	0.10
JUN 83	Large	0.026	0.026	2	0.470	0.131	7	7.0	-1.72	0.13	0.05
	Medium-large	0	0	2	0.010	0.008	6	6.0	-0.72	0.50	0.05
JUL 83	Large	0.238	0.102	3	0.581	0.128	8	9.0	-1.53	0.16	0.13
	Medium-large	0.034	0.023	5	0.212	0.101	8	7.7	-1.72	0.12	0.07
	Medium-small	0.003	0.003	5	0.013	0.011	10	9.9	-0.88	0.40	0.05
AUG 83	Large	0.031	0.009	3	0.806	0.109	6	5.1	-7.07	0.0008*	0.06
	Medium-large	0.122	0.071	5	0.536	0.135	8	11.0	-2.27	0.04*	0.09
	Medium-small	0.053	0.040	5	0.225	0.086	8	9.6	-1.82	0.10	0.08
AUG 86	Large	0.961	0.021	7	0.906	0.033	10	15.0	1.29	0.22	1.0
	Medium-large	0.709	0.050	13	0.737	0.054	11	22.0	-0.38	0.71	1.0

Table E-10

T-tests comparing the fraction of female sand crabs that had spent clutches between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% difference (of the mean of beaches within 20 km of SONGS) between Near and Far beaches at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	NEAR BEACHES MEAN	SE	N	FAR BEACHES MEAN	SE	N	DF	T	P	POWER
JUL 81	Large	0.648	0.150	4	0.037	–	1	3.0	1.82	0.17	0.32
	Medium-large	0.483	0.091	5	0.069	–	1	4.0	1.85	0.14	0.52
	Medium-small	0.112	0.031	5	0	–	1	4.0	1.43	0.23	0.27
AUG 81	Large	0.469	0.156	3	0	0	4	5.0	3.59	0.01*	0.31
	Medium-large	0.437	0..051	5	0.050	0.050	4	7.0	5.30	0.001*	0.73
	Medium-small	0.070	0.029	5	0	0	4	7.0	2.12	0.07	0.15
SEP 81	Large	0.299	0.077	4	0.098	0.094	3	5.0	1.67	0.16	0.17
	Medium-large	0.366	0.047	4	0.031	0.030	3	5.0	5.45	0.003*	0.67
	Medium-small	0.031	0.011	4	0	0	3	5.0	2.33	0.07	0.16
JUN 83	Large	0.566	0.145	2	0.051	0.021	7	1.0	3.51	0.17	0.09
JUL 83	Large	0.240	0.051	3	0.036	0.015	8	2.3	3.37	0.07	0.13
	Medium-large	0.056	0.029	5	0.008	0.006	8	4.4	1.63	0.17	0.09
	Medium-small	0.004	0.002	5	0.0002	0.0002	10	4.1	1.78	0.15	0.07
AUG 83	Large	0.646	0.035	3	0.110	0.072	6	7.0	5.00	0.002*	0.67
	Medium-large	0.259	0.063	5	0.111	0.056	8	11.0	1.70	0.12	0.27
	Medium-small	0.090	0.042	5	0.045	0.021	8	11.0	1.07	0.31	0.16
AUG 86	Large	0.015	0.007	7	0.043	0.015	10	12.3	-1.71	0.11	0.14
	Medium-large	0.084	0.018	13	0.062	0.009	11	22.0	1.04	0.31	0.41

Table E-11

Pearson product-moment correlation coefficients of female sand crabs that had spent clutches (fraction spent) versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	SIZE CLASS	r	N	P	POWER
JUL 81	Large	0.75	4	0.25	0.08
	Medium-large	0.32	5	0.60	0.08
	Medium-small	-0.80	5	0.11	0.08
AUG 81	Large	0.84	3	0.36	0.06
	Medium-large	0.58	5	0.31	0.14
	Medium-small	-0.60	5	0.29	0.06
SEP 81	Large	0.75	4	0.25	0.07
	Medium-large	0.92	4	0.08	0.25
	Medium-small	-0.81	4	0.19	0.06
JUN 83	Large	-0.91	3	0.27	0.07
JUL 83	Large	-0.85	5	0.07	0.14
	Medium-large	-0.60	8	0.12	0.10
	Medium-small	-0.70	9	0.04*	0.10
AUG 83	Large	-0.98	4	0.02*	1.0
	Medium-large	-0.22	8	0.61	0.18
	Medium-small	-0.26	8	0.53	0.10
AUG 86	Large	0.15	16	0.57	0.07
	Medium-large	-0.06	22	0.80	0.30

Table E-12

Pearson product-moment correlation coefficients of mean minimum size of reproduction by female sand crabs versus distance from SONGS. Data from sites 20 km or closer to SONGS were used. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a change of 50 % of the mean (for all beaches used in the analysis) over a 10 km distance at the 0.05 level.

DATE (MO. YR.)	r	N	P	POWER
JUN 77	0.82	5	0.09	0.41
JUL 77	0.77	5	0.13	0.65
AUG 77	0.89	5	0.04*	0.58
JUL 80	0.06	3	0.96	0.12
MAY 81	0.94	4	0.06	0.26
JUL 81	0.89	5	0.04*	0.93
AUG 81	0.10	5	0.87	1.0
SEP 81	0.52	4	0.48	0.20
JUN 83	-0.97	3	0.17	1.0
JUL 83	-0.27	7	0.56	0.97
AUG 83	-0.18	8	0.66	0.94

Table E-13

T-tests comparing mean minimum size of reproduction by female sand crabs between Near (impact) versus Far (control) beaches. Tests were done including beaches 6.5 km or closer in the Near group. * indicates a significant ($p < 0.05$) result. Power is the probability of detecting a 50% difference (of the mean of beaches within 20 km of SONGS) between Near and Far beaches at the 0.05 level.

DATE	NEAR BEACHES			FAR BEACHES						
(MO. YR.)	MEAN	SE	N	MEAN	SE	N	DF	T	P	POWER
JUL 77	9.77	0.504	5	11.81	–	1	4.0	-1.65	0.17	1.0
AUG 77	8.63	0.681	5	9.18	–	1	4.0	-0.33	0.76	1.0
JUL 80	15.84	2.040	2	13.40	0.599	6	6.0	1.67	0.15	0.99
MAY 81	21.74	3.220	4	15.78	–	1	3.0	0.83	0.47	0.62
JUL 81	10.64	0.501	5	10.33	–	1	4.0	0.25	0.81	1.0
AUG 81	10.66	0.208	5	10.97	–	1	4.0	-0.61	0.58	1.0
JUN 83	18.50	0.606	2	15.68	0.560	6	6.0	2.66	0.04*	1.0
JUL 83	14.45	0.682	5	13.95	0.742	8	11.0	0.45	0.66	1.0
AUG 83	12.38	0.930	5	9.98	1.320	8	11.0	1.31	0.22	0.83