MEC 1983 SAND CRAB PROJECT
FINAL REPORT

VOLUME 1

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October 5, 1984

Mr. H. Kaspar
Marine Review Committee
531 Encinitas Blvd. Suite 105
Encinitas, CA 92024

Dear Mr. Kaspar:

Marine Ecological Consultants (MEC) is pleased to submit the Final Report for the 1983 Sand Crab Project. The report presented here benefited from reviews of an earlier draft submitted in June 1984. MEC completed all agreed upon changes, which are fully integrated into this report, within the time frame authorized by the MRC.

The Report contains:

(1) Volume 1, which includes an Executive Summary, the report proper, Summary and Conclusions, and References; and

(2) Volume 2, comprised of eight Appendices giving detailed support to information presented in the report body, and one Appendix which provides an annotated history of sand crab studies that were conducted relative to SONGS.

The 1983 study demonstrated that sand crab populations in the San Onofre area differed from those in other areas of the southern California Bight primarily in terms of female reproduction, which appeared to be less. The occurrence of high percentages of females in the San Onofre area with clutches of spent egg cases rather than developing eggs, which had been reported in previous studies, was observed in 1983. A question still remaining after the present study is whether or not these clutches of spent egg cases resulted from normal hatching of eggs or disrupted egg maturation. Additional study is needed to conclusively answer this question.

Results of the 1983 study showed that much of the variability among beach sites in the measured attributes of sand crabs could be accounted for by correlations with the physical/chemical environment of the beach habitats. However, it must be emphasized that correlation does not demonstrate causal relationship and additional work will have to be done before causal relationships can be established.

Finally, without metal and non-metallic pollutant data, we were unable to determine whether pollutants were related to the sand crab attributes that differed between beach sites near SONGS and other beach sites to the north and south. We did find that the sand crab attributes that previous investigators had suggested were potentially related to metals could be attributed to natural environmental factors.

Sincerely,

Arthur M. Barnett

Arthur M. Barnett
Principal Investigator

EXECUTIVE SUMMARY

The sand crab *Emerita analoga*, a prominent component of the open sand beach community adjacent to SONGS, was investigated relative to SONGS during 1976-1977 (Auyong, 1981) and during 1980-1982 (Wenner, 1980;1982). These studies suggested that sand crab populations near SONGS were different from those farther away. The Marine Review Committee (MRC) commissioned a study in 1983 to determine whether or not this difference was significant when the variability among populations from several different beaches in southern California was considered. If SONGS beach sites were found to be significantly different possible explanations were to be explored. This report presents the findings of the 1983 study, conducted for the MRC by Marine Ecological Consultants (MEC).

This study statistically compares sand crab populations at fifteen beaches in southern California, including six sites sampled in the earlier studies (Auyong, 1981; Wenner, 1980, 1982). Three surveys were made during the season (June, July, August) when sand crabs were most abundant and breeding on the beaches. Quantitative random or stratified-random sampling strategies, with replication, were used to control for within-beach variation. All beach sites were sampled within a four or five day period to control for short-term temporal variation.

Variables were measured to characterize both the physical-chemical environment and the potential food resource for sand crabs at each beach site. In addition, sand crab population attributes were examined that related to abundance, size distribution, female reproduction, and genetics. To provide continuity with the previous studies, attributes of size distribution and reproduction examined in past studies were re-examined when appropriate.

The abundances of male and female sand crabs appeared lower at beach sites within 12 km of SONGS in June relative to other sites, seemingly as a result of both a delay in recruitment of planktonic young and a delay in colonization by juveniles and adults from the subtidal zone. In July and August, the abundances of males and females at sites within 12 km of SONGS were within the variation found elsewhere.

Size attributes appeared to be related, at least in part, to differences in recruitment, presence of overwintered individuals in the population, and initiation of reproduction. Consequently, sizes of sand crabs at beach sites near SONGS typically fell within the variation found at other beach sites. However, fewer large overwintered individuals were generally found at sites within 15.5 km of SONGS.

The principal sand crab breeding season in 1983 spanned about two months (August - September), which is shorter than previously reported. This may have been related to the atypical El Nino conditions, which caused high cobble conditions on some beaches in early summer and reduced overall primary production.

Within 12 km of SONGS, the fraction of reproductive females (bearing either eggs or spent egg cases or both) generally was lower than at beach sites elsewhere. Also there was a decrease with proximity to SONGS in the fraction of the spent females (8-13 mm carapace length) preparing to brood again in August. This, together with the late start of the reproductive season at SONGS beaches, indicates that females within 12 km of SONGS produced fewer clutches of eggs than at sites elsewhere.

Reproductive females within 12 km of SONGS differed from those at most other sites in that they predominantly carried clutches comprised of spent egg cases in August and September. High percentages of spent females also occurred at Hermosa Beach (100 km N) and Venice Beach (115 km N) in September. Reproductive females at other sites, and at Hermosa Beach in August, predominantly had clutches of developing eggs.

The occurrence of high percentages of females with spent egg cases near SONGS previously has been suggested to result from premature disruption of egg maturation (Wenner, 1982). It was further suggested by Siegel and Wenner (1984) that the disruption might be related to metals contamination from SONGS operation, agricultural runoff of pesticides, and/or increased turbidity due to Plant operation.

However, the implications of high fractions of spent females near SONGS in 1983 remain uncertain and controversial. Alternatives based on disrupted egg maturation, reproductive synchrony, or end of season persistence of spent egg cases were examined; supportive information was found for each alternative. Of particular importance was the finding that there was a higher incidence of spent egg cases in clutches of developing eggs from females near SONGS and Hermosa Beach. This indicates that a certain amount of egg disruption occurred at sites near SONGS and at least at one Los Angeles beach in 1983.

For those attributes that differed between SONGS and other sites, identification of related environmental variables was made by multiple regression analyses. Cluster analyses of beach sites were consulted to indicate whether the correlations with individual variables made ecological sense.

The apparent delay in recruitment and colonization of sand crabs to beach sites within 12 km of SONGS seemed to be related to the physical character of the habitats. Since sand crab larvae are planktonic, we cannot disregard the possibility that later recruitment in the San Onofre area may have been related to intake withdrawal or entrainment, even though SONGS operation occurred only intermittently in 1983.

The fraction of females in breeding condition (bearing either eggs or spent egg cases) was generally lower at beach sites where food availability was reduced, seston was higher, where the water was cooler, and where the sediment was coarser. More clutches of developing eggs had spent egg cases at beach sites with coarser sediments or extensive cobble coverage, or both. Furthermore, fewer batches of eggs were produced by females at sites where recruitment may have been later, where sediments were coarser, and where food was generally less available. These observations suggest that, in general, reduced reproductive potential is associated with later recruitment, less food, more seston, and coarse, unstable beach substrate. These habitat attributes characterize beach sites near San Onofre. Some of the habitat variations are natural, and some may be related to SONGS construction or operation. The relatively coarser sediment of beach sites within 15.5 km of SONGS is primarily natural, having been identified as such before SONGS Unit 1 was built (Shepard, 1950). However, there is some evidence that beach sediments in the immediate vicinity of SONGS have been altered by SONGS construction activities (ECO-M, 1984).

The association of increased breeding activity with sites having more chlorophyll-phaeopigments and less particulates in the water (seston) suggests that seston could be unacceptable as sand crab food and could inhibit feeding by clogging their setose antennae. The SONGS discharge water is expected to contain an increased seston component, comprising fine-grained inorganic particles and organics. However, although the Unit 1 discharge water can mix into the surf zone, the discharges from Units 2 and 3 are expected to be directed offshore by the diffuser system and therefore are unlikely to impact the beach.

The charge that metal pollutants from SONGS or other sources, or non-metallic pollutants from agricultural sources might disrupt egg maturation or reduce breeding was not addressed in this study, although the appropriate samples have been collected.

This report is organized into two volumes, the main text and supplementary appendices. Volume 1 contains 6 chapters: (1) Introduction, (2) Methods and Materials, (3) Results and Discussion, (4) Summary and Conclusions, (5) Tables and Figures, and (6) Literature Cited. Volume 2 contains nine appendices (A-I) of supplementary information. For those interested only in the objectives and conclusions of this report, we recommend reading the Introduction, Summary and Conclusions, and Appendix I, which presents an annotated history of sand crab studies that were related to SONGS.

TABLE OF CONTENTS

VOLUME 1

VOLUME 2 (IN SEPARATE BINDING)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Under a mandate from the California Coastal Commission the Marine Review Committee (MRC) has undertaken studies of the effects of the San Onofre Nuclear Generating Station (SONGS) on the surrounding marine environment and its inhabitants. The shoreline habitat adjacent to SONGS is open sand beach. The sand crab, Emerita analoga, is a prominent component of the sand beach community, and was investigated relative to SONGS during 1976-1977 (Auyong, 1981) and during 1980-1982 (Wenner, 1980; 1982). This report presents the findings of a 1983 study, conducted for the MRC by Marine Ecological Consultants.

Sand crabs, Emerita analoga (Stimpson, 1857), live on intertidal sand beaches along the west coasts of North and South America (Efford, 1970). On the beach they feed by passively straining small food particles from the wave wash with their plumose antennae (Efford, 1966). Because of the constant movement of water and sand they are not strictly sedentary and may move some distance in a given beach area during their juvenile-adult lifetime. It has been estimated that males may live for a little more than one year and females perhaps up to 3 to 5 years (Dudley, 1967).

The life cycle of sand crabs includes a planktonic larval stage. Although breeding can occur year-round, most reproductive females are found on the beaches during late spring and summer months (MacGinitie, 1938; Cox and Dudley, 1968). The eggs, fertilized externally by males, are carried by the brooding females for about a month (Cox and Dudley, 1968; Fusaro, 1980a). The young hatch in the surf zone as zoea larvae and drift in the coastal currents for an estimated 1.5 to 4 months (Johnson, 1940; Wharton, 1942; Barnes and Wenner, 1968). Females may produce from one to several broods during the summer, depending on their age and environmental conditions (Cox and Dudley, 1968; Fusaro, 1980a).

At the shore, the successful larvae metamorphose from the more advanced, megalopa larval stage into juvenile sand crabs (Johnson, 1940; Dudley, 1967). Depending on when they recruit, the juveniles may mature into sexually active adults during their first summer on the beach. Abundances on beaches are usually highest in spring and summer as a result of recruitment from the plankton. Not all the post-megalops sand crabs are necessarily up on the beach faces at a particular time, however. Subpopulations apparently take refuge in the subtidal sands at least some of the time, where they are inaccessible to beach sampling (sections 2.1.3.1 and 3.2.2.1 of this report).

Age structures, average individual growth rates, and egg production can differ between natural populations of sand crabs on nearby beaches (Cox and Dudley, 1968; Fusaro, 1980a). These variations are related to differences in time of recruitment (Efford, 1970) and to differences in environment (Fusaro, 1980a). Well-defined natural genetic differences between populations seem unlikely because recruits from the plankton probably originate from a mixture of parent beaches.

During their life cycle, sand crabs could be directly affected by SONGS in at least three ways. SONGS might change the availability of food--most of the plankton which pass through the seawater cooling system is killed and appear in the discharge water as detritus (EQA and MBC, 1973; Barnett et al., 1980). An increase in detritus of an inappropriate size (1 mm to 2 mm) could interfere with the filter feeding of sand crabs.

SONGS Unit 1 releases metals (primarily copper) as a result of corrosion of condenser tubing (USAEC, 1973), which might interfere with enzyme actions or other physiological functions. Toxicity studies have indicated that growth of crab larvae is adversely affected by concentrations of free cupric ions in seawater slightly above ambient levels (Sanders et al., 1983). SONGS Units 2 and 3 condenser tubes are made of titanium rather than of a copper-nickel alloy, which should preclude copper and nickel discharges (USNRC, 1981).

SONGS might affect recruitment to beach populations by affecting pelagic larval stages. Most larvae drawn into the plant are killed (EQA and MBC, 1973; Barnett et al., 1980) and therefore unavailable as recruits to beach populations. Larvae entrained in the discharge plume also could be lost to local beach populations either through mortality or physical displacement.

SONGS may indirectly affect sand crabs by altering their beach habitat. There is some evidence that the median grain size of the beach sediment directly to the south of the plant has increased because of construction activities. Non-beach sediment excavated from the bluffs adjacent to the plant was deposited on the beach. Also, normal downcoast sand transport has been interrupted since 1974 by a temporary seawall (equipment laydown pad) directly seaward of the plant (ECO-M, 1984).

Although SONGS has a thermal discharge, it is not predicted that elevated temperatures will significantly affect beach populations of sand crabs. No correlation was found between temperature and sand crab population structure during a period of Unit 1 operation (Auyong, 1981). This was so despite the tendency for the Unit 1 discharge to direct the plume towards shore (Koh et al., 1974). Because of the projected dispersive effect of the diffuser systems and offshore movement of the discharge plume, temperature effects are not predicted from the operation of Units 2 and 3.

The reports from the previous studies have suggested that SONGS may affect the growth and reproduction of sand crabs. Because there are no appropriate pre-SONGS observations of sand crabs at San Onofre, the effects were evaluated by comparing sites at varying distances from SONGS. From a survey of five beach locations within 6.5 km of SONGS, Auyong (1981) reported that sand crabs living within 1.5 km north of the plant grew less rapidly and matured at a smaller size during the 1977 breeding season (primarily July and August). No correlation emerged between observed differences in habitat variables (temperature and organic solids in the wave wash zone) and these differences in sand crab population structure.

Wenner (1980, 1982) compared those 1977 data with observations from other years. From this he inferred that growth and reproduction were curtailed in the vicinity of San Onofre by SONGS operation in 1977. Wenner's assessment of sand crab population structures in 1980, 1981 and 1982, when SONGS was semi-operational, seemed to indicate less of an effect on growth. But he found unexpectedly low incidences of females carrying eggs at sites within 6.5 km of the plant in July 1981 and at distances to about 15 km north and 20 km south of SONGS in July 1982. Instead of carrying eggs, adult females were carrying masses of empty egg shells.

Wenner considered the high proportion of females with spent egg cases to have been a consequence of disrupted egg maturation rather than post-partum observations of synchronized release of larvae. This interpretation was based in part on a laboratory experiment. Living specimens of mature females ($\geq$ 12 mm carapace length), most of which had spent egg cases, and males were taken to the laboratory and held in flowing-water tanks. After 3 weeks 37% of the females had extruded new (orange-colored) and apparently healthy egg masses. In contrast, only 5% of the females > 13 mm carapace length in the population at the original collecting site had extruded orange eggs during the interim. From his analyses, Wenner (1982) concluded that the stretch of beach at San Onofre, with SONGS at its center, was a poor habitat for sand crabs.

These findings of Wenner and others for 1982 and before do not clearly establish that SONGS interfered significantly with sand crabs. This is so primarily because differences occur not only between sites, without regard to distance from SONGS, but between seasons and years at the same site. There were few occasions of concurrent data from the same season, in a given year, from San Onofre and other beaches, which limits evaluation of among-beach comparisons. Finally, insufficient information was collected regarding the beach habitats themselves. Thus, it was not possible to evaluate whether differences in sand crab populations were related to the habitats of the beach sites or to SONGS effects.

The MRC reviewed the above-mentioned studies and concluded that information was insufficient to evaluate whether beach populations of sand crabs were affected by the operation of SONGS. But the findings were considered to be of sufficient importance to warrant more study.

The present study was designed to further the investigation. The combination of haphazard time-space arrival of recruits and influence of environmental and behavioral forces could lead to the kind of variability in population structure actually observed between beach sites in previous studies. For these reasons, the 1983 investigations were designed to contrast several quasi-synoptically sampled beach sites near and away from SONGS both in terms of their habitats and their sand crab populations.

The present study statistically compares sand crab populations at fifteen beach sites in southern California, including six of the beach sites sampled by Auyong (1981) or Wenner (1980, 1982). A quantitative, stratified-random sampling strategy, with replication, was used to control for instantaneous within-beach variation. Three surveys were made in 1983, during the season (June, July, August) when sand crabs are most abundant and are breeding on southern California beaches (MacGinitie, 1938; Barnes and Wenner, 1968; Cox and Dudley, 1968; Auyong, 1981). Concurrent sampling was done to control for short-term temporal variation. Variables were measured that were related to the physical and chemical environment of the beach sites and that represented potential food resources for sand crabs. The sand crab population attributes that were examined are related to abundance, size distribution, female reproduction, and genetics. To provide further continuity with the previous studies, attributes of size distribution and reproduction that had been examined in past studies were re-examined, if deemed appropriate.

SONGS circulated water intermittently through Units 1, 2, and 3 during the 1983 study. Therefore 1983 may not be wholly representative of potential impact during full-scale operation. The sand crab habitat also was atypical in 1983, because elevated water temperatures, reduced plant nutrients, and severe coastal storms accompanied the prolonged El Nino event of 1982-1983 (section 3.1 and 3.3 of this report). Keeping in mind these limitations, the 1983 study addressed whether population attributes at beach sites near SONGS were within the variation observed at other beach sites. If sand crab attributes varied relative to SONGS, then the relationships with the physical-chemical environment were investigated by multiple regression analysis combined with cluster analysis. SONGS effects would be indicated if correlations between sand crab measurements and the environment were poor. On the other hand, the occurrence of strong correlations does not necessarily indicate that SONGS effects were absent. It is possible that effects could be masked by environmental variation or that effects from SONGS act in concert with the environment. It should be noted that the 1983 sand crab study was not designed to provide a direct evaluation of the potential impacts from SONGS. To do so would have entailed a combination of laboratory and field experiments designed to control for environmental variation.

This report emphasizes the results of the sand crab investigation in light of the selected environmental variables that were analyzed. Equal treatment cannot be given at this time to relationships with other variables such as metallic or non-metallic pollutants because, although pollutant samples were collected, their analyses have not as yet been funded by the MRC. Furthermore, effects from intake withdrawal were not investigated and are not specifically addressed. This is so because models of circulation in the SONGS area that translate intake losses into potential areas of lowered meroplanktonic abundances are not presently available.

2.0 METHODS AND MATERIALS

Where possible and appropriate, continuity with previous studies was furthered by the use of comparable methods. The unprecedented scope of the field sampling, however, required some new strategies, devices, and procedures. These are described briefly herein. The more detailed elements of sampling and analysis protocols are given in Appendices A, B, and C.

2.1 Beach Sampling

The objectives were to find fifteen similar beach sites known to be frequented by sand crabs, to sample all sites as concurrently as possible during each of three surveys, and to obtain representative samples from each beach site. Fielding fifteen beach crews simultaneously was beyond the logistic capability of the program. But, four uniformly trained and equipped crews were able to complete a fifteen-beach survey within a period of four or five days.

2.1.1 Beach Site Selection

San Onofre Nuclear Generating Station is located in the Southern California Bight, about 33° 22.5 ' N and 117° 32.5' W, between the cities of San Clemente and Oceanside (Figure 2-1). San Onofre is about midway within the Oceanside littoral cell (Inman and Frautschy, 1966). There are five such cells along the southern California coast, each containing a complete sand-transport cycle. Most sand is brought to the coast by streams, carried along the shore by wave-induced currents, and lost into offshore basins by way of submarine canyons.

The coastline is fairly uniform at San Onofre, and runs NW to SE (310° to 130°). The adjacent shelf slopes regularly for about 7 km out to a break at the 70 m depth contour. The beach is partially protected by the Channel Islands from North Pacific swells that approach between SW and NW (230^{0} or greater); it is exposed to summer southern swell (Pawka and Guza, 1983).

Criteria for beach selection included distance from SONGS, similarity of sediments, presence of sand crabs, location relative to littoral cells, and whether the site had been sampled in previous MRC sand crab studies. Besides three sites very near SONGS (1.5 km N, 0.4 km N, 1.5 km S), the selection included six sites upcoast (seven during the August survey) and six sites downcoast (Figure 2-1).

The following six sites, all within the Oceanside Littoral Cell, were selected because they were near sites sampled by Auyong (1981) or Wenner (1980, 1982): 65 km S (La Jolla), 6.5 km S, 1.5 km S, 0.4 km N, 1.5 km N, and 6.5 km N (San Clemente State Beach). Six additional sites were selected from within the Oceanside littoral cell. Four of these were pairs located similar distances south and north of SONGS: 12 km S (Camp Pendleton), 12 km N (San Juan Capistrano Beach), 18 km S (Camp Pendleton), and 15.5 km N (North Doheny State Beach). The remaining two provided additional geographic coverage between La Jolla and Camp Pendleton: 45 km S (Moonlight State Beach), and 25 km S (Oceanside City Beach).

Four beach sites were selected north of the Oceanside littoral cell. Cabrillo Beach (79 km N) was chosen because its cobble composition closely matched the sites just north of SONGS. Hermosa Beach (100 km N) and Venice Beach (115 km N) were selected because adult sand crabs are generally abundant there. Because of their closer proximity to domestic and industrial discharges, these three beaches within the San Pedro and Santa Monica littoral cells may have higher concentrations of metallic and non-metallic pollutants than those near San Onofre. Since metallic pollution is one of the potential ways SONGS could affect sand crab populations, it was desirable to sample other beach sites that had the potential for a similar type of impact.

Morro Bay State Park sand spit (450 km N) was added to the sampling sites for the August survey. This site was of interest because the sediments contain more coarse sand and gravel than the beach near San Onofre, yet the beach near Morro Bay apparently supports greater numbers of sand crabs than the beach near San Onofre (Wenner*, pers. comm.).

Although beach areas were selected originally for historical reasons or for having tendencies for certain environmental characteristics or general sand crab abundance, it should be emphasized that an element of randomness was introduced in the selection of the specific sampling sites. This was because the specific stretches of beach to be sampled were also selected on the basis of other factors such as maximizing ease of access while at the same time minimizing the influence of night lighting, beachgoers, and obstructions, where possible.

At most of the selected sites, a suitable 500 m stretch of beach was identified in advance of sampling. Since sand crabs aggregate near piers and rock outcrops (Herbinson**, pers. comm.) and because of the variable type and number of obstructions on different beaches, only open stretches of beach at least 100 m away from any pier and 30 m from any outcrop were sampled. For the same reasons, areas within 30 m of

* Dr. Adrian M. Wenner, previous investigator for MRC sand crab studies, University of California, Santa Barbara.

** Mr. Kevin Herbinson, previous sand crab fisherman, Southern California Edison, Rosemead.

freshwater streams were avoided. The few areas not preselected were identified at the beginning of the first survey. Areas sampled during the first survey were retained for the remaining two surveys. The beach site 65 km S was an exception. During the first survey, the preselected 500 m area was partly below tide level, and an area that overlapped the preselected area but extended farther south was sampled instead. The preselected area at 65 km S was sampled during the two subsequent surveys.

2.1.2 Beach Sampling Gear

Quantitative samples of sand crabs were collected with a portable, hand-towed sled-net device (Figure 2-2), which was developed specifically for these studies. After extensive field trials, four identical samplers of the optimal design were built. The mouth of the sampler is a metal box (25 cm X 16 cm mouth opening) which extends 7.6 cm (3 inches) below the skids at an attack angle of 15 degrees below horizontal. A sled cut to a uniform depth of 7.6 cm when pulled at approximately 30 cm/sec. The sand crabs were captured by scooping up the sand in which they are partly buried. Series of tests showed that fewer than 1% of the crabs avoided the sampler by burrowing downward.

The sampler net was constructed of 1 mm X 2 mm polyester mesh, which retained all size groups of crabs, and was 4.6 m long. At the start of each tow the net was folded like an accordion at the trailing edge of the sampler box. Then as the tow was made (about 30 cm/sec) the net filled with sand (including crabs) and unfolded progressively until it was fully extended. Since the sampling device purposely took beach sand as well as crabs, the sample was washed clean at the end of each tow.

Following washing, the sample was sieved through a set of perforated plastic tubs to separate the sand crabs into graded size groups. Actually, the crabs separate themselves by backing down in water-saturated sand until encountering a tub with an orifice smaller than their bodies. They then remain in that tub as a separate subset of the sample.

Four sets of sorting sieves, similar to those used in earlier SONGS sand crab studies (Wenner, 1982), were made for sorting live sand crabs in the field. Each sieve set consisted of an array of eighteen heavy plastic 3 gallon (11.4 liter) buckets. The bottom of the first bucket was perforated with 20/32 inch (15.9 mm) diameter holes. Succeeding buckets ranged, by 1/32 inch (0.8 mm) decrements, from 19/32 inch (15.5 mm) to 3/32 inch (2.4 mm). The sieves were stacked in a graded sequence so that the sieve with the largest holes (20/32) was on top and the sieve with the smallest holes (3/32 inch) was on the bottom. The sieves were numbered according to hole size (e.g., #20 = 20/32 inch). Each of the four sieve sets was color coded (black, blue, green, or red).

To compare and calibrate the four sieve sets, each of five technicians measured the carapace length of five randomly selected animals from each sieve of each set (Appendix A). The long dimension of the carapace was measured with calipers to the nearest 0.1 mm. The calibrated mean carapace lengths, for all eighteen sieves of each of the four color-coded sieve sets, were later used to convert tub count data to carapace length frequencies.

In addition to these sampling and sorting devices, shovels were used to take qualitative samples. Five gallon plastic containers were used at each beach to collect water for subsequently holding live animals in the laboratory. Appropriate glass or plastic containers were used to collect water and sediment samples at each tow location for analysis of environmental variables.

2.1.3 Beach Sampling and Field Processing

Full-scale surveys were made in June, July, and early August, which is the period when sand crabs are most abundant on southern California beaches. These surveys included quantitative sampling, qualitative sampling, and detailed observations of the beach environments. Additional surveys, of female reproductive state, were made between late August and mid-October, the end of the sand crab breeding season.

2.1.3.1 Full-Scale Beach Surveys

Sand crabs and the environmental characteristics of the beach sites were surveyed 11-14 June, 30 June-3 July, and 2-5 August. The survey periods were selected with consideration to day-night and tidal cycle. Sampling was conducted after dark, when sand crabs are more uniformly distributed across the beach slope and longshore (Fusaro, 1980b; Wenner, 1982). Most samples were taken during the ebb and slack periods of the tide, when sand crabs tend to become more aggregated in the onshore-offshore direction of the beach slope and therefore are easier to sample (Wenner and Herbinson, pers. comm.; MEC observations). Beach sites were sampled during the ebb and slack periods of a spring tide in June; however, the extreme tidal fluctuation made sampling difficult at most beaches. On the upper part of the ebb cycle, sand crabs were sometimes washed over the berm, and on the lower part of the cycle, they sometimes migrated down the beach slope to very coarse sand

and/or rocky areas. To facilitate sled tow sampling, subsequent surveys were conducted primarily during the ebb and slack periods of neap tides that had minimal tidal fluctuations.

During July, it was not possible to sample all the beach sites on the same cycle of the tide. A consecutive four-five day period was not available that satisfied the sampling design; i.e., a nighttime ebb cycle during a period of low tidal fluctuation. A four-day period of low tidal fluctuation that included two days suitable for sampling the ebb cycle at night was selected as the best compromise. Beach sites 12 km, 18 km, and 45 km south of SONGS and those at and north of the site 6.5 km N were sampled during the ebb cycle of a neap tide. Other beach sites south of 6.5 km N (i.e., 1.5 km N, 0.4 km N, 1.5 km S, 6.5 km S, 25 km S, and 65 km S) were sampled during the period when the slack tide turned toward the flood cycle. Bias due to sampling some beach sites on a different tidal cycle in July was mitigated in this instance by the sampling design for the following reasons: (1) there was a small tidal range (less than 0.7 m = 2 feet) during these July neap tides, therefore, sand crabs did not migrate great distances up and down the beach; (2) although the width of the patches may have varied with the tidal cycle, it was possible to fully sample the sand crab patches; and (3) samples were taken at night when large sand crabs are more evenly distributed shoreward with the small sand crabs (Fusaro, 1980b).

Although sampling bias was not expected for the July sampling, the potential for its occurrence is further examined in light of the data analysis and is discussed in section 3.3 of this report.

In August, all beach sites were sampled during the ebb cycle of a neap tide.

Except for the first day of sampling in June, all beach sites were sampled in the same way during a given survey, but some techniques were modified between surveys. Appendix B contains details of the beach sampling protocol for each of the three surveys.

After the first sampling night of June, the number of sites sampled on each beach was decreased from nine (which turned out to be infeasible due to time constraints) to six, and instead of filtering the chlorophyll and seston samples in the field, they were filtered in the laboratory.

Although more evenly distributed in the longshore direction at night, it was found that sand crabs nevertheless may be stratified in patches. In June the sampling locations within the 500 m study sites were randomly preselected (by consulting a random numbers table) without regard to the observed locations of sand crab patches. In subsequent surveys, a stratified-random sampling method was used to improve estimates of sand crab abundance. Random sampling locations were selected within sand crab patch and interpatch areas (strata) at each study site and samples were taken at a distance of at least 1 m within the borders of the selected patch and interpatch areas. The following generalized discussion of procedures refers to this latter method of selecting sampling locations.

Prior to sampling, observers paced the 500 m stretch of beach to map the general distribution of sand crabs. They counted patches, measured patch dimensions and distances between patches, and estimated cobble coverage on the sand. Then sled sampling was done at one random position in each of four randomly selected patches and at two random positions between patches, when possible. When a beach site had fewer than four patches, it was sampled according to a predetermined scheme

(Figure 2-3). Sled tows were made completely through the width of patches, from water's edge towards shore, to reduce the effects of small-scale variability in population structure that may occur within aggregations. Patches wider than the length of the net were sampled either by a second sled tow or by shovel. Usually the sled was towed the length of the net in interpatch areas.

After being processed through the sorting sieves (section 2.1.2), the sand crabs (18 subsamples per tow) were preserved in 10% formalin-seawater. Each subsample was labeled with the following information: survey, beach study site, sample location, type of sample (i.e., sled tow or shovel), and sieve size. The color of the sieve set used to sort the animals was recorded in the field report.

At some sites coarse sediments clogged the two smaller sieves (4/32 and 3/32 inch). Therefore, they were removed from the set at those sites. Counts of sand crabs retained by the two smaller sizes of sieves at beach sites with fine sediments were deleted from all data analyses.

Additional qualitative sand crab samples were taken with shovels during the July and August surveys and were used as follows: (1) to supplement, when appropriate, sled tow collections for the population structure studies; (2) to supplement, when necessary, the animals used for studies of gut contents, parasites, and clutch size; (3) for histological analysis of ovaries of female sand crabs; (4) for genetic studies (third survey only); and (5) to be potentially used for metallic and non-metallic pollutant analyses. These sand crabs transported alive to the laboratory in damp sand inside open mesh laundry bags for processing the next day at a nearby beach (not a study site).

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During the July survey they were processed through sorting sieves, counted according to sex, and examined for reproductive condition (females, to a maximum of 100 per sieve). Male, newly-molted, and damaged sand crabs were preserved in formalin. Females retained on sieves 8-20 (maximum of 120) were kept alive for depuration (gut cleansing) in water taken from their particular beach site, and for subsequent processing for potential analyses of pollutants. The remaining females were placed in separate jars corresponding to sieve size and preserved in formalin.

During the August survey, two sets of shovel samples were collected to provide enough sand crabs for the supplementary and potential analyses (described above). One set (designated category 3 in the field protocol, Appendix B) was sorted through sieves 15, 11, and 8. Category 3 female sand crabs from each sieve were kept separate and taken to the laboratory for depuration. They were then processed for use in analyses of metal and non-metal pollutants. Sand crabs smaller than sieve 8 were preserved in formalin. The second set of shovel samples (designated category 2 in the field protocol) was processed like the July survey samples. That is, sand crabs were sorted, counted according to sex, and the females were examined for reproductive condition. If not enough females were collected in the first set of shovel samples (category 3), category 2 female sand crabs from sieves 8-20 were also processed for potential analyses of metals and synthetic organics. Male and female sand crabs retained on sieves 6-9 were saved (maximum of 100) for genetic studies. These were stored in plastic bags on dry ice for transport back to the laboratory, where they were processed further.

At each beach site, wave height, period, and angle of incidence to the beach (August survey) were estimated. At each sled sampling location, estimates were made of the beach width and slope, and the percent cobble coverage on the beach face, in the wave wash, and in knee-deep water. The ocean temperature was measured in knee-deep water. Sand and water samples were taken at each sled location for analyses of environmental variables. Sand samples for grain size distribution, salinity/moisture content, total organic carbon, chlorophyll-a, "phaeophytin" (phaeopigments: phaeophytin-a and phaeophorbide-a), and pollutant analyses were taken with sediment coring cups. During the August survey, water samples were taken immediately from the core holes for direct salinity measurements. A water sample also was taken from the adjacent wave wash for measurement of seston, organic carbon, chlorophyll-a, and phaeophytin.

Water samples, and sand samples for non-metal pollutant analyses, were held in glass containers. Other sand samples were held in plastic containers. Water samples and sediment moisture/salinity samples were stored on ice in the field. Other sediment samples were stored in the field on dry ice prior to laboratory processing. On departure from each beach site, a 5 gallon plastic carboy was filled with water for holding and depurating live sand crabs.

Near five of the beach sites (45 km S, 25 km S, 18 km S, 6.5 km N, 15.5 km N) sand core and water samples were collected at the mouths of streams that empty into the sea (Figure 2-1). Each of these streams is located within a kilometer of the associated beach sampling area. Water samples and sand samples for analyses of non-metal pollutants were held in glass containers. Sand samples for metal assays were held in plastic containers. All samples were stored on ice in the field until arrival at the laboratory. The stream mouths were sampled immediately after the July and August beach site surveys.

Sand crabs were not fully sampled at two beach sites during the full-scale August beach survey. Surf prevented adequate sampling at Venice Beach (115 km N) on 5 August. After the survey team had mapped the beach but prior to actual sampling, 3 m waves began to pound at the shore break of this steep beach. About 15 minutes before the first set of large waves, all the visible sand crab patches disappeared. Two subsequent sled tows yielded few crabs. The heavy surf conditions lasted for a week. Venice Beach was checked again just before dusk and at night on 12-13 August, after two days of mild sea. No sand crab patches were observed. Since the next acceptable sampling tide was a week later (2 weeks after sampling the other beaches), Venice Beach was not fully surveyed in August.

The beach sampling site at 18 km S is within the boundaries of Camp Pendleton Marine Corps base. On arrival there in August, the survey crew found the beach covered with amphibious vehicle tracks as a result of military training maneuvers. The survey team checked the beach for sand crabs during both the outgoing and incoming tides. No sand crabs were found in sled tows nor in random shovel samples taken in low, mid, and high tide zones, nor were any found in shovel samples taken below the wave wash zone. Eight hours were spent searching within the study site, and 500 m to the north and south. The beach was revisited 5 days later at night on the outgoing tide. The sand was marked with vehicle tracks, but fewer than the first visit. Again, no sand crabs were found. The beach site 18 km S was not visited again in 1983.

2.1.3.2 Abbreviated Beach Surveys

In late August and September, abbreviated surveys were made to observe the proportion of the female population with eggs, the developmental stage of the eggs, and the occurrence of spent egg cases. The physical environment was ignored during these surveys. An initial examination of female sand crabs at five beach sites in late August was followed by examinations at six sites in September (two visits to each) (Table 2-1). Visits were made at 2 week intervals during ebb tide at night, if possible. To observe reproductive state, female sand crabs were sampled by shovel from three different patches (two at 65 km S) on each site visit during September. The two southern-most sites had reproductive females in September and were revisited in October (Table 2-1).

During the first (9 September) appraisal of the six sites, sand crabs were found at all sites but 45 km S. However, sand crabs were found at 45 km S the following day. During the second (23 September) appraisal of the six beaches, sand crabs were sparse or not evident at four beaches (65 km S, 45 km S, 100 km N, 115 km N). These four sites were successfully sampled the following day (24 September).

Only sand crabs of sieve size 5 or larger were collected from the shovel samples. These were taken alive to the laboratory, sorted into sieve size category (5-20), preserved, and examined for egg condition. Since reproductive females were found at 65 km S on 24 September, this site was checked again on 5 October. A 4 hour search on ebb tide during the day yielded one sand crab. To further document the end of the reproductive season, three other beach visits were made in October: 45 km S on 6 October and 19 October, and 50 km S (Cardiff Beach) on 12 October; no sand crabs were found during these later abbreviated surveys.

2.2 Laboratory Processing and Analyses

Field collections were primarily of five kinds -- beach environment samples, sand crab population samples, sand crab histological samples, sand crab genetic samples, and pollutant samples. Each kind of sample was processed differently. Comprehensive laboratory protocols are given in Appendix C.

2.2.1 Beach Environment Samples

The environmental sample examination included analyses of sand cores, water from sand core holes, and water from the wave wash area adjacent to each sand crab sampling location.

The sediment core samples -- three per beach for each survey -- were analyzed for grain size, moisture content, interstitial salinity, total organic carbon, chlorophyll-a, and phaeophytin. For the June survey, samples were from cores taken at three randomly preselected sled tow locations. For the July and August surveys, three composite samples were formed by combining samples from cores taken from each of two similar sled tow sites. Similarity of sled tow sites was determined by proximity on the beach and/or whether the sites were reported as patch or interpatch.

Sediment cores for grain size analyses were held at $0^{\circ}C$. For analysis a 30-50 ml subsample was transferred to a 240 ml bottle, mixed with 150 ml of deflocculent (sodium hexametaphosphate), and allowed to stand for 8 hours. Then the suspended silt/clay portion was decanted, dried, and weighed. The sand fraction was shaken through and collected on eleven U.S.A. Standard Testing Sieves, which ranged in 0.5 phi intervals from 4.0 to -1.0 phi. When combined with the silt/clay weight, the weights of the fraction retained on each sieve and on the bottom catch plate gave the grain size distribution for each sample.

Sediment cores taken for moisture and salinity analyses and sediment core hole water samples for salinity measurement (August survey) were held at 10°C. Interstitial moisture was determined by weighing a 100 ml subsample of wet sand, drying, and re-weighing. To determine salinity, the dried subsample was rehydrated with distilled water, agitated, and decanted. Temperature, salinity, and conductivity were measured with a Yellow Springs Instrument (YSI) salinometer. The YSI salinometer also was used to measure the salinity of sea water samples collected from sediment core holes during the August survey.

Total organic carbon in sediment samples was measured with an Oceanography International model 524-B analyzer. Subsamples (20-50 g) were dried at 70°C for 12 hours, ground to powder, placed in preweighed and precombusted ampules, and reweighed. Phosphoric acid and potassium persulfate were added and then oxygen was introduced to oxidize and purge the inorganic carbon. The ampules were then sealed, heated in an autoclave, and the CO_2 was measured with a non-dispersive infrared analyzer. Standard concentrations of potassium biphthalate were measured at the same time for reference.

Chlorophyll-a and "phaeophytin" (phaeopigments: phaeophytin-a and phaeophorbide-a) were extracted from sand core samples with 100% acetone and measured with a Turner III filter fluorometer. Each sample was acidified and re-measured. The pigment concentration calculations and the analytic procedure are given in Appendix C.

Wave wash water samples were analysed for chlorophyll-a/phaeophytin, and for seston/organic carbon. Water samples collected for chlorophyll-a and phaeophytin analyses were filtered (Millipore AA) immediately upon arrival at the laboratory. The filters were stored in acetone (100% in June and July, 90% in August), frozen, and kept in the dark until measured with the fluorometer. Each sample was acidified and remeasured.

Wave wash water samples for seston and organic carbon analyses were filtered through pretreated, preweighed GFC filters as soon as they arrived at the laboratory. The filters were held in the dark at 0^{0}C until analyzed. Seston and carbon analyses consisted of drying the filters (70^{0}C for 1 hour), weighing them, combusting them (450-500^{0}C for 24 hours), and reweighing them. The dry weight of the sample was the estimate of seston, and the combustion loss was proportional to the carbon in the wave wash sample (0.5 x ash-free dry weight).

2.2.2 Sand Crab Population Samples

The population attributes examined for the three full-scale summer surveys were: sex-specific abundance, size distribution, and breeding condition of females. Preserved samples, which had already been sorted by sieve size in the field, were enumerated in ten sex/fecundity categories. The pre-sorted samples containing more than 150 sand crabs were split with a Folsom plankton splitter until a subsample of about 70 individuals was obtained. Samples with fewer than 150 animals were examined in their entirety. The variability associated with splitting sand crab samples was calculated for ten samples, each with 80 or more sand crabs. The mean coefficient of variation was less than 10% (Appendix A).

The ten enumeration categories included six categories for females -- each related to a breeding state -- one category for males, one for damaged females or juveniles, one for unidentifiable damaged sand crabs, and one for unidentifiable molting sand crabs.

Before the inception of breeding, and presumably between broods, female sand crabs have unencumbered abdominal pleopods. Upon extrusion, eggs are attached by stalks to the hairs of the pleopods (Knox and Boolootian, 1963). Newly extruded eggs are bright orange and yolky (Wharton, 1942; MEC, pers. observation). As the embryos within develop, the eyes become visible and the amount of yolk in the egg decreases. The color of the egg darkens as more pigment from the eyes becomes visible. Just before hatching, when the embryos are nearly fully developed larvae, the eyes are conspicuous, there is little yolk, and the eggs appear grey to the unaided eye (Wharton, 1942; MEC, pers. observation). Upon hatching the young become free-swimming transparent zoea larvae; the ruptured egg cases remain attached to the pleopods of the parent female for a time.

The six breeding state categories assigned to females included the five regular states -- clean pleopods, bright orange eggs, burnt-orange eggs (yolky with eyespots), grey eggs, and attached spent egg capsules. The sixth category was females with spent egg cases and a few residual orange or burnt-orange eggs as well. This condition might occur if most of the eggs had prematurely ruptured by the time they could reach the stage of the remaining intact eggs, or in the case of the bright orange eggs, if the few remaining eggs had not been fertilized.

In addition to being enumerated according to the six categories, ovigerous females were subsampled and examined for external abdominal parasites, clutch size, and gut contents. Each of these subsamples included ten females with bright orange eggs. The ten specimens were selected according to size by random subsampling procedures from the sled tow or shovel samples from each beach patch (4 patches each beach site) sampled during each of the full-scale summer surveys.

A search image for external parasites was developed by consulting references (Sinderman, 1970; Couch, 1978; Wickham, 1980; Fisher, 1983) and a local authority on crustaceans (Dr. John Garth*). The examinations, done under a dissecting microscope, concentrated on the abdominal region of the sand crab and the egg mass.

To determine clutch size, the volume of each egg mass was measured by displacement, and the egg mass volume was converted to numbers of eggs in a clutch by measuring (ocular micrometer) and calculating the volumes of ten individual eggs each from two females from each patch on a beach (Efford, 1969).

Gut contents were examined after egg masses had been removed. The foregut and the hindgut were excised and examined separately. Relative fullness (none, < 1/2, > 1/2) of foregut and of hindgut were determined under a dissecting microscope. Then the contents were removed and examined under a compound microscope. The relative amounts of sand, phytoplankton, and unidentified detritus were estimated, and the presence of clearly recognizable organisms was noted.

2.2.3 Sand Crab Histological Samples

Reproductive female sand crabs were selected from sled tow and shovel samples for histological analysis of their ovaries. The relationship between the developmental stage of the external eggs and stage of the oogenesis cycle was investigated to examine whether a high frequency of females with spent egg cases indicates disruption of egg maturation or a normal synchronized hatching event. As a further indicator of potential environmental stress, the incidence of atresia (degeneration of ovarian follicles) in the ovary was examined.

* Dr. John Garth, Curator Emeritus, Crustaceans, University of Southern California, Los Angeles.

Sixty females were randomly selected from three reproductive categories (20 animals each)--females with bright-orange eggs, females with burnt-orange or grey eggs, and females with spent egg cases--from each of the four beach sites that had females in all these different reproductive stages (i.e., 100 km N, 0.4 km N, 25 km S, and 45 km S). This was done to establish the relationships between the developmental stages of the external eggs and internal developmental stages of the ovaries. Also, 20 females with spent egg cases were randomly selected from each of the following beach sites near SONGS: 12 km N, 6.5 km N, 1.5 km S, 6.5 km S, and 12 km S. These beach sites lacked sufficient numbers of females in the other reproductive stages.

Females were selected for histological analysis from the August survey, which had the only set of samples with sufficient numbers of females in each reproductive category. Most of the reproductive females at beach sites near SONGS were smaller than 13 mm carapace length, therefore, most females for this analysis were selected among the smaller-sized females; however, larger sized females also were selected from 100 km N. Reproductive females were delivered to a histologist (Dr. Steven Goldberg of Whittier College) on 18 April 1984.

2.2.4 Sand Crab Genetic Samples

Sand crabs for genetic studies (August survey) were collected with shovels and processed at the same time as those for pollutant analyses. About 50 sand crabs from sieves 6-9 were selected from at least two patches from each beach that had sand crabs (18 km S, 1.5 km N, and 115 km N did not), placed in plastic bags, and held at $0^{o}C$. The samples were delivered to the geneticist (Dr. Richard Beckwitt of Occidental College) within 8 days of the first night of sampling. Genetic studies were under the direction and funding of Southern California Edison.

2.2.5 Pollutant Samples

The female sand crabs to be analysed for metals and non-metallic pollutants were depurated for 24 hours. For the July and August surveys, they were sorted into three sieve size categories: 8-10, 11-14, 15-20. Each size category was divided into females with eggs and females without eggs. Part of each size/breeding state category was wrapped in aluminum foil for non-metallic pollutants analyses, and part was wrapped in plastic for the metals analyses. These were frozen and stored at -80^{0}C.

For the June survey, only females from sieves 11-15 were used for metal analyses. Four beach sites sampled in June (0.4 km N, 1.5 km N, 12 km N, and 15.5 km N) produced no live females for these studies. All fifteen beaches produced live females in July. In August, three (18 km S, 1.5 km N, and 115 km N) did not. Tissue analyses for metallic and non-metallic pollutants are pending.

Sand samples collected during all three surveys for analyses of metals, and those collected during July and August for the analyses of non-metallic pollutants, were stored at MEC in the dark at 0^{0}C. Within 8 days of the first night of sampling, they were turned over to the subcontractor, who is storing them in the dark at -5^{0}C.

The water samples for analyses of metals are being kept in the dark at room temperature. The water samples for analyses of non-metallic pollutants underwent a hexane extraction within 30 days of collection. The extracts were placed in kiln-fired (3000^{0}F) glass jars with aluminum-foil lined tops. These jars are being kept in a dark cabinet in an air conditioned room.

Analyses of these sand and water pollutant samples are also pending funding by the MRC.

2.3 Data Management

Beach characteristic information noted in the field, laboratory analyses of environmental samples, and laboratory analyses of biological samples for all three full-scale surveys were entered into MRC data bases established by the MRC's data support group (Titan, Inc.). Data bases were verified by error checks built into the establishment program and by cross checks against original data sheets by MEC personnel. Data base establishment programs are documented in the MRC's Data Standards Document (Compunet, 1983).

3.0 RESULTS AND DISCUSSION

Several attributes of sand crab populations related to abundance, size, and reproduction were evaluated for the 1983 reproductive season. Three questions were addressed: (1) whether the attributes previously reported to vary within 6.5 km of SONGS varied thus in 1983, and whether there was a locality effect when distances farther than 6.5 km from SONGS were considered; (2) whether attributes at beach sites near SONGS were within the variation observed at other beaches in 1983; (3) to what extent selected attributes were correlated with the physical-chemical environments; and (4) whether the attributes exhibited a distinct trend with distance from SONGS.

The first two questions overlap. Therefore, both were addressed statistically in the same way. A one-way analysis of variance (ANOVA; Sokal and Rohlf, 1981; SAS, 1982) was done to determine whether among-beach differences existed. A Student-Newman-Keuls (SNK) multiple range test (Sokal and Rohlf, 1981; SAS, 1982) was performed to determine which beach sites were different. The first question, whether attributes varied in the manner of previous studies, was evaluated by examining the SNK groupings of sites within 6.5 km of SONGS and those just beyond. The second question, whether attributes at beach sites near SONGS were within the variations found elsewhere, was evaluated by examining the overall SNK groupings of sites. Auyong (1981) and Wenner (1982) reported that attributes near SONGS were usually at extremes (lower or upper) of the range of values. Therefore, a SNK grouping of sites near SONGS that was at the upper or lower extreme and significantly different from other SNK groupings, which comprised sites away from SONGS, was used to classify sites near SONGS as "totally outside the range of variation". However, if most sites near SONGS formed a unique group and one or two sites near SONGS had attributes statistically more like other sites, then this was considered to be "generally out of the range of variation " and was noted in the Report.

The third question, to what extent selected attributes of sand crab populations were correlated with environmental variables, was addressed by multiple regression analyses using a backward elimination procedure (see Appendix D for a full description of the procedure). Attributes were subjected to regression analysis only if a distinct SNK grouping of sites in the vicinity of SONGS resulted from the analyses applied to the earlier questions. The measured habitat variables most clearly associated with the selected sand crab population variables were identified from the regression analyses. Partial r^2 values were consulted to determine the relative influence of each environmental variable in the final regression equation. A cluster analysis of environmental variables on beach sites was used to interpret the relationships identified by the regression results.

Multiple regression analyses initially included all beach sites. Cabrillo Beach, however, had extreme values for several environmental variables (see section 3.1), and sand crabs did not grow and mature there (see section 3.2.2.1). These inordinate relationships caused this site to overinfluence the regression analyses as indicated by significant Cook's D values (Cook, 1977, 1979). To improve the evaluation of the relationships between sand crabs and the other beach habitats, Cabrillo Beach was excluded from the final regression results. When another beach site(s) had a significant Cook's D value(s), regressions were evaluated with and without the influential observation(s).

Additional regressions were undertaken to specifically address whether the relationships between the environmental and biological variables at sites nearest SONGS were reasonably predicted by the relationships that occurred at sites farther away. Two of the three beach sites near SONGS (1.5 km S, 0.4 km N, and 1.5 km S) were dropped from the model, a regression was run on this reduced data set, and Cook's D values were examined to see if the third SONGS beach site was an influential observation. Significant Cook's D values for the sites nearest SONGS would indicate either that the regression relationships at these SONGS sites were poorly predicted based on relationships further from SONGS, that the regression relationship is the same but the environmental variables are outliers, or both. If the third SONGS beach site was influential, the data were examined to determine which of the above three cases applied.

To answer the fourth question, regression results were also evaluated in two ways to determine whether there were any clear trends with distance from SONGS. First, residuals from the final regression results were examined as a function of distance from SONGS (Appendix D). Second, additional regressions using a forward selection procedure (SAS, 1982) were performed on sites within 15.5 km of SONGS with distance from SONGS added as an independent variable. A trend with distance from SONGS would be indicated if the distance variable outperformed other environmental variables by being included in the final regression result.

The results and discussion are presented in two sections, beach environments and sand crab biology. The results of the environmental observations are presented first so that they can be referred to in discussing sand crab populations.

3.1 Beach Environments

Beach site descriptions included gross physical variables, sediment characteristics, and potential sand crab food resources (Tables 3-1 to 3-3). With two exceptions, the sediment and food variables were subjected to cluster analysis to classify the beach sites for each survey (Figures 3-1 to 3-3). The gross physical characteristics of the sites (Table 3-1) were excluded from the cluster analysis because the variables had missing values or lacked geographic trends. The cluster analysis employed a hierarchical average linkage strategy based on Euclidean distances (SAS, 1982). Prior to the cluster analysis, environmental variables were standardized to the same scale (mean 0, standard deviation 1).

The exceptions from the cluster analysis were sediment salinity and total organic carbon in the water. Sediment salinity measurements were found to be erroneous and therefore were excluded. Gut content examinations of potential food (see section 2.2.1) showed that the sand crabs primarily were ingesting phytoplankton (primarily Prorocentrum sp.) and detritus but not zooplankton (Table 3-4). Since zooplankton occurred in the total organic carbon (TOC) samples from the water, TOC in the water was excluded from the cluster analysis.

The cluster analysis showed that, with few exceptions (listed below), the habitats within 15.5 km of SONGS differed from more northern and southern sites (Figures 3-1 to 3-3). In general, the sites within 15.5 km of SONGS had coarser sediment with a higher grain size dispersion and less moisture. Sediment chlorophyll and phaeophytin concentrations often were less, and wave wash seston concentrations often were higher than at all other sites. Also, cobble was present at most of the beach sites nearer SONGS.

The exceptions were 6.5 km N (June and July) and 6.5 km S (July) which sometimes had finer sediments. The San Clemente site (6.5 km N) further differed in having much less cobble and higher sediment chlorophyll/phaeophytin concentrations than other sites within 15.5 km of SONGS.

The far north site near Morro Bay (450 km N) was more like sites within 15.5 km of SONGS than like other sites in southern California (Figure 3-3), although the sediment was coarser and the concentration of chlorophyll and phaeophytin in the wave wash was higher. Morro Bay had pea-size gravel instead of cobble.

The northern sites at Venice Beach (115 km N) and Hermosa Beach (100 km N) shared many characteristics with the southern beach sites (18 km S to 65 km S). Collectively, these beach sites were similar to each other in having finer sediments and more potential food than most beach sites within 15.5 km of SONGS. They differed between each other in that the southern beach sites had even finer sediments than those at 100 km N and 115 km N.

Cabrillo Beach was unique. It had concentrations of carbon in the sediment that were ten times those at any of the other beach sites. Also, sediment phaeophytin concentrations were the highest. The extreme sediment carbon values suggest that this beach may have been polluted. The Joint Water Pollution Control Plant, located offshore from Cabrillo Beach, is a possible source of pollution. Cabrillo Beach also differs in facing south and being protected from the northwest by a headland (all others face west to southwest). Cabrillo Beach had fine sediments; cobble was present in knee deep water in variable amounts between surveys.

When considering the relationships between sand crab biology and beach environments it is prudent to keep in mind that 1983 was a year of intense El Nino conditions. The ocean waters in the southern California Bight were abnormally warm, the typical downcoast currents were reduced to almost nil, and the water column was unusually stable. The nutricline was depressed, often below the level of the shelf, plant nutrients were sparse, and overall primary production was reduced (Reitzel and Zabloudil, 1983; Barnett et al., 1983).

The El Nino event was accompanied by a series of eleven powerful storms during the winter of 1982-83 and the spring of 1983. Seven of these storms had wave periods of more than 20 seconds (Dayton and Tegner, 1984). Severe wave action and shore erosion occurred in various locations along the exposed coasts. This no doubt affected the sand grain size distributions and cobble coverage of sand crab beaches, and probably did so non-uniformly.

3.2 Sand Crab Biology

Subsections within the biology section include description of the analytical techniques unique to each examined attribute and comparison with the results of previous studies, when appropriate. These attributes are related to population abundance, size distribution, reproduction, and genetics. Previous MRC studies of sand crabs concentrated on attributes related to size and reproduction; more expanded discussions of these two variables are presented.

3.2.1 Weighted Mean Abundance

How favorable the beach sites were in terms of sand crab numbers in 1983 was determined from estimates of abundance. Since natural variations among populations may be related to differences in recruitment (Fusaro, 1980a), the abundance estimates also were examined for seasonal changes that might indicate differential recruitment.

The abundance calculations took into account the habitable area within the study sites and the stratified random sampling design. Maps of the beach sites (Figures 3-4 to 3-6) were prepared from field notes. The field reports gave locations and dimensions of sand crab aggregations (patch areas), interpatch areas, and the percent cobble coverage for the entire sampling area of the study site. To calculate mean abundance per beach, the log-transformed abundances from sand crab patch and from interpatch samples were weighted according to the area mapped for these two strata within the habitable area (< 80% cobble) of the 500 m beach site.

Despite being observed at similar times and similar tide states during a survey (except in July; see section 2.1.3.1), the sand crab distributions varied among sites. Sand crabs were in continuous bands or patchy aggregations on some beaches and scattered on others (Figures 3-4, 3-5, and 3-6). Sand crab patches were not found in areas with more than 30% cobble coverage.

Equations appropriate to a stratified random sampling scheme (Cochran, 1963) were used to calculate weighted mean abundances, variances, and degrees of freedom. The equations and an example of their application are presented in Appendix D, section D.1. Data were log (x + 1) transformed because the untransformed abundance estimate was strongly affected by one or a few exceptional replicates at some sites (e.g., 65 km S in June). Differences in transformed weighted mean abundances between beaches were tested by ANOVA and SNK.

Separate tests for males, for females, and for the total population were done for each survey. The abundance estimates include all sizes of sand crabs (above sieve size 4 = > 5 mm carapace length). Because the 1983 populations in southern California were dominated by first year sand crabs (see section 3.2.2.1), the estimates are not unduly biased by different year classes of animals. The abundance associated with different size classes is examined in the next section (see section 3.2.2.1).

The log (x + 1) weighted mean abundances (females, males, all) differed among beach sites during June, July, and August (one-way ANOVA, $p < 0.001$). Statistical tests (SNK) on transformed abundances of sand crabs, regardless of sex, showed that abundances were lower within 1.5 km of SONGS compared to sites at 6.5 km in June and July but not in August. The tests showed that there was no extended trend in abundance with increased distance from SONGS, regardless of survey, and the abundance of males and females at sites in the vicinity of SONGS were well within the variation found elsewhere (Figures 3-7a-c, 3-8a-c, and 3-9a-c).

However, the transformed mean abundances, which were used to statistically compare beach sites, do not necessarily correspond exactly to the untransformed means. This was evident in June when sites within 12 km of SONGS generally differed from more southern and northern beach sites in having substantially fewer male and female sand crabs (Figure 3-10a-c). The untransformed means for July and August did not show any trends relative to SONGS (Appendix F, Figures F-1a-c to F-2a-c). The lower abundance of sand crabs at sites within 12 km of SONGS in June was supported by an analysis of the size frequency distributions of the populations, which suggested that recruitment and/or colonization may have been delayed at these sites (see section 3.2.2.1). Therefore, we chose to interpret that sites within 12 to 15.5 km of SONGS and at Cabrillo Beach had lower abundances than other sites in June. Possible reasons for the apparent delay in recruitment and/or colonization to sites near SONGS were investigated by multiple regression analysis. The relationship between the physical-chemical environments of the beach sites and the untransformed abundances of all sizes of sand crabs was examined in June to address both differential recruitment and colonization at the same time. The relationship between the beach habitats and the abundances of newly recruited (6-9 mm C.L.) sand crabs was examined to address differential recruitment.

The results of the multiple regression analyses indicated that differential recruitment/colonization of beach sites in June ($R^2 = 0.71$ with 6 variables, $n = 13$, $p = 0.0953$; Tables 3-5 and 3-6) was influenced by seston, coarseness of the sediment, cobble on the sand, temperature, and chlorophyll and phaeophytin concentrations in the sediment. Similar environmental variables were correlated with recruitment of small sand crabs ($R^2 = 0.59$ with 6 variables, $n = 38$, $p < 0.001$; Tables 3-5 and 3-6). The regression analyses indicate that recruitment and colonization of beaches by sand crabs are rather poorly explained by the environmental variables. However, in general, abundances were less at beach sites with steeper slopes, coarser sediments, greater cobble coverage, lower temperatures, and lower potential food resources in the sediment.

The relatively poor fits were not the result of one or two beach sites unduly influencing the relationships, for no high values of Cook's D were found for any sites when all sites were considered (Table 3-7). From the low values of Cook's D in Table 3-8, it is demonstrated that the physical/chemical variables at other beach sites predicted recruitment and colonization at beach sites near SONGS (1.5 N, 0.4 N, 1.5 S) just as well as at sites farther away. Finally, no trend in abundance was found with distance from SONGS. The variable distance did not outcompete environmental variables in the multiple regression restricted to sites within 15.5 km of SONGS.

The relative favorableness of the different beach habitats for sand crabs was examined by taking into account the differential recruitment/colonization to the beach sites and weighted mean abundance estimates. Beach sites with a weighted mean abundance of greater than 200 crabs per tow for two or more surveys were considered to be favorable for sand crab habitation. The five more favorable beach habitats were 6.5 km S, 6.5 km N, 25 km S, 100 km N, and 115 km N. The four beaches least favorable for sand crab habitation (weighted mean abundance < 60 crabs per tow) were 79 km N, 15.5 km N, 1.5 km N, and 12 km S.

3.2.2 Size Distribution

The size distributions of beach populations of sand crabs are often polymodal because of colonization by overwintered animals and successive recruitments of larvae from the plankton (Cox and Dudley, 1968). Size distributions may vary between populations because of differences in the ages of the sand crabs (i.e., time from initial recruitment to time of sampling) as well as because of differences in rates of growth, which may be affected by the environment (Fusaro, 1978; Wenner, 1982). Of particular interest in this study is whether beach sites near SONGS had populations with abnormal colonization of adults, recruitment of young, and/or growth relative to populations away from SONGS in 1983.

Previous MRC studies primarily compared populations by using indirect measures of growth that were considered to be independent of the confounding effect of differential recruitment and colonization because they were based on a portion of the older members of the population. The mean of the maximum size mode of males and mean of the minimum size mode at which females produce eggs were used by Auyong (1981) and Wenner (1982) as two such measures. Male sand crabs mature at a small size and growth asymptotically slows (Dudley, 1967). Therefore, after a certain size, the age and reproductive condition does not unduly bias comparisons of the average maximum size that males reach during a season. This is particularly true by the end of the season, when comparisons of the growth of the season's recruits are most meaningful. On the other hand, females grow faster than males and usually reach a much larger size during their first season on a beach (Dudley, 1967; Efford, 1967). Unfortunately, the confounding effects of differential recruitment, colonization, and initiation of reproduction cannot be avoided when using an indirect measure to attempt to compare growth of females in different populations. This is so because there does not appear to be any fixed length of time to sexual maturity (Fusaro, 1978). For continuity with previous MRC studies, the statistics related to size modes were examined in the 1983 study.

The mean size of males and the mean size of females were also examined by Auyong (1981) and Wenner (1982). The mean size of males (or females) was not examined herein because size frequency distributions of sand crabs are often asymmetrical, and the mean is affected by extreme values. The median size of reproductive females was examined. This measure should be less affected by extreme values than the mean.

The overall size frequency distributions of male and female populations were examined to provide necessary background information on colonization by adults, recruitment of young, initiation of reproduction by females, and estimated growth. This information aided the interpretation of the statistics related to size. Therefore, size frequency is described first and is followed by the results of the analyses of size modes and median size.

3.2.2.1 Size Frequency

Sand crabs metamorphose from megalopa to first stage juveniles at about 4 mm (Efford, 1967). The sexes of juvenile crabs (< 6 mm) are difficult to distinguish. For this reason, and because they were not adequately sampled at beach sites with coarse sediments (see section 2.2), small (4-5 mm) sand crabs were excluded from the analysis.

Sand crabs identifiable as females (sieves 5-20), ranged from 6 mm to more than 23 mm in carapace length at some beach sites. Males collected in sieves 5 to 15, ranged from 6 mm to 17 mm. Females grow faster than males and attain a larger maximum size (Efford, 1967). Therefore, their size distributions were treated separately.

The frequency distribution for each beach site and survey was calculated from the mean of the total number of females (or males) across all replicates (excluding interpatch) for each sieve. The scale of the frequency histograms was kept constant for each beach site to facilitate temporal comparisons. The mean of the total number of females (or males) used to calculate the frequency distributions is presented with each histogram. In the histograms, the females are identified as having external eggs (coded as E), spent egg cases (coded as S), or clean pleopods without eggs or spent egg cases (coded as C).

3.2.2.1.1 Males

Male sand crabs mostly (> 80%) occurred in sizes between 6 mm and 9 mm in 1983. Histograms of the size distribution of males are not presented, however, the results are summarized in Table 3-9. Males larger than 9 mm were present but not abundant at most beach sites. Three sites (15.5 km N, 1.5 km N, and 0.4 km N) lacked larger males throughout the study period. The male population was unimodal at these sites, whereas there were two or three modes at beach sites with larger males. The size distributions of males at other sites near SONGS were within the variation of northern and southern beach sites. The site near Morro Bay (450 km N) differed from those in southern California in that large males were nearly as abundant as small males.

3.2.2.1.2 Females

The several size modes of females observed in 1983 are thought to represent different recruitment classes (sensu Dudley, 1967) of megalopa from the plankton and different colonizations of adults possibly from the subtidal zone. Small sand crabs (6 mm to 9 mm) were abundant at some sites in June, at most in July, and at a few in August. Females smaller than 13 mm dominated the populations at southern California beach sites regardless of whether large females, which probably had overwintered, were present (Appendix E). This indicates that the 1983 populations were derived primarily from recruitment in 1983 or late 1982. Overwintered females, which are much larger than first year females early in the season, were scarce or absent at most beach sites within 15.5 km of SONGS (Figure 3-11a-c). Like sites farther north and south, they were present at sites 6.5 km N and 6.5 km S. As with the males, the site near Morro Bay differed from those in southern California in that overwintered females were as abundant as first year females.

Beach sites within 15.5 km of SONGS generally had lower abundances of females of all sizes in June relative to all other surveys and beach sites except 79 km N (Figure 3-11a-c; note, mean abundance per tow is given for each beach site). The increase of females in many size classes simultaneously from the low numbers found in June implies that both recruitment and colonization were delayed at these sites relative to most sites farther north and south. Note for example, that the numbers of females found at 6.5 km S in July (187 per tow) could not be accounted for by the numbers (27 per tow) found there in June.

The smaller females could have recruited from the plankton between June and July. The larger females must have come from an extant subtidal population that did not present itself on the beach face during June sampling. It is unlikely that the July increases in medium and large females on beach sites in the vicinity of SONGS resulted from longshore migration from other beaches. This is because the nearest beach site that could have provided these females was 18 km south and the abundances there in July did not show depletions of females. Although beach sites north of 15.5 km N were not sampled, except those more than 79 km away, it is considered unlikely that sand crabs would have migrated to the south past the headland and harbor at Dana Point.

Evidence exists that some subpopulations of adult sand crabs live somewhere below the reach of intertidal sampling for long periods. Edwards and Irving (1943) found that E. talpoida overwinter in the subtidal area. In the present study, sand crabs left the beach at 115 km N fifteen minutes before heavy surf occurred and did not reappear until two weeks later. This means that somewhere below the intertidal zone there is a third sand crab habitat, neither beach nor pelagic.

Although the multiple regression on sites within 15.5 km of SONGS showed no trend in abundance with distance (see section 3.2.1), there appeared to be a trend in recruitment/colonization relative to distance from SONGS when all sites were considered. Populations at sites within 12 km of SONGS became established later than those farther north (except Cabrillo Beach) and south, and of the sites within 12 km of SONGS, 0.4 km N became established even later (i.e., August).

Information is scant regarding factors that might account for differential recruitment and colonization to different beaches. No single environmental factor appeared to be directly related to the delay in recruitment/colonization at sites within 15.5 km of SONGS. This is so because the habitat at many of these beach sites did not appreciably vary between surveys. Results of multiple regression analyses suggest that the suite of physical-chemical factors that were measured may be only weakly influential or the errors in the measurement of the dependent or independent variables or both were too great to discern clear relationships (Table 3-5). Efford (1970) suggested that localized coastal current eddies might affect recruitment. However, information is too scant regarding small-scale circulation patterns in the Southern California Bight to evaluate whether this could have affected recruitment patterns in 1983.

The observation that the two sites 6.5 km N and 6.5 km S had recruitment and colonization histories similar to other sites near SONGS, but that they had more large, overwintered individuals than other sites near SONGS, implies that differences in population structure may be related to differences in the environment. The cluster analyses showed that, of the sites within 15.5 km of SONGS, 6.5 km N had finer sediments than the other sites, and the beach site 6.5 km S had finer sediments in July.

The change of beaches from primarily sand to exposed boulders, by the denuding action of winter storms, has been suggested as a reason for the lack of overwintered sand crabs in some populations (Efford, 1970). This may account, at least in part, for the low numbers of overwintered females at most sites within 15.5 km of SONGS, which had coarse sediments and subtidal cobble.

3.2.2.1.3 Comparison With Past Studies

The differences in the size frequency distributions of male and female populations among sites within 6.5 km of SONGS in 1983 are similar to results from previous MRC studies. During the 1977 reproductive season, populations at 6.5 km N, 1.5 km S, and 6.5 km S were comprised of both large and small individuals, whereas males and females were predominantly smaller at 0.4 and 1.5 km N (Auyong, 1981: Figure 5, note that the labels of plots of males and females are reversed). On the expanded geographic sampling scale of 1983, there were no consistent trends in female size frequencies relative to SONGS. Male and female populations at sites 0.4 km N and 1.5 km N had only smaller individuals and their distributions were similar to those at sites 12 km and 15.5 km away from SONGS. Size frequencies at the 6.5 km sites looked more like beaches farther north and south.

3.2.2.2 Estimated Growth of Females

Growth of females was qualitatively estimated by examining size frequency distributions and noting changes in abundance relative to size between surveys. This method only provides a gross estimation of growth and is therefore a conservative measure in the sense that only large differences in growth would be indicated if differences among beach sites were identified using this technique.

At most sites, peak abundances in the size frequency distributions of females shifted toward larger sizes as the season progressed (Appendix E). These shifts between surveys indicated an estimated growth rate of 1 mm to 2 mm per month at most beach sites. This rate is about the same as published accounts based on laboratory and field estimations (Dudley, 1967; Elliott, 1972; Fusaro, 1978).

One exception was Cabrillo Beach, where the size of females (all small) changed little between surveys, probably indicating either very slow growth or more likely high mortality and successive sampling of different recruitments. There did not appear to be an extended trend in estimated growth rates with distance from SONGS. However, of the sites within 6.5 km of SONGS, 0.4 km N had the least shift towards larger sizes from July to August.

During the comparison of sites for trends in estimated growth rates, the reproductive condition of the females was examined. It has been suggested by Cox and Dudley (1968) that food energy may be allocated more towards growth or reproduction depending on the size of the female and season.

Two specific examples suggest that the reproductive condition of the female may be related to growth, one at 45 km S and one at 110 km N. At Moonlight Beach (45 km S) peak abundances were found in the same size groups in both July and August. More than 80% of the females were brooding at Moonlight Beach in July and August. The apparent slow estimated growth may indicate that energy was being used more for egg production than for growth. At Hermosa Beach (100 km N), the situation was reversed. The size frequency distribution of female populations at Hermosa Beach shifted about 2 to 3 sieve sizes (2-3 mm) from July to August. This suggests that females grew faster there than at other sites. A significantly smaller proportion of the larger females were breeding at Hermosa Beach (and also at 115 km N) relative to sites farther south in July (see section 3.2.3). Perhaps at Hermosa Beach the energy was used more for growth than for egg production. It was not possible to further investigate the suggested relationship between reproduction and growth, which was outside the proposed scope of the study, because the data was not sufficient for this purpose.

In 1983, the size at first breeding decreased from June to August or from July to August for females at all beaches. This is because smaller females became reproductive as the season progressed. Auyong (1981) found that reproductive females were smallest at 0.4 km N and 1.5 km N relative to other sites within 6.5 km of SONGS during the 1977 reproductive season. It was suggested that this was because of decreased growth, but there was no clear geographic trend in growth as determined by a study of molting frequency. In the more comprehensive sampling of 1983, the smallest reproductive females (7-9 mm) were collected mostly from 15.5 km N, 12 km N, 0.4 km N, and 45 km S, indicating no geographic trend relative to SONGS in the smallest size at which females began to breed (also see section 3.2.2.2 below). Reproductive females at 45 km S may have been relatively smaller as a result of slower growth because they began to reproduce earlier in the season. In contrast, reproductive females may have been relatively smaller at sites within 15.5 km of SONGS because of later recruitment or colonization.

3.2.2.3 Size Modes

The mean of the maximum size mode of males and mean of the minimum size mode of females with eggs were determined by using probability paper in the manner of Wenner (1982) (see Appendix D, section D.2). Differences between beaches were tested (one-way ANOVA and SNK) separately for the mean of the maximum size mode of males and the mean of the minimum size mode of females with eggs for each survey. Males and egg-bearing females were each analyzed in the same manner. All beach site samples (patch and interpatch) with five or more animals were used as replicates.

The mean of the maximum size mode of males differed significantly ($p < 0.001$) among the beach sites during June, July, and August. Of the sites within 6.5 km of SONGS, the SNK results showed that the maximum size of males was generally smaller at 0.4 km N and 1.5 km N than at 1.5 km S, 6.5 km N, and 6.5 km S (Figures 3-12, 3-13, and 3-14). Similar results were reported by Auyong (1981) and Wenner (1982). On the expanded geographic scale of 1983 sampling, there was no extended trend in the size of males relative to SONGS because the maximum size decreased again at some sites more than 6.5 km from SONGS (12 km S, 18 km S, 12 km N, and 15.5 km N). The means of the maximum size mode of males at sites near SONGS were within the variation found elsewhere. Therefore, correlations between this variable and the environment were not examined.

On the expanded scale of 1983 sampling, the mean of the minimum size mode of females with eggs differed significantly among beach sites in July and August ($p < 0.001$) but not in June. Too few females with eggs were available at beach sites within 6.5 km of SONGS to make the shorter scale beach comparisons reported by Auyong (1981). For instance, ovigerous females were present only at 0.4 km N in July, and were smallest there (Figure 3-15). Ovigerous females were present at 0.4 km N and some other sites near SONGS in August (15.5 km N, 12 km N, 12 km S), but no statistical difference in size relative to SONGS was found (Figure 3-16). Therefore, as with the males, the relationship between the minimum size modes of females with eggs and the beach habitats was not investigated.

3.2.2.4 Median Size

The median size of reproductive females was compared among beach sites, for each survey, by one-way ANOVA and SNK. To discriminate between categories of reproductive females (see section 3.2.3), females with eggs, females with spent egg cases, and both categories combined were tested separately. First the females of all sizes were tested, then they were separated into two size categories (smaller and larger than 13 mm) to examine the possible effect of overwintering females on the median size. The results of the combined categories (females with eggs or spent egg cases) are shown because few beach sites near SONGS had females with eggs; also, the sizes of females with eggs or spent egg cases were similar at the sites where they both occurred. Plots of the mean of the median size for each beach and the results of the SNK are presented for each size category (Figures 3-17 to 3-21). All beach site samples (except interpatch) with ten or more reproductive females in the size category being tested were used as replicates.

Females with eggs or spent egg cases were too rare for meaningful comparisons of median size in either June or July (Figures 3-17 and 3-18).

In August 1983, the beach sites differed significantly ($p < 0.001$) in median size of females in all three categories (eggs, spent egg cases, and both combined). On the limited scale of sampling (i.e., within 6.5 km of SONGS), Auyong (1981) reported that the mean size of ovigerous females was significantly less at 1.5 km N and 0.4 km N than at 1.5 km S, 6.5 km S, and 6.5 km N in 1977. In August 1983, the median size of reproductive females (primarily spent) was significantly less at 0.4 km N than at other sites within 6.5 km of SONGS. Too few reproductive females were collected at 1.5 km N in 1983 for comparison with other sites or seasons. However, the size frequency distribution of females at this site was similar to that at 0.4 km N (see section 3.2.2.1.2).

On the expanded sampling scale, SNK tests showed that females with eggs were smaller (median size) at 0.4 km N, 15.5 km N, and 45 km S than at 65 km S, 100 km N, and 450 km N (Figure 3-19a). Females with spent egg cases were smaller (median size) at 0.4 km N, 12 km N, and 45 km S than at other sites near and away from SONGS (Figure 3-19b). Similarly, no geographic trend relative to SONGS was found in the median size of females with eggs or spent egg cases combined (Figure 3-19c). The median sizes of reproductive females at beach sites in the vicinity of SONGS were within the variation found elsewhere. An analysis of the females divided into two size groups (larger and smaller than 13 mm) gave the same result (Figures 3-20 and 3-21).

Differences in the median size of reproductive females appear to be unrelated to distance from SONGS. Rather they appear to be related to the influence of overwintered females, to recruitment, and to site-specific seasonal variations in breeding. For example, 0.4 km N, 12 km N, and 15.5 km N had similar size frequency distributions, few overwintered females, and the smallest overall median size of breeding females. Although not tested, 1.5 km N also belongs in this group. Other sites within 12 km of SONGS had an additional recruitment class (< 13 mm) (see Appendix E), more overwintered females, and a larger overall median size. Reproductive females were relatively small at Moonlight

Beach (45 km S). As previously mentioned, a larger proportion of the smaller females were breeding at 45 km S earlier in the season, and growth appeared to have been slower at this site. In contrast, the median size of breeding females was larger at sites where older females (> 13 mm) were present, recruitment was earlier, and in the case of 100 km N, when reproduction occurred later.

3.2.3 Female Reproduction

Several variables associated with the reproduction of female sand crabs were examined. The percentage of mature females (larger than or equal to the minimum size of egg-bearing females) that were reproductive was compared among beach sites to determine whether the reported low incidence of egg production near SONGS (Wenner, 1982) persisted through the 1983 season. Wenner defined reproductive females as only those carrying apparently viable egg masses. He considered (pers. comm.) that anything more than a small fraction (5%) of the mature females with spent egg cases indicated disrupted reproduction, and that spent females should not be included in the reproductive fraction. However, spent egg cases can also result from normal hatching of young. Some evidence (Cox and Dudley, 1968) suggests that the proportion of mature females with spent egg cases may fluctuate because females of a similar age may have synchronous reproductive cycles.

To address both of these alternatives, the fraction of mature females with eggs, the fraction with spent egg cases, and the fraction with either eggs or spent egg cases (designated "reproductive" for lack of a better term) were determined in 1983. Each of these fractions was compared between beach sites in the context of the size frequency distributions and estimated recruitment patterns of the female populations.

Evidence for disruption of egg maturation and/or reproductive synchrony was investigated by examining the clutch size of newly extruded egg masses, incidence of external parasites in the egg mass region, external appearance of spent females, external development of eggs, and internal development of oocytes.

3.2.3.1 Percentage of Females in Reproductive Condition

The percentage of female sand crabs that were reproductive was examined according to size categories to prevent any single size group (e.g., overwintered females or immature females) from dominating the results. With the exceptions of Morro Bay (450 km N) and Cabrillo Beach (79 km N) (see section 3.2.2.1.2 and 3.2.2.2), this allowed us to test groups of about the same sexual maturity.

According to Wenner (review of October 1983 MEC Sand Crab Report, unpubl.), sand crabs at Morro Bay do not produce eggs their first year on the beach. The 1983 data support this. Even as late in the season as August, female sand crabs smaller than 13 mm did not carry eggs or spent egg cases. At Cabrillo Beach there were few females larger than 10 mm in June and most of these disappeared by July. After June no females grew to sexual maturity at Cabrillo Beach. These exceptions were taken into consideration when the results of between-beach comparisons were interpreted.

Three size categories of females were compared among beach sites: larger than 13 mm carapace length, larger than 10 mm to 13 mm, and 7 mm to 10 mm (Table 3-10). In June only overwintered females were reproductive. Female recruits of late 1982-1983 became reproductive at progressively smaller sizes as summer progressed. Many females that had grown to medium size (> 10 mm-13 mm) by July were reproductive for the first time in that month. A subsequent recruitment class that had grown to 7 mm-10 mm by August, first became reproductive in that month. Therefore, the size classes tested for beach differences were restricted to > 13 mm in June, > 13 mm and > 10 mm-13 mm in July, and all 3 size categories in August (Table 3-10). For each of these size categories and surveys, the percentage of females with external eggs (bright-orange, burnt-orange, grey), spent egg cases, and both categories combined were tested separately for beach differences by ANOVA and SNK. To describe the overall seasonal development of reproductive activity, all females, regardless of size, were considered first (Figure 3-22).

In these tests, all beach site samples (except interpatch) with ten or more females in the size category examined were used as replicates. Plots of the mean percentage of reproductive females for each beach and the results of the SNK are presented in Figures 3-23 to 3-31. The percentages of females with eggs and females with spent egg cases are shown on separate figures as are the two categories combined, which may or may not represent the total percentage of "reproductive" females. Whether or not both categories (F_e = females with eggs, F_s = females with spent egg cases) represent the total percentage of reproductive females depends on whether females with spent egg cases resulted from normal or abnormal reproduction; see section 3.2.3.2 for further discussion.

3.2.3.1.1 Females with Eggs and Spent Egg Cases (F_{e+s})

Females with eggs or spent egg cases attached to their pleopods will be referred to hereafter as F_{e+s}. The fraction of F_{e+s} of the total female population increased from June to August, with the greatest increase occurring between July and August (Figure 3-22). The progression of the increase varied among beach sites. There appeared to be a delay in the reproductive activity of females at the two northern beach sites in southern California (115 km N and 100 km N), which was more apparent when size groups were considered (see below). In July 42% of the females were reproductive at 18 km S and 80% were reproductive at 45 km S. Such high percentages were not seen at other sites until August. The tendency for sites near SONGS to have lower percentages of F_{e+s} is addressed below with regard to size groups.

SONGS beach sites tended to differ from most other beach sites in August but not in June and July (Table 3-10). There were essentially no differences between beach sites for the overwintered (> 13 mm) or medium size (> 10 mm-13 mm) F_{e+s} in June (Figures 3-23a and 3-23b). Females larger than 13 mm were not found at SONGS beach sites during July, so comparisons could not be made (Figure 3-24a). Furthermore, there was no geographic trend in the reproductive fraction of medium size (> 10 mm - 13 mm) females in July (Figure 3-24b).

In August, there were significantly ($p < 0.05$) fewer large (> 13 mm) reproductive females within 12 km of SONGS relative to sites farther north or south (Figure 3-25a). In addition, the reproductive fractions of medium (> 10 mm - 13 mm) and small (7 mm - 10 mm) females were lower at sites within 12 km of SONGS (except 0.4 km N) than at most other sites (Figures 3-25b and 3-25c).

3.2.3.1.2 Females with Eggs (F_e)

In June, only the overwintered females carried eggs (Figures 3-26a and 3-26b), and they were found primarily at the southern beach sites (18 km S to 65 km S). In July, females > 13 mm with eggs were not found at beach sites near SONGS (Figure 3-27a). The percentages of medium-size F_e at SONGS were within the range of other beach sites in July (Figure 3-27b). In August, the percentages of F_e were significantly ($p < 0.05$) lower at beach sites near SONGS than at other beach sites for the two larger size classes (Figures 3-28a and 3-28b). The percentages of small F_e (7 mm-10 mm) were lower at most beach sites near SONGS (Figure 3-28c).

3.2.3.1.3 Females with Spent Egg Cases (F_s)

In June, only the overwintered females had clutches of spent egg cases. Of the populations within 12 km of SONGS, only sites 6.5 km N and 6.5 km S had overwintered females and they had significantly more clutches with spent egg cases than females away from SONGS. (Figures 3-29a and 3-29b). In July, females > 13 mm with spent egg cases were not found at beach sites near SONGS (Figure 3-30a). The percentages of medium-size F_s at most sites near SONGS were low and within the range of other beach sites (Figure 3-30b).

In August, larger fractions of the females greater than 13 mm and > 10 mm to 13 mm had spent egg cases at beach sites within 12 km of SONGS relative to females at other beach sites (Figures 3-31a and 3-31b). Although this trend was similar for the smallest (7 mm - 10 mm) reproductive females, differences between sites were not statistically significant (Figure 3-31c).

3.2.3.1.4 Summary of Analyses of Reproductive Condition

In June, beach sites near San Onofre had lower percentages of overwintered females carrying eggs and higher percentages of overwintered females that carrying spent egg cases. In July no differences between beach sites near and away from SONGS were found where comparisons could be made. In August, beach sites near SONGS again had lower percentages of females with eggs and higher percentages with spent egg cases. In addition, the percentage of females with eggs or spent egg cases was generally lower within 12 km of SONGS than at other sites surveyed in southern California.

If the spent egg cases at sites near SONGS resulted from disrupted egg maturation, then the difference in the reproductive output of females between sites within 12 km of SONGS and farther away is dramatic. However, even if spent egg cases represented normally hatched egg masses, beach sites near SONGS generally had lower percentages of reproductive females (F_{e+s}) in August. This difference was significant for the larger-size females. Although this difference was generally true for the medium and smaller-size females, reproductive females were abundant at 0.4 km N.

3.2.3.1.5 Female Reproduction Relative to the Environment

The relationships between the physical-chemical environments of the beach sites and the F_{e+s}, F_e, and F_s were examined separately for the female population as a whole, for females larger than 13 mm, and for females > 10 mm to 13 mm. Data from July was added to that of August, when appropriate, to increase the number of observations and consequently, the degrees of freedom in the models.

For the female with eggs or spent egg cases (F_{e+s}) category, the several multiple regression analyses accounted for similar amounts (R^2 = 0.72 to 0.78) of the variability among beach sites (Table 3-5). The combinations of independent variables varied with the analyses, but sediment character and food levels in the water were important in each

(Table 3-6). Temperature was influential both when one considered all females regardless of size and the medium-sized female category.

No sites imposed an undue influence on the three regression results (Table 3-7), however, the percentage F_{e+s} in the > 10 mm-13 mm size range at 0.4 km N was not predicted well based on the environmental variables collected at sites > 1.5 km from SONGS (Cook's D of 4.399 at site 0.4 km N, Table 3-8). The poor prediction at 0.4 km N resulted because there were many more reproductive females than expected from the amount of cobble coverage at the site. Cobble was identified as being influential because the regression coefficient for this variable changed by a factor of 2 while other coefficients changed by less than 10% when the regression was run with and then without 0.4 km N. Because the Cook's D value for 0.4 km N was not significant in the regression when all sites were considered, the influence of 0.4 km N was not considered inappropriate in the regression result. The independent variable "distance from SONGS" did not outperform the environmental variables when sites within 15.5 km of SONGS were considered.

The cluster analyses of beaches in July (Figure 3-2) and August (Figure 3-3) showed that sites with lesser fractions of F_{e+s} generally had coarser sediments, less food in the water, and more seston. Food and the seston load may have been more limiting than sediment size. For instance, at Morro Bay where a large fraction of the large females were breeding in August, sediments were very coarse, food levels were moderate to high, and seston levels were low relative to other sites. The association of greater breeding activity with sites having more chlorophyll/phaeophytin and generally less seston (which was poorly correlated with any food variable: $r^2 < 0.20$) suggests that seston may not be acceptable as food for sand crabs.

The fraction of ovigerous females has been reported to decrease monotonically with decreasing temperature from about 25°C to 11°C (Fusaro, 1980a). The water was very cool at Morro Bay, where medium-size females were not reproductive, and generally cool at sites near SONGS (Table 3-1), where the percentages of medium-size females with eggs plus spent egg cases were generally lower.

For the F_e category, the regression analyses (R^2 = 0.69 to 0.74, Table 3-5) indicated that seston in the water, food in the sediment, water temperature, sediment size dispersion, and percent silt-clay were important (Table 3-6). No site had an exceptional influence on the regression relationships and the models correctly predicted the egg carrying characteristic near SONGS for all size categories (Tables 3-7 and 3-8). Therefore, these regressions indicate that lower percentages of females with eggs were found at beach sites near SONGS where food generally was less, water was cooler, and sediment was coarser (Figures 3-2 and 3-3; Tables 3-1 and 3-2). The multiple regression run on sites within 15.5 km of SONGS showed a trend in F_e with distance from SONGS in July and August (R^2 = .60, p = .028, n = 16, partial r^2 for "distance" = .38) when all females regardless of size were considered. However, this result appears to be due to one observation: 15.5 km N in August (note that the percentages of F_e were significantly higher at 15.5 km N in August for the medium and smaller-size females, Figures 3-28b and 3-28c).

Relationships between the physical-chemical environment and the percentage of females (all sizes, > 13 mm, and > 10 mm - 13 mm) with spent egg cases (F_s) were examined only for August; beach sites away from SONGS lacked sufficient numbers of females with spent egg cases for meaningful comparison in July. The regression analyses (R^2 = 0.73 to

0.95) indicated that frequent occurrences of spent egg cases were most strongly associated with coarse sediments, more dense cobble coverage, and food levels in July, a month prior to sampling (Tables 3-5 and 3-6).

In the case of the regression of all females (regardless of size) with spent egg cases, two influential observations were detected. Sites 6.5 km S and 0.4 km N had significant Cook's D values (Table 3-7; Table 3-8 for 0.4 km N). When both influential observations were deleted, a regression without significant Cook's D values was obtained (Table 3-11). The adjusted equation differed from the original primarily in the magnitude of the regression coefficients. Examination of the regression coefficients when the influential beach sites were deleted one at a time indicated that weighted cobble coverage on sand accounted for the poor fit of 0.4 km N, and weighted cobble coverage on sand, cobble on sand at sled sampling sites, and sediment carbon accounted for the poor fit at 6.5 km S.

The cluster analysis of August (Figure 3-3) showed that coarse sediment or high cobble coverage conditions or both existed at beach sites within 12 km of SONGS, where the percentages of females with spent egg cases were highest. This suggests a positive relationship between coarse, cobbled beach substrate and the frequency of spent egg cases. The food concentrations in the wave wash in July, however, were moderate to high at almost all of the beaches (Table 3-3). Therefore, the relevance of July food levels in distinguishing beach sites in terms of the frequency of females with spent egg cases in August is difficult to understand.

3.2.3.2 Spent Egg Cases: Egg Disruption or Reproductive Synchrony?

Wenner (pers. comm.) suggested that in a normal female population less than 5% of the females should have spent egg cases at any time. Wenner contends that spent egg cases are removed (actively by the female) or sloughed (during molting) from a female within 2 days after a normal hatching of its eggs. According to Fusaro (1980a), the gestation period for sand crab eggs can vary from 18 days at 25°C to 33 days at 18°C, therefore, one would expect a period of about 30 days at temperatures usual to southern California. Wenner's estimate of 5% spent females, based on about a 30 day gestation period (i.e., 30 days x 5% spent females = 1.5 days of spent females), assumes that females are unsynchronized in the hatching of their eggs.

According to Wenner's hypothesis, a fraction of spent females in a population higher than 5% would indicate that spent egg cases were being retained for longer than 2 days. Wenner (1982) suggested that the high percentages of spent females at sites within 15-20 km of SONGS in 1982 indicated that the eggs had prematurely ruptured within the first 2 weeks of extrusion and the spent egg cases remained attached to the females for the remainder of the gestation period (i.e., approximately 2-3 weeks). No direct evidence of abortion was noted by Wenner (1982).

The occurrence of high percentages of females with spent egg cases near SONGS during the 1983 summer reproductive season agrees with the results presented by Wenner (1982) for the 1980-1982 seasons. According to Wenner's hypothesis, the 1983 results suggest disruption of egg maturation among sand crab populations in the vicinity of SONGS.

Even if higher percentages of females with spent eggs occurred near SONGS, the apparent correlations between them and habitat variables caution deliberation about assigning the effect directly to

SONGS. Whether the maturation of eggs was disrupted or not is still open to question. We did four kinds of additional analyses which bear on this question. These analyses included clutch size examinations of recently extruded egg masses, abbreviated surveys of female breeding condition toward the end of the reproductive season, examination of gestation cycles of external eggs, and oogenesis cycles of internal eggs.

Did individual egg volume differ among beaches?

3.2.3.2.1 Clutch Size

Clutch size (egg mass volume divided by mean individual egg volume) was determined for females with recently extruded (bright-orange) eggs. Mean egg volume was found to be unrelated to female size, but larger females tended to carry more eggs (Appendix D, section D.3). Therefore, log of the clutch size was compared among beach sites by analysis of covariance (Sokal and Rohlf, 1981; SAS, 1982), wherein the size of the crabs was a covariate. Several beach sites had fewer than ten females for the statistical comparisons. For this reason, the sites were combined in three groups: "north" of SONGS (100 and 115 km N), "near" SONGS (± 12 km), and "south" of SONGS (18 km S to 65 km S).

Analyses of covariance showed that clutch sizes were not significantly different ($p > 0.85$) among beach sites in June (Figure 3-32), but they differed significantly in July and August ($p < 0.001$). SNK analyses showed that clutches were smaller within 12 km of SONGS and at 100 km N and 115 km N in July (Figure 3-33) and within 12 km of SONGS in August (Figure 3-34).

The differences in clutch size among beach sites appeared to result from spent egg cases in the clutches of bright-orange eggs (see Appendix D, section D.3) rather than differences in the volume of individual developing eggs or the number of eggs (note that the volume of egg masses did not significantly differ among beach sites in June). Of the examined egg masses, 64% from the "near" group, 38% from the "north" group, and only 2% from the "south" group had spent egg cases (Table 3-12). To control for some of the bias associated with comparing egg masses with different amounts of spent egg cases, clutches with several spent egg cases (spent egg cases as numerous as eggs) were not included in the analysis of clutch size. Even with this restriction, 19% of the clutches from the "north" sites and 57% of the clutches from the "near" sites had some spent egg cases. A contingency analysis using Chi-square showed that the occurrence of the spent condition was not independent of beach groups (Appendix D, section D.3).

Whether or not clutches comprised entirely of spent egg cases resulted from egg hatching, abortion, or both was not answered by these analyses. However, the results indicate that a certain amount of egg disruption occurred among viable eggs of females from beach sites near and north of SONGS. The spent egg cases were considered to be evidence of disruption rather than unfertilized eggs because it has been observed that unfertilized eggs remain intact and bright-orange until sloughed (Cox and Dudley, 1968).

No parasites were found in examinations made to see whether gross external parasites were associated with the spent egg cases in the newly extruded egg masses. Therefore, the relationships between the physical-chemical environments of the beach sites and clutch sizes were examined for July and August to ascertain what factors might contribute to the reduced number of viable eggs. The regression model had an R^2 of 0.75 with 5 variables (Table 3-5). There were no unduly influential beach sites in the model (Table 3-7) and clutch sizes were predicted as well at beach sites within 1.5 km of SONGS as at other beach sites (Table 3-8). The model indicates that the incidence of spent egg cases in clutches of developing eggs increases at beach sites with steep slopes, coarse sediments, and extensive cobble coverage. This suggests that a factor such as mechanical stress may influence the incidence of ruptured egg cases among recently extruded egg masses. However, it should be emphasized that a causal relationship has not been established.

3.2.3.2.2 Additional Abbreviated Surveys

To extend the beach observations of the reproductive condition of female sand crabs through the reproductive season, abbreviated surveys during which only sand crabs were sampled at a limited number of sites were conducted from late August into October (see section 2.1.3.2). The results from these abbreviated surveys were merged with results of the full scale surveys and the combined data were reanalysed (Table 3-12). The fractions of females carrying clutches comprised entirely of spent egg cases were computed as ratios of spent females to total numbers of females collected, at each beach site, rather than as means of the fractions found in the beach replicates (as previously tested by ANOVA and SNK, section 3.2.3.1). why?

This comparison showed that, at one time or another, more than 5% of the females had spent egg cases at all beach sites, and that higher percentages occurred mainly in August and September. Unlike the full scale summer survey comparisons (Section 3.2.3.1), the late season comparisons showed that high fractions of spent females were not restricted to sites within 12 km of SONGS. Venice Beach (115 km N) and Hermosa Beach (100 km N) had some percentages even higher than beach sites near SONGS in late August and in September.

The late season observations could indicate that there is no functional relationship between spent females and human-induced perturbations because beach sites within 12 km of SONGS were within the range of variation of northern beach sites. On the other hand, the consistently low fractions of spent females at the southern beach sites (18 km S-65 km S) could be taken as evidence that they were unperturbed while females were perturbed at the SONGS and Los Angeles area beach sites. The late season observations also could be interpreted as indicating longer than normal retention of spent egg cases toward the end of the main reproductive season. The uncertain and controversial implications of high fractions of spent egg cases call for the integration of field population observations with sand crab reproductive biology. Therefore, we further investigated these alternatives by examining gestation and oogenesis cycles in sand crabs.

3.2.3.2.3 Gestation Cycles

A quasi-simultaneous hatch among normal females having about the same phase and period in the breeding cycle could appear in field samples as a high fraction of spent females if the sampling coincided with the hatching event. Wenner (1982) considered the possibility of reproductive synchrony as an explanation for high fractions of spent females, but dismissed it because of the results of a laboratory experiment. About one-third of a collection of live spent females (from 6.5 km N in 1982) produced new batches of eggs in Dr. Wenner's laboratory after a 2-3 week period, whereas only 5% of similar size females in the field population produced new batches of eggs during the interim. Rather than show that spent egg cases represented egg disruption, the laboratory experiment showed that after at least a two week period, females from the same population were able to produce a higher percentage of eggs under laboratory conditions using seawater from Santa Barbara than they were able to produce under field conditions near San Clemente. Information was not presented by Wenner that permits evaluation of whether the difference in reproductive output could have been related to the conditions of the experiment (e.g., food).

Sand crabs, particularly large ones, may produce several batches of eggs per reproductive season (Cox and Dudley, 1968). The percentages of females with eggs in the different stages of maturation can be predicted in a non-synchronous population if the duration of selected developmental stages and total gestation time are known. The degree of deviation from the predicted percentages provides indirect evidence for or against reproductive synchrony.

The gestation cycle of sand crabs is incompletely documented. According to Fusaro (1980a), the gestation period for *Emerita analoga* eggs can vary from 18 days at 25°C to 33 days at 18°C. Therefore, a period of about 30 days seems likely at the wave wash temperatures (about 18-20°C) observed during the 1983 reproductive season (Table 3-1). After being fertilized, the developing eggs pass through three visually-identifiable stages (see section 2.2.2): bright-orange, burnt-orange (eye pigment visible), and grey (developed embryo visible). The duration of these stages has not been determined for *Emerita*. Determinations for two genera of the same taxonomic tribe as *Emerita* --*Blepharipoda* and *Lepidopa* -- indicate that the bright-orange egg stage lasts for about two-thirds of the gestation period (M. Knight*, pers. comm.).

* M. Knight, crustacean biologist, Scripps Institution of Oceanography, San Diego.

We have used this two-thirds value as the best estimate of the relative duration of the bright-orange egg stage in Emerita. To account for the remaining one-third of the gestation cycle we have assigned 20% of the cycle to the burnt-orange stage, 8% to the grey stage, and (after Wenner) 5% to the spent egg case stage.

The fractions of females with eggs in the different stages of development were computed as ratios based on the total number of females with clutches of eggs or spent egg cases collected during the 1983 full-scale summer surveys (Table 3-14). The percentages of females with eggs in the different stages of development (including spent egg cases) were examined separately for females > 13 mm and for females > 10 mm to 13 mm for each survey. Supplementary tables that summarize the reproductive condition of all females (> 13 mm and > 10 mm to 13 mm) collected at each beach site during each survey are presented in Appendix F, Tables F-2 and F-3.

The percentages of females with eggs in different stages of development were then compared with the theoretical duration of each developmental stage. The field data suggest that synchrony differed between sites but was common in 1983. When one considers only the breeding-state females (bearing eggs or spent egg cases), the fractions within each of the reproductive categories were sometimes larger and sometimes smaller than would be expected if an unperturbed state of non-synchrony existed. Only at Oceanside Beach (25 km S) in August, for females larger than 13 mm, was the distribution of stages particularly close to the theoretical distribution (Table 3-14). Females at the southern beach sites generally had higher fractions of earlier stage eggs. Northern beaches were mixed. Beach sites within 12 km of SONGS had higher fractions of females with spent egg cases.

3.2.3.2.4 Histological Examinations of Ovaries

It has been reported that the ovarian cycle is linked with the gestation cycle of external eggs in some crustaceans that produce more than one clutch of eggs per season (Haefner, 1977; E. Wenner, 1979). It was thought that if this was also true for sand crabs, then it might be possible to shed light on the controversial observations of high frequencies of females bearing spent egg cases in the vicinity of San Onofre. It was hypothesized that if the spent condition was a normal part of the gestation cycle of external eggs, then the development of the ovary during this period should be distinct from that seen during other stages of the gestation cycle. On the other hand, if the development of the ovaries of females with spent egg cases was similar to that of females with developing external eggs, then this would indicate either disruption of egg maturation or possibly disruption of the ovarian cycle.

Female sand crabs with external eggs in different stages of development and with spent egg cases were selected, when available (primarily August), from beach sites near SONGS (0.4 km N) and to the north (100 km N) and south (25 km S and 45 km S). These beach sites served as models for examining the relationships between the developmental stages of the external eggs and the internal oogenesis cycle. The ovaries of additional females with spent egg cases from the August survey were examined from beach sites within 12 km of SONGS. It was assumed that the relationship between the ovarian and gestation cycles at those sites would be similar to that at the site 0.4 km N. The methods for selecting the specimens are described in Section 2.2.3 and a full description of the laboratory investigation performed by Dr. Steven Goldberg is given in Appendix H.

Ovarian development within a reproductive female sand crab is synchronous in that only one group of oocytes undergoes yolk deposition (vitellogenesis) at a given time. Among females that are in the process of producing another batch of eggs, vitellogenesis is linked with the developmental stage of the external eggs (Table 3-15). The ovaries are undeveloped with either resting or early vitellogenic oocytes in females with bright-orange (immature) external eggs, whereas ovaries are enlarged and contain mature, yolk-filled oocytes in females bearing spent egg cases. This confirms that spent egg cases occur normally at the end of completed brooding cycles. At the end of the reproductive season, the ovarian cycle is completed and there is no longer a relationship between the appearance of the ovary and the development of the female's final batch of external eggs. The ovaries are inactive, and resemble those found in females with newly extruded bright-orange eggs.

Whether the high percentages of females with spent egg cases observed at beach sites within 12 km of SONGS in August and at 100 km N in September represented normally hatched or disrupted egg maturation was not definitely settled by the ovarian analyses. The ability to address the import of high percentages of females with spent egg cases hinged on two requirements: repeated egg production and examination of sufficient numbers of females with external eggs in different stages of development for comparison with oogenesis. Although these requirements were met for the southern beach sites (Oceanside Beach and Moonlight Beach; designated as OCEA and MOON, respectively, in Table 2, Appendix H), one or both of these requirements were not met for the sites near and north of SONGS. Of the beach sites near SONGS, only 0.4 km N had enough females in August with external eggs in different stages of development for comparison with oogenesis, but most of these females, regardless of stage, had inactive ovaries. Sufficient numbers of females with external eggs in different stages of development were not available from other sites near SONGS, or in the case of 0.4 km N, from other surveys.

At the northern site, 100 km N (designated as HERM in Table 2, Appendix H), it was possible to establish that vitellogenesis was linked with the maturation stage of external eggs and spent egg cases in August. However, only three females with spent egg cases were available in that month for histological analysis. Additional females with spent egg cases were examined from September (designated as 8304 HERM in Table 2, Appendix H), but they had inactive ovaries.

The ovarian condition (inactive ovaries) of females with spent egg cases from Hermosa Beach (100 km N) in September and sites near SONGS in August was interpreted by Goldberg (Appendix H) as an indication of the end of the reproductive season rather than abnormal termination of the reproductive cycle. This interpretation was based on several reasons. None of the specimens, including spent females from near SONGS, showed physical signs of trauma, nor abnormal atresia (spontaneous breakdown of oocyctes). The presence of food in the stomachs and fecal matter in the intestines indicated that they had been feeding and digesting food. The apparent good health of the females and the low incidence of atresia in the ovaries implies that they had not experienced recent abrupt environmental stress (Goldberg, Appendix H).

In the case of females from Hermosa Beach, it can be argued that the high percentages of females with spent egg cases in September represented females at the end of the brooding cycle. Most females were carrying bright-orange (newly extruded) egg masses in August. The 37 day interval between sampling at Hermosa Beach in August and September is only a few days longer than the estimated gestation period (ca. 30 days) for external eggs. Because normal vitellogenesis of oocytes was linked with the maturation cycle of external eggs in August, the reproductive cycle of females appeared normal in August. The ovaries of spent females in September did not indicate that prior vitellogenetic cycles had been disrupted since there was a low incidence of atretic oocytes. These results taken together suggest that the high percentage of females with spent egg cases at Hermosa Beach in September reached that condition through normal maturation of their external eggs.

Similar arguments cannot be made for the high percentages of females with spent egg cases at beach sites near SONGS. Although the ovaries of spent and egg carrying females appeared normal, without a clear link between internal and external development of the eggs any statement regarding the fate of the external eggs from when they were extruded to when they became spent would be entirely speculative.

The histological analysis did not fully answer the question about high percentages of spent females, but it did provide evidence of a trend in the variability of reproductive activity. The beach sites differed in the percentage of reproductive females that were producing yolk-invested ova (and presumably another batch of eggs) in August. Among spent females at sites within 12 km of SONGS, the continuity of brooding was considerably less than at sites farther north and south. Of the sites within 12 km of SONGS, the percentages of spent (clutches of spent egg cases) females with developed ovaries decreased with proximity to SONGS (Figure 3-35). This information, together with the results of examining a few females from sites within 1.5 km of SONGS in July, indicated that most reproductive females produced only one clutch of eggs at sites within 12 km of SONGS, whereas females elsewhere produced two or more clutches.

Although the females were selected for the histological analysis from a restricted size range (mainly 8-13 mm), differences among sites in the time of initial recruitment to the beach populations may have affected the results. It appeared that sand crabs generally recruited later at sites within 12 km of SONGS than at sites farther north or south. It is possible that the delay in recruitment could have reduced the amount of time the females at these beach sites had to store the energy reserves necessary for reproduction.

The relationship between the physical-chemical environments of the beach sites and the percentages of spent females producing another batch of internal eggs was examined for August 1983. Only females between 8 and 13 mm were included in the analysis. Because only 3 spent females of this size were collected in August at Hermosa Beach, that site was excluded from the analysis. The regression model, which had an R^2 of 0.95 with two variables, suggested that females tended to produce fewer egg masses at beach sites with coarser sediments and lower food levels in the water (Tables 3-5 and 3-6). No sites had excessive influence on the relationships (Table 3-7) and the percentages of females producing another clutch were predicted as well at sites near SONGS as at other sites (Table 3-8). However, the regression analysis on data from sites within 15.5 km of SONGS indicated that distance from SONGS was a better predictor than sediment coarseness of the percentage of females in the spent condition which were producing a new batch of internal eggs. This confirmed the earlier observation based on Figure 3-35.

Seems to be a shorter repro. season in 83 too.

3.2.3.2.5 Conclusions Regarding Spent Egg Cases

In summary, it was not possible to arrive at an unequivocal conclusion regarding the cause(s) of the observed higher than expected proportions of females with spent egg cases. These high proportions could have resulted from disruption of the normal egg maturation cycle (abortion), or from normal end-of-season phenomena (synchrony and/or prolonged retention of spent egg cases). Evaluation of clutches of developing eggs suggested that abortion did occur to some extent at beach sites near and north of SONGS (section 3.2.3.2.1), while estimation of gestation cycles (section 3.2.3.2.3) and histological examination of ovaries (section 3.2.3.2.4) suggested that synchrony occurred as well. However, the possibility of extended retention of spent egg cases at the end of the reproductive season (section 3.2.3.2.2) could not be clearly separated from end-of-season synchrony.

Although we have evidence strongly suggestive of the existence of at least two of the mechanisms for producing high proportions of females with spent egg cases, we cannot evaluate their relative contributions to the observed percentages. This is because our sampling frequency did not allow us to meet the necessary criteria of sampling repeated egg production cycles and collecting adequate numbers of females with eggs in different stages of development during each of these cycles. Further work is needed before definitive statements regarding the cause(s) of high percentages of spent females in populations near SONGS can be made.

3.2.4 Genetic Studies of Sand Crabs

The population genetics of Emerita analoga collected during the August 1983 survey were examined by Dr. Richard Beckwitt of Occidental College (Appendix G). There was no obvious geographic difference among samples of Emerita, and there was no evidence of regular or clinal variation at any enzyme locus.

Sand crabs from beach sites near SONGS differed from those collected from several of the other sites in the activity of two important metabolic enzymes. Samples from sites within 15.5 km of SONGS and from Cabrillo Beach (79 km N) stained poorly for phosphoglucomutase and glucosephophate isomerase relative to those from sites farther south or north. These enzymes are elemental in the metabolism of glucose or glycogen (Beckwitt, pers. comm.).

Dr. Beckwitt offered two alternative explanations for the observed lowered enzyme activity. First, an alteration in the control of enzyme production might be caused by a genetic (or unknown) factor at some beach sites. Second, enzyme activity could be modified by a pollutant. Heavy metals were suggested as one possibility because the enzymes have a metal (Mn) cofactor.

The relationship between the physical-chemical environment of the beach sites and phosphoglucomutase, whose results were emphasized by Beckwitt (1983), was investigated by multiple regression analysis. The model (R^2 = 0.82 with 3 variables, Tables 3-5 and 3-6) suggested that food in the sediment and the grain dispersion in the sediment were correlated with phosphoglucomutase activity. No sites had extraordinary influence in the model (Table 3-7), which predicted the PGM at sites near SONGS as well as at sites farther away (Table 3-10).

Comparison of the enzyme activity with results of the cluster analysis for August (Figure 3-3) showed that beach sites with low enzyme activity generally had less food in the sediments, higher grain size dispersion, and coarser sediments. One exception, Cabrillo Beach, had fine sediments with low dispersion and a high concentration of food in the sediment. As noted previously, the chemical and biological measurements at Cabrillo Beach suggested that the site was aberrant.

Some questions have been raised (Wudl, pers. comm.) regarding the likelihood of either of the alternative explanations for differences in enzyme activity. Wudl suggested that such variation could represent natural polymorphism, and that it was highly unlikely that both of the enzymes would be affected by genotoxic agents in several individuals at once. We feel that a dialog between Drs. Wuld and Beckwitt might resolve the differences in their interpretations.

3.2.5 Overall Favorableness of Beach Sites for Sand Crabs

The overall positioning of the beach sites in terms of the biological variables was examined by a semi-quantitative ranking procedure. Beach sites were ranked for a number of selected biological variables and the median rank was used to summarize overall differences in sand crab populations among beach sites. The site 450 km N (Morro Bay) was not included in this analysis because sand crab populations fundamentally differed from those in southern California in several respects. Most notably, sand crabs were generally larger and only the largest females were reproductive.

Representative (non-redundant) biological variables were selected from the categories related to abundance, size, reproduction, and genetics. The selected variables were required to have observations for at least 8 of the 15 beach sites with 4 of those sites within 15.5 km of SONGS. The mean values of the selected variables for each beach site, which were tested by ANOVA and SNK, were ranked in order of magnitude according to beach site from 1 to 15, with 15 representing the most favorable rank. For instance, since a high percentage of females with eggs was considered favorable, the beach site with the highest percentage for the survey considered received a rank of 15. In the case where fewer than 15 beach sites had observations, the ranks were adjusted to a common scale by multiplying each rank by the factor 15/(number of observations). Finally, the median adjusted rank was determined for each beach site as a measure of overall favorableness for sand crabs.

Results demonstrated no clear trend in the overall ranking of beach sites in terms of sand crab biology (Table 3-16). Beach sites within 1.5 km of SONGS had some of the lowest median ranks, indicating that these sites were relatively unfavorable for sand crabs; however, the median ranks were as high or higher than those at sites 12 km N, 15.5 km N, and 79 km N of SONGS. Sites 6.5 km N and 6.5 km S had ranks similar to those at sites 115 km N and 18 km S, indicating that sand crab populations from sites nearest the Plant were not unique in possessing a full suite of negative characteristics (as measured in this study).

However, these results do not detract from those described previously. Rather they point out that sand crab populations in the vicinity of SONGS differed from other populations in some respects and not in others during 1983. The ranks across sites reflect the interpretations of the SNK analyses for the biological variables identified as being different at beach sites near SONGS. These variables, denoted by asterisks (*) after the adjustment factor in Table 3-16, are related primarily to reproduction, as noted earlier.

3.3 Sand Crab Results Relative to Sampling Design

Results of the sand crab study were examined for potential sources of sampling bias to determine whether or not to add a cautionary note to the interpretation of the data. Three problem areas were identified and investigated. First, in July a few beach sites were sampled during a different tidal cycle than that during which the other sites were sampled (see section 2.1.3.1). Second, sites were sampled during the ebb cycle of spring tides in June, whereas sites were sampled during the ebb cycle of neap tides in July (except where noted) and August. Finally, the sampling was not fully stratified in June, but was changed to a stratified design in July and August.

There was no obvious indication of bias being introduced by sampling different tidal cycles in July. If extensive bias had occurred, one would have expected to see a group comprised of the beach sites sampled on the same tidal cycle in the results of the different biological variables tested by ANOVA and SNK. That is, a SNK analysis would group July sites 1.5 km N, 0.4 km N, 1.5 km S, 6.5 km S, 25 km S, and 65 km S, which were sampled during the period when the slack tide turned toward the flood cycle. In no instance was a statistically significant SNK grouping of these sites encountered in July. Furthermore, statistically significant SNK groupings of different combinations of the above-mentioned sites were not reported for July for any of the examined variables.

Similarly, bias was not evident in the results that could be attributed to sampling during spring tides in June but sampling neap tides in July and August. Although differences were observed between surveys, they did not appear to be the result of sampling bias. For instance, at most beach sites more females became reproductive as the season progressed. The abundance of sand crabs increased across surveys at some sites, decreased at others, and remained about the same at still others. If any bias occurred, we suspect that it may have been in underestimating the abundance of sand crabs at the La Jolla site, 65 km S, in June. The tide was extremely high and the beach was submerged most of the night. When the tide finally began to recede, it was rapid. It appeared that the sand crabs were unable to keep up with the receding tide and became more spread out across the intertidal zone than usually observed.

No evidence was found to indicate a bias due to the random and stratified random sampling designs that were used in the June and July/August surveys, respectively. This was primarily because data was analyzed across beach sites within a survey and not across surveys. Also both the stratified and non-stratified sampling methods give unbiased estimates of central tendency. It should be noted that qualitative comparisons between surveys were not seriously affected because most samples collected in June, by random chance or because of the distribution of the sand crabs on the beach, were collected in strata comparable to subsequent surveys (see beach maps, Figures 3-4 to 3-6).

In conclusion, any biases due to changes in the sampling design were not substantial. Had they been substantial, the ability to detect differences among beach sites would have been reduced. Therefore, differences that were noted between beach sites should be considered real.

3.4 Sand Crabs and El Nino

During the 1983 season sand crabs experienced a habitat variation brought on by the El Nino event. Three environmental effects accompanied the event (section 3.1): beach substrate sorting, elevated ambient temperature, and reduced phytoplankton production. Variations in sand crab population attributes among beach sites in 1983 were associated with sand grain size and cobble coverage, temperature, and the availability of appropriate food (section 3.2). It is not known to what extent these sand crab population attributes and beach habitat variables were affected by El Nino, but speculations are presented here based on known environmental and biological processes.

Beach sites in the San Onofre area generally had coarser sediments and steeper slopes than other sites sampled in southern California in 1983. This coarse and unstable sediment is primarily natural (Shepard, 1950); however, because coarse, steep beaches are physically less stable than finer, flatter beaches, the storms accompaning El Nino could have caused greater shore erosion, with even steeper beach slopes and coarser grain size (Bascom, 1951) in the vicinity of SONGS. It is speculated that this coarser and cobbled substrate in the San Onofre area could have provided a relatively unfavorable habitat for sand crabs. On steeper and coarser beaches the distance and duration of the wave uprush-backwash is less, partly because of slope geometry and partly because of increased percolation. This could give sand crabs less time to filter phytoplankton out of the thin layer of swash water. Also, rolling, shifting cobbles could crush sand crabs or keep them agitated.

Given sufficient food, sand crab growth rates and reproduction rates can both increase with increased temperature (Fusaro, 1978, 1980a). There is some evidence that each of these alternatives was experienced, each by a different beach populations (see section 3.2.2.1). In the San Onofre area, the wave wash zone of beach sites generally had cooler temperatures and less potential food for sand crabs than other sites in southern California in 1983. This could have accounted for the lower reproductive output of females within 12 km of SONGS.

Dudley (1967) contended that repeated breeding is the usual condition for sand crabs. Cox and Dudley (1968) calculated that over a 7 month breeding season individual females could brood between five and six successive clutches of eggs. In support of this, they reported high frequencies of brooding females (60%-90%) through the 1967 season at La Jolla. Conversely, they reported almost no breeding at the same site during the same season of the year before. The year before, 1966, was an El Nino period, although less intense than the 1982-1983 event.

In contrast to the long, relatively continuous breeding observed by Dudley in 1967, the 1983 sand crab breeding season was short and somewhat sporadic. The principal breeding activity in 1983 spanned about two months (August-September), which may have been related to food availability. Food concentrations were generally higher in July than in June and much lower in August (Table 3-3). Breeding activity was mainly by females small enough to be in their active growth phase. The lower frequency of breeding in 1983 could have occurred because the smaller females could afford only limited diversion of their energy stores to egg production and yolk investment. At sites near SONGS, a delay in recruitment may have decreased the amount of time for storing energy reserves, thus contributing to a lower reproductive output by females within 12 km of SONGS.

3.5 Sand Crab Studies Relative to SONGS Operation

There were no pertinent pre-SONGS observations made on sand crabs at San Onofre to compare with observations made during Plant operation. Therefore, the alternative has been to evaluate possible SONGS effects by comparing sites at varying distances from SONGS, and when possible, to look for differences that might be associated with SONGS operation.

Information is not available to address potential effects on sand crab beach populations from intake losses of larvae. Also the potential for contamination of beach habitats by metals discharged during operation of Unit 1 presently cannot be addressed. The potential for SONGS effects has been investigated here by examining the results of the past and present studies relative to different levels of SONGS pumping operations. In addition, speculations regarding the potential for SONGS influence on factors identified as being important in the multiple regressions performed on 1983 data are presented.

The pre-1983 sand crab studies included few concurrent observations from sites near SONGS and at varying distances from SONGS. Although some broad patterns of sand crab population attributes relative to SONGS were suggested by the previous studies (e.g., Wenner, 1982, Table 10), interpretation is hampered by the disjunct distribution of sampling sites and discordant timing of the various observations.

Past comparisons between sand crab population attributes at different levels of SONGS operation have been incomplete because detailed cooling water circulation data were not available. Recent information shows that SONGS circulating water volumes have fluctuated markedly and erratically since sand crab studies were initiated in 1976 (Figure 3-36). To the detriment of sand crab population comparisons, there were no comparable blocks of either full-time operation or full-time shut down that occurred with suitable seasonal timing and duration.

Previous MRC studies (Auyong, 1981; Wenner, 1982) reported that larger-mode males and egg-bearing females were smaller at distances up to 1.5 km north of the Plant relative to sites farther away or to the south in 1977 and 1981, but not in 1980. In 1983 the size distributions of sand crabs were similar to those reported by Auyong for the 1977 season. Wenner (1982) implied that the differences between the pre-1983 years were attributable to the Plant having been on-line in 1977, inoperative in 1980, and semi-operational in 1981. These findings need to be examined with respect to SONGS circulating water volumes.

At full capacity, SONGS (all three units) can circulate about 127 m^3/sec, or about 3.3 x 10^8 m^3/month (SCE, 1981; from Table 1-2). To facilitate comparisons, the SONGS circulating water volumes for particular periods were expressed as fractions of this full capacity. For the five years during which sand crabs were sampled in MRC studies, the flows and number of Units operating varied. The SONGS flows relative to full capacity measured during the principal sand crab season (April - August) and number of Units operating were as follows (Table 3-17): 1977-0.16 (Unit 1), 1980-0.06 (Unit 1), 1981-0.14 (Units 1 and 2), 1982-0.27 (Units 1, 2, and 3), and 1983-0.54 (Units 1, 2, and 3).

In light of these data, sand crab size did coincide with Plant operation prior to 1983. However, similar sand crab size attributes were seen in 1977 and 1983, even though the 1977 water circulation was only one-third of the 1983 circulation. Thus, no clear relationship between sand crab size and volume of water circulated through the Plant is demonstrated. On the expanded geographic sampling scale of 1983, it was apparent that sand crab size at beach sites near SONGS were within the variation found elsewhere in southern California.

Because flows from Units 2 and 3 are directed offshore and non-corrosive metals (titanium) were installed in the circulating system of these Units, a comparison of the flows of Unit 1 between years may be more appropriate for examining the potential for Plant related effects. The flow from Unit 1 is not directed offshore and metals (copper/nickel) subject to corrosion are in the circulating system. The SONGS flows relative to Unit 1 full capacity (about 5.5 x 10^7 m^3/month) measured during April - August were as follows (Table 3-16): 1977-0.95, 1980-0.36, 1981-0.56, 1982-0.19, 1983-0.29. Based on these flows, there is no clear relationship between sand crab size and Unit 1 operation between years. Similarly, there is no clear relationship between the volume of water circulated, at a particular time, and the occurrence of high percentages of females with spent egg cases, which have been reported since 1980.

The lack of a clear relationship between specific attributes of sand crab populations and the actual volumes of water circulated through the Plant does not imply that differences in beach populations of sand crabs are not related to SONGS operation. It only points out that differences between years in sand crab populations did not increase or decrease on the same scale as the varying circulating volumes of seawater. Potential effects from metallic pollutants dispersed intermittently from Unit 1 have not been ruled out by this analysis.

Differences between sand crab populations relative to the San Onofre area primarily concerned female reproduction in 1983. The multiple regression analyses suggested that, in general, lesser reproductive potential could be accounted for by factors such as later recruitment, coarse beach substrate, cooler temperatures, less food, and more seston. The identified habitat variables, in turn, were associated with beach sites near San Onofre. Some of these habitat variations are natural, and some may be related to SONGS construction or operation. The coarser sediment at beach sites within 15.5 km of SONGS is primarily natural and was identified as such before SONGS Unit 1 was built (Shepard, 1950). However, there is some evidence that beach sediment composition in the immediate vicinity of SONGS has been altered by SONGS construction activities (ECO-M, 1984).

The association of less breeding activity with cooler temperatures is consistent with the findings of Fusaro (1980a), who indicated that the proportion of breeding females in the population and egg development time are influenced by temperature. He also suggested that this in turn may have an effect on the number of clutches of eggs produced per female per reproductive season. The observation of generally cooler temperatures in the vicinity of SONGS relative to other sites (except Cabrillo Beach) surveyed in southern California was unexpected. Temperature anomalies, particularly lowered temperatures, are not predicted from SONGS operation. It is more likely that the lowered temperatures in the vicinity of SONGS resulted either from a persistence of localized upwelling or intrusion of colder offshore waters into the nearshore area (ECO-M, 1984).

The association of greater breeding activity with sites having more chlorophyll-phaeopigments and less seston suggests that seston may not be acceptable as food and could possibly reduce the feeding efficiency of sand crabs. When operating, SONGS discharge water is expected to contain increased seston comprised in part by fine-grained inorganic particles and in part by organic detritus. The discharge from Unit 1 can mix into the surf zone, but the discharges of Units 2 and 3 are expected to be directed offshore by the diffuser systems and therefore will not likely impact the beach. The suggestion that seston is a negative influence is consistent, in part, with that made by Siegel and Wenner (1984), who contend that increased turbidity as a result of SONGS operation may, singly or in concert with another factor(s), affect sand crab reproduction.

4.0 SUMMARY AND CONCLUSIONS

Variables associated with abundances, size distributions, female reproduction, and genetics[1] of sand crab (Emerita analoga) populations differed among the fifteen beach sites surveyed in southern California in 1983. When all measured variables were considered together, there was no overall trend in sand crab biology relative to SONGS. However, for several of the variables considered individually, sand crab populations from beach sites in the San Onofre area, sometimes up to 12-15.5 km away from the Plant, did differ from other sites farther away. The largest differences concerned sand crab reproduction. Individual variables are discussed below.

4.1 Abundance

The abundances of male and female sand crabs were generally lower at beach sites within 12 km of SONGS in June relative to other sites. This appeared to be the result of both a delay in recruitment of young from the plankton and a delay in colonization by juveniles and adults from the subtidal zone to the adjacent intertidal populations. In July and August, the abundances of males and females at sites within 12 km of SONGS were within the variation found elsewhere. The apparent delay in recruitment and colonization of sand crabs to beach sites within 12 km of SONGS was not strongly related to the physical character of the habitats. However, recruitment and colonization tended to occur later at beach sites with coarse sediments, steep beach slopes, higher percentages of cobble on the sand, lower temperatures, and poor potential food concentrations in the sediments.

1 This was an ancillary study performed outside the direct auspices of the MRC. It is summarized in the text, and the full results are given in Appendix G.

4.2 Size

Measurements associated with the sizes of males and reproductive females varied among beach sites with no particular relationship to those sites near SONGS. This was also true when the size of females initiating reproduction (minimum size mode of brooding females) as well as the size of overwintered individuals (females > 13 mm) were considered. However, although size showed no relationship with distance from SONGS, fewer of the large overwintered sand crabs were collected at sites within 15.5 km from SONGS (except at 6.5 km north and south) than were collected at sites further north (except Cabrillo Beach) or south.

Differences in the size attributes related to size modes or median size of sand crabs at a site appeared to be a consequence of factors such as the presence of overwintered individuals in the population, differences in recruitment, and in the case of females, initiation of reproduction. Size frequency distributions of the first year females were skewed towards smaller sizes at sites where recruitment appeared to be later or where most of the population initiated reproduction earlier. The result of all of these factors was that, overall, sizes at beach sites near SONGS fell within the variation found at beach sites elsewhere. It should be noted that direct measurements of growth were outside the scope of this study.

4.3 Reproduction

Female sand crabs within 12 km of SONGS differed from those farther away in several measurements of reproduction. In general, a lower percentage of females were reproductive (i.e., carrying clutches of eggs or spent egg cases) in the vicinity of SONGS during August, which was the peak reproductive period at most of the sites sampled in southern California. Besides this difference during the peak period, the results indicated that females within 12 km of SONGS produced fewer clutches of eggs in 1983 relative to sites farther away. Finally, of the females that were reproductive, those within 12 km of SONGS predominantly carried clutches of spent egg cases rather than developing eggs. Later in the reproductive season (September 1983), large percentages of females at the Los Angeles beach sites (115 km N and 100 km N of SONGS) also carried clutches of spent egg cases.

The only trend detected in any measure of reproduction was a decrease with proximity to SONGS in spent females (8 mm-13 mm) producing another clutch of eggs in August.

4.3.1 The Spent Condition

The presence of spent egg cases on reproductive females may occur in either (or both) of two ways: abortion or normal hatching. The occurrence of abortion is indicated by the presence of spent egg cases within clutches of developing immature eggs. Clutches composed principally of spent egg cases may result either from extensive abortion, or from normal hatching. Frequent sampling and evaluation of maturation cycles of eggs can separate these alternatives.

Abortion was clearly visible in the high proportion of reproductive females with clutches containing both immature eggs and spent egg cases in the vicinity of SONGS (64%) and at the northern beaches (38%). (This condition occurred in fewer than 2% of the reproductive females at the southern sites.)

In addition to these clutches containing both developing eggs and spent egg cases, a high proportion (more than 5%: see section 3.2.3.2.3) of reproductive females within 12 km of SONGS carried clutches composed entirely of spent egg cases. Siegel and Wenner (1984), also noting a high incidence of females with clutches of spent egg cases in the vicinity of SONGS, attributed this occurrence to abnormal reproduction.

However, the percentage of reproductive females with clutches of spent egg cases increased at most beach sites toward the end of the reproductive season. This late build up of the spent condition suggests that females may retain spent egg cases for a longer than usual period at the end of the season. Indirect evidence, based on evaluating the relationship between the gestation cycle of external eggs and the oocyte cycle, indicated that female populations were somewhat synchronized in their production and development of eggs in 1983. This suggests that the differences among beach sites in the frequency of spent females could have been, at least in part, the result of sampling populations that initiated breeding at different times. Unfortunately, sampling was too infrequent to demonstate whether hatching (synchrony and/or prolonged retention of egg cases) or abortion was more important in producing the observed high proportions of spent females. Therefore, none of these can be ruled out as possible causes of the high percentages of reproductive females with clutches comprised entirely of spent egg cases within 12 km of SONGS in 1983.

4.3.2 Correlations with Environmental Measures

Comparisons of reproductive measures with selected measures of the physical/chemical environment of the beach habitat showed strong correlations between the reproduction variables and food concentrations, temperature, and sediment characteristics. The fraction of females in breeding condition (i.e., bearing clutches of interest but was not addressed in this report. Siegel and Wenner (1984) stated that in 1982 "the variation in egg mass condition apparently resulted from a toxic substance emanating from near the center of the area under study {SONGS}." Two potential sources of pollution were suggested by Siegel and Wenner: metallic pollution from seawater corrosion of condenser tubing and pipes in Unit 1; or organic pollution from pesticides or other agricultural pollutants from nearby farms that drain into San Mateo Creek, which enters the ocean approximately 3 km north of SONGS. Although the contention that metal pollutants from SONGS or non-metallic pollutants from agricultural sources might disrupt egg maturation or reduce breeding was not addressed in this study, the appropriate samples have been collected.

either developing eggs or spent egg cases) was generally lower where: (1) food was less; (2) particulates in the water (seston) was higher; (3) water temperature was cooler; and (4) sediment was coarser. Higher percentages of females with clutches of spent egg cases rather than eggs were generally related to lower concentrations of food, coarser sediments, and higher cobble coverage. Clutches of developing eggs with a higher incidence of spent egg cases were related to coarser sediments, extensive cobble coverage, or both. If spent egg cases are a sign of abnormal reproduction, then the results of the multiple regression analyses suggest that mechanical stress from coarser sediment and cobble may be one possible cause.

1983 was a year of intense El Nino conditions. How the conditions (e.g., powerful storms, reduced overall primary production, overall warming of nearshore waters) affected sand crabs is unknown, but it was speculated that the short 1983 reproductive season may have been related to this anomaly.

The 1983 study was not designed to directly address potential effects from SONGS operation. An indirect approach showed no clear relationship between the volumes of seawater circulated by SONGS from 1977 to 1984 and the reported differences in sand crab populations in past MRC studies and 1983.

Although the physical/chemical environment of the beach habitats could account for much of the variability among sand crab populations, it must be emphasized that more work is required before causal relationships can be established. Quantitative establishment of relationships (between the environmental variables and sand crabs) that were suggested in this study is needed. In addition, the likelihood of other anthropogenic (man-made) factors influencing sand crabs is of

5.0 TABLES AND FIGURES

Table 2-1. Beach sites surveyed from late August through October 1983 to monitor the end of the reproductive season and the occurrence of spent egg cases on female sand crabs.

	Beach Sites (Distance from SONGS)							
Survey Date	65 km S	45 km S	6.5 km S	1.5 km S	0.4 km N	6.5 km N	100 km N	115 km N
30 Aug.- 3 Sept.		x		x	x	x	x	
9-10 Sept.	x	x	x		x	x	x	x
23-24 Sept.	x	x	x			x	x	x
6 Oct.	x	x						
19 Oct.		x						

where are these data?

Table 3-1. Physical characteristics of the beach sites surveyed in June, July, and August 1983.

		Distance from SONGS (km)															
VARIABLE	SURVEY	450 N	115 N	100 N	79 N	15.5 N	12 N	6.5 N	1.5 N	0.4 N	1.5 S	6.5 S	12 S	18 S	25 S	45 S	65 S
Beach slope	Jun.		0.09	0.21	0.07		0.08	0.09	0.12	0.08	0.20	0.14	0.16		0.08	0.08	0.01
	Jul.		0.18	0.16	0.08	0.14	0.11	0.13	0.23	0.10	0.22	0.16	0.15	0.05	0.08	0.07	0.08
	Aug.	0.13		0.08	0.04	0.21	0.23	0.08	0.17	0.06	0.16	0.18	0.16	0.09	0.07	0.05	0.04
Beach width (meters)	Jun.		84	150	50	100	100	11	100	50	46	27	200	61	36	60	35
	Jul.		125	130	17	54	65	26	65	46	31	35	30	61	15	37	13
	Aug.	75	150	100	55	65	100	37	110	50	22	20	33	40	38	37	25
Wave angle	Aug.	0.00	-5.00	0.00		10.00	-20	-5.00	-5.00		5.00	77.70		-10	50.00	-15	10.00
Wave height, (meters)	Jun.		0.46	0.61	0.30	0.00	0.30	0.61	0.61	0.76	0.61	0.61	0.91	0.30	0.61	0.76	0.91
	Jul.		0.61	0.46	0.15	0.46	0.61	0.46	0.61	0.30	0.76	0.46	0.61	0.46	0.76	0.61	0.61
	Aug.	0.91	3.05	0.76	0.76	0.61	0.76	1.07	0.76	1.07	0.76	1.37	1.07	0.61	0.61	0.61	0.46
Waves per minute	Jun.		4.00	6.00	6.00	6.00	6.00	4.00	4.00	5.00	6.00	6.00	6.00	7.00	7.00	4.00	5.00
	Jul.		5.00	5.00	8.00	4.00	5.00	5.00	5.00	5.00	3.00	5.00	4.00	5.00	6.00	5.00	4.00
	Aug.	4.00	5.00	4.00	5.00	5.00	8.00	4.00	6.00	5.00	4.00	4.00	5.00	5.00	5.00	5.00	5.00
Water temperature (°C)	Jun.		19.47	19.07		18.85	19.10	18.97	17.50	17.48	17.60	17.70	18.27	17.97	17.28	17.44	17.90
	Jul.		20.08	20.63	18.20	19.97	20.00	19.52	18.93	19.10	19.23	19.77	19.63	20.80	20.52	20.40	19.80
	Aug.	17.70	22.10	22.30	17.50	20.27	19.47	19.40	18.62	19.00	19.42	18.24	19.73		19.70	20.60	19.78

Table 3-2. Sediment characteristics of the beach sites surveyed in June, July, and August 1983.

VARIABLE	SURVEY	450 N	115 N	100 N	79 N	15.5 N	12 N	6.5 N	1.5 N	0.4 N	1.5 S	6.5 S	12 S	18 S	25 S	45 S	65 S
		Distance from SONGS (km)															
Grain size median (phi)	Jun.		1.16	1.42	2.33	0.93	0.45	1.19	1.03	0.78	0.32	0.71	0.69	1.89	1.57	1.83	2.34
	Jul.		1.36	1.56	2.14	1.07	1.13	1.80	1.05	0.86	0.96	1.50	0.71	1.97	1.92	1.84	2.14
	Aug.	0.36		1.55	2.67	0.67	0.88	1.09	0.79	0.98	0.88	0.75	0.99	1.81	2.29	2.11	2.28
Grain size dispersion	Jun.		0.66	0.46	0.62	0.85	0.95	0.81	1.04	0.98	1.15	0.73	0.93	0.79	0.73	0.61	0.40
	Jul.		0.55	0.49	0.55	0.78	0.87	0.52	0.75	0.75	0.85	0.56	0.71	0.73	0.70	0.56	0.55
	Aug.	1.00		0.62	0.52	0.99	0.90	0.73	0.71	1.06	0.85	0.79	0.66	0.60	0.54	0.54	0.48
Grain size skewness	Jun.		-0.00	0.07	-0.17	-0.01	0.42	0.04	-0.23	-1.21	-0.87	0.18	0.01	-0.04	0.04	0.06	0.12
	Jul.		0.13	0.00	-0.13	0.03	0.06	0.04	-0.17	-0.18	-0.21	0.07	0.12	-0.16	-0.05	-0.12	1.51
	Aug.	-0.12		0.14	-0.06	-0.10	-0.16	-0.17	-0.12	-0.23	-0.22	-0.16	-0.13	0.03	-0.03	-0.04	-0.05
Percent coarse sand	Jun.		16.04	1.92	4.31	29.82	43.18	19.26	31.56	42.01	55.07	38.57	41.34	4.26	5.20	3.34	0.09
	Jul.		5.97	1.62	7.79	18.88	21.03	0.61	24.66	33.37	30.56	3.62	37.54	3.93	6.64	0.19	14.17
	Aug.	54.48		2.45	0.71	42.30	33.56	22.83	32.85	32.97	33.83	38.08	24.99	2.86	0.84	0.49	0.15
Percent silt/clay	Jun.		2.90	2.01	2.47	1.73	2.47	2.37	2.24	1.90	2.01	2.43	1.85	1.89	2.17	1.82	2.55
	Jul.		0.74	0.87	1.30	1.71	1.33	0.93	1.03	0.95	0.87	1.28	1.13	1.08	1.46	1.41	1.75
	Aug.	1.19		1.21	2.33	1.13	1.19	1.14	0.91	1.42	0.86	1.32	0.74	1.32	2.02	1.51	1.96
Weighted cobble coverage (%)	Jun.		0.00	0.00	46.20	4.00	6.00	0.00	0.00	37.60	0.00	0.00	0.00	0.00	0.00	29.00	2.10
	Jul.		0.00	0.00	38.10	6.10	0.00	0.00	40.00	5.40	0.00	0.00	0.00	0.00	0.00	10.20	16.60
	Aug.	0.00	0.00	0.00	41.80	0.00	0.00	0.00	2.10	61.40	0.00	0.20	0.00	0.00	0.00	8.60	1.00
Cobble coverage in sand (%)	Jun.		0.00	0.00	0.00	6.67	6.00	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	10.00	6.00
	Jul.		0.00	0.00	1.50	3.33	0.00	0.00	0.00	5.00	1.67	1.67	0.00	0.00	0.83	5.83	40.00
	Aug.	0.00		0.00	0.00	0.00	0.00	0.00	0.00	23.75	0.00	36.67	5.00	0.00	0.00	3.33	0.00
Cobble coverage in water (%)	Jun.		0.00	0.00	14.50	91.67	0.00	1.67	78.33	40.00	80.00	40.00	0.00	0.00	0.00	16.00	0.00
	Jul.		0.00	2.50	76.67	38.33	71.67	0.00	70.00	85.00	86.67	66.67	25.00	0.00	0.83	23.33	56.67
	Aug.	0.00		0.00	0.00	93.33	0.00	0.00	100	50.00	100	100	41.67	0.00	0.00	0.00	0.83
Moisture (gm/gm)	Jun.		0.18	0.18	0.21	0.16	0.17	0.18	0.16	0.07	0.17	0.17	0.09	0.19	0.18	0.23	0.18
	Jul.		0.14	0.17	0.20	0.17	0.17	0.15	0.16	0.15	0.16	0.17	0.14	0.19	0.19	0.19	0.16
	Aug.	0.11	0.17	0.18	0.23	0.17	0.15	0.16	0.16	0.17	0.17	0.16	0.17	0.20	0.20	0.20	0.21
Salinity (o/oo)	Jun.		18.87	21.14	21.67	17.55	21.03	17.14	11.03	6.88	19.09	15.67	12.75	16.86	20.48	22.30	20.63
	Jul.		20.01	13.30	18.75	14.55	16.10	17.39	11.30	11.28	20.49	12.47	19.25	23.25	16.68	15.51	12.25
	Aug.	23.68	11.62	14.26	16.76	21.04	11.17	17.61	14.54	17.45	18.20	19.80	21.78	22.76	16.81	15.40	19.36
Core hole salinity (o/oo)	Aug.	27.60	26.75	27.00	26.77	27.62	26.62	26.83	27.25	26.40	26.77	26.75	26.25	27.34	23.40	24.95	26.67

Table 3-3. Measures of potential food resources in the water column and sediment at beach sites surveys in June, July, and August 1983.

VARIABLE	SURVEY	450 N	115 N	100 N	79 N	15.5 N	12 N	6.5 N	1.5 N	0.4 N	1.5 S	6.5 S	12 S	18 S	25 S	45 S	65 S
									Distance from SONGS (km)								
WATER																	
Chlorophyll (ug/l)	Jun.		1.81	0.79	1.37	0.96	0.69	0.48	2.15	1.86	1.22	2.45	1.76	2.79	1.23	2.81	1.00
	Jul.		2.31	2.56	1.07	2.62	2.60	1.78	2.73	2.04	2.42	4.41	1.67	4.28	2.92	2.05	1.40
	Aug.	1.20	0.64	2.71	0.78	0.54	0.44	0.56	0.53	0.29	0.56	0.45	0.34	0.54	0.31	0.25	0.44
Phaeophytin (ug/l)	Jun.		0.20	0.17	0.58	0.09	0.36	0.93	0.19	0.80	0.17	0.00	0.20	0.06	0.28	1.06	0.10
	Jul.		0.11	0.29	0.61	0.58	0.21	0.37	0.67	0.59	0.17	0.07	1.34	0.23	0.15	0.18	0.10
	Aug.	1.56	0.90	2.04	1.18	0.75	1.01	0.72	1.20	1.12	1.05	0.71	0.39	0.42	0.39	0.35	0.41
Ash-free dry weight (mg/l)	Jun.		7.71	2.75	5.83	15.33	8.42	3.26	3.26	2.65	2.33	29.59	25.61	2.36	4.09	6.86	1.06
	Jul.		4.45	4.75	4.22	2.63	5.40	9.32	2.70	2.00	1.88	4.87	8.11	5.20	1.54	0.91	0.59
	Aug.	1.78	3.94	2.07	2.92	4.70	3.05	2.40	1.80	2.79	4.08	10.57	3.06	2.02	3.48	2.69	1.72
Seston (mg/l)	Jun.		23.32	5.66	32.27	37.37	51.91	12.34	59.02	30.06	24.57	66.08	44.10	11.32	10.78	37.72	3.56
	Jul.		18.03	9.34	21.27	19.61	57.09	21.38	24.28	20.64	17.76	23.14	17.79	6.20	6.72	6.18	2.83
	Aug.	5.31	9.74	10.42	13.73	21.00	20.05	12.63	4.59	11.42	24.76	24.90	7.95	5.52	5.33	23.57	5.58
SEDIMENT																	
Chlorophyll (ug/cm2)	Jun.		0.12	0.12	0.33	0.06	0.06	0.60	0.11	0.13	0.02	0.11	0.12	0.43	0.11	1.12	2.08
	Jul.		0.07	0.17	0.25	0.07	0.23	0.73	0.18	0.07	0.10	0.14	0.21	0.32	0.15	1.20	1.88
	Aug.	0.09	0.03	0.76	2.46	0.03	0.09	0.33	0.05	0.17	0.09	0.08	0.04	0.30	0.40	2.80	6.47
Phaeophytin (ug/cm2)	Jun.		0.11	0.10	0.98	0.05	0.10	0.12	0.06	0.06	0.03	0.05	0.05	0.12	0.07	0.40	0.62
	Jul.		0.10	0.14	0.64	0.09	0.11	0.26	0.10	0.11	0.10	0.19	0.21	0.17	0.17	0.52	0.37
	Aug.	0.19	0.14	0.39	2.58	0.08	0.08	0.14	0.06	0.09	0.06	0.07	0.08	0.26	0.29	1.34	1.73
Total organic carbon (%)	Jun.		0.02	0.01	0.21	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01
	Jul.		0.01	0.01	0.26	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.03
	Aug.	0.02		0.01	0.48	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.00	0.01	0.01	0.01	0.01

Table 3-4. Summary of gut contents found in samples collected from beaches surveyed in June, July and August, 1983.

Survey	Variable	450 N	115 N	100 N	79 N	15.5 N	12 N	6.5 N	1.5 N	0.4 N	1.5 S	6.5 S	12 S	18 S	25 S	45 S	65 S
		Distance from SONGS (km)															
June	Number examined			8	4			1						8	8	8	8
	Foregut																
	Number full			5	0			0						6	5	1	5
	Fullness			+										*	+	+	+
	Detritus			-										-	-	-	-
	Sand			*										+	*	*	+
	Phytoplankton			+										*	+	+	*
	Zooplankton			-										-	-	-	-
	Hindgut																
	Number full			6	0			1						7	7	3	6
	Fullness			*				*						*	*	*	+
	Detritus			-				-						-	-	-	-
	Sand			*				*						+	*	*	*
	Phytoplankton			*				+						*	+	+	+
	Zooplankton			-				+						-	-	-	-
July	Number examined		8	8			7	5	1			6	7	8	8	8	8
	Foregut																
	Number full		4	1			5	1	1			2	5	5	4	4	4
	Fullness		*	*			*	+	*			*	*	+	*	+	*
	Detritus		-	-			+	-	-			-	-	-	-	-	+
	Sand		*	*			*	+	*			*	+	+	*	*	*
	Phytoplankton		+	+			+	*	+			+	*	*	+	+	+
	Zooplankton		-	-			-	-	-			-	-	-	-	-	-
	Hindgut																
	Number full		8	5			6	1	1			4	6	6	6	7	7
	Fullness		*	+			*	*	*			*	*	+	*	+	*
	Detritus		+	-			+	*	+			+	+	-	-	-	-
	Sand		*	*			*	+	*			*	+	*	*	*	*
	Phytoplankton		+	+			+	+	+			+	*	+	+	+	+
	Zooplankton		-	-			-	-	-			-	-	-	-	-	-
August	Number examined	8	1	8			7	4	1	8	4	1	8		8	8	
	Foregut																
	Number full	7	1	5			4	4	1	3	3	0	6		0	0	
	Fullness	*	*	*			*	*	*	*	*		*				
	Detritus	+	+	-			-	-	-	-	-		-				
	Sand	*	*	*			*	*	*	*	*		*				
	Phytoplankton	+	+	+			+	+	+	+	+		+				
	Zooplankton	-	-	-			-	-	-	-	-		-				
	Hindgut																
	Number full	7	1	6			6	4	1	8	4	0	8		5	6	
	Fullness	*	*	*			*	*	*	*	*		*		*	*	
	Detritus	+	*	+			+	+	+	+	+		-		+	+	
	Sand	*	+	*			*	*	*	*	*		*		*	*	
	Phytoplankton	+	+	-			+	+	+	-	+		+		-	+	
	Zooplankton	-	-	-			-	-	-	-	-		-		-	-	

* = > 50%, + = < 50%, - = none

Table 3-5. Summary of the relationships between the physical/chemical environment and selected measurements of sand crab population structure. Results were based on multiple regression analysis of all beach sites except Cabrillo Beach.

Biological Measurements	Linear Regression Equation	V *	R^2	n**	P>F
weighted mean abundance of sand crabs of all sizes in June (recruitment/colonization)	3795.0 - 7.6 seston - 1007.6 sediment chlorophyll + 3141.7 sediment phaeophytin - 637.7 grain size dispersion - 156.9 temperature - 8.0 weighted cobble coverage on sand	6	0.71	13	0.0953
weighted mean abundance of sand crabs 6-9 mm in June, July, and August (recruitment)	1757.8 - 67.6 sediment chlorophyll + 9912.3 sediment carbon - 8.2% coarse sand - 686.9 beach slope - 5.4 cobble on sand - 73.1 temperature	6	0.59	38	0.0001
% of all females with eggs or spent egg cases in July and August	-392.0 + 35.6 sediment phaeophytin - 11.9 water chlorophyll - 0.8 seston + 63.7 grain size dispersion + 20.4 temperature	5	0.73	26	0.0001
% of females > 13 mm with eggs or spent egg cases in July and August	94.1 - 5.3 water chlorophyll + 61.2 grain size dispersion -509.3 beach slope + 0.2 cobble in water - 0.6 weighted cobble coverage on sand	5	0.72	21	0.0005
% of females > 10 mm and < 13 mm with eggs or spent egg cases in July and August	-463.5 - 17.5 water chlorophyll + 1.3% coarse sand + 49.5 median grain size - 40.5 grain size skewness + 21.9 temperature + 0.5 weighted cobble coverage on sand	6	0.78	26	0.0001
% of all females with eggs in July and August	-235.7 - 1.0 seston - 15.4 sediment chlorophyll + 106.8 sediment phaeophytin + 58.0 grain size dispersion + 11.0 temperature	5	0.69	26	0.0001
% of females > 13 mm with eggs in July and August	-457.1 - 1.2 seston + 30.6 sediment phaeophytin + 135.1 grain size dispersion + 54.2% silt/clay + 18.0 temperature	5	0.74	21	0.0003
% of females > 10 mm and < 13 mm with eggs in July and August	-267.3 - 8.5 water chlorophyll - 17.1 sediment chlorophyll + 89.3 sediment phaeophytin + 20.4% silt/clay + 13.3 temperature	5	0.71	26	0.0001
% of all females with spent egg cases in August	103.6 - 10.8 July water chlorophyll - 21.2 July water phaeophytin - 2117.4 cobble on sand - 0.6 weighted cobble coverage on sand - 22.7 median grain size - 2117.4 sediment carbon	5	0.90	13	0.0036
% of females > 13 mm with spent egg cases in August	233.8 - 68.0 sediment phaeophytin - 1582.7 sediment carbon - 61.7 July water chlorophyll - 68.1 July water phaeophytin + 4.8 cobble on sand	5	0.95	8	0.0348
% of females > 10 mm and < 13 mm with spent egg cases in August	90.3 - 2022.3 sediment carbon - 5.4 July water chlorophyll - 15.6 July water phaeophytin - 23.4 median grain size + 1.4 cobble on sand	5	0.75	12	0.0420
clutch size in July and August	4.0 + 0.2% silt/clay + 0.2 median grain size - 7.5 moisture - 1.8 beach slope - 0.0 cobble on sand	5	0.75	22	0.0001
% of spent females 8-13 mm producing another clutch of eggs in August	46.5 - 63.2 water phaeophytin + 27.3 median grain size	2	0.95	7	0.0004
phosphoglucomutase activity in August	2.4 + 0.6 sediment phaeophytin + 1.1 water phaeophytin - 2.6 grain size dispersion	3	0.82	11	0.0026

V * = number of independent variables included in the selected step of the backward elimination multiple regression analysis
n** = corrected total degrees of freedom which is equal to the number of observations of the biological variable minus 1

Table 3-6. Square of the partial correlation coefficients (r^2) for the "parsimonious" regression equations.

Dependent Variable	Independent Variables
weighted mean abundance of sand crabs of all sizes in June (recruitment/colonization)	seston .92, sediment chlorophyll .22, sediment phaeophytin .17, grain size dispersion .15, temperature .21, weighted cobble coverage on sand .15
weighted mean abundance of sand crabs 6-9 mm in June, July, and August (recruitment)	sediment chlorophyll .23, sediment carbon .16, % coarse sand .45, beach slope .07, cobble on sand .08, temperature .26
% of all females with eggs or spent egg cases in July and August	sediment phaeophytin .28, water chlorophyll .32, seston .18, grain size dispersion .17, temperature .42
% of females > 13 mm with eggs or spent egg cases in July and August	water chlorophyll .14, grain size dispersion .23, beach slope .60, cobble in water .14, weighted cobble coverage on sand .15
% of females > 10 mm and < 13 mm with eggs or spent egg cases in July and August	water chlorophyll .52, % coarse sand .13, median grain size .23, grain size skewness .30, temperature .39, weighted cobble coverage on sand .15
% of all females with eggs in July and August	seston .24, sediment chlorophyll .09, sediment phaeophytin .29, grain size dispersion .14, temperature .17
% of females > 13 mm with eggs in July and August	seston .28, sediment phaeophytin .16, grain size dispersion .43, % silt/clay .33, temperature .31
% of females > 10 mm and < 13 mm with eggs in July and August	water chlorophyll .19, sediment chlorophyll .12, sediment phaeophytin .23, % silt/clay .12, temperature .22
% of all females with spent egg cases in August	July water chlorophyll .56, July water phaeophytin .55, cobble on sand .72, weighted cobble coverage on sand .50, median grain size .75, sediment carbon .73
% of females > 13 mm with spent egg cases in August	sediment phaeophytin .85, sediment carbon .47, July water chlorophyll .76, July water phaeophytin .75, cobble on sand .78
% of females > 10 mm and < 13 mm with spent egg cases in August	sediment carbon .59, July water chlorophyll .06, July water phaeophytin .15, median grain size .48, cobble on sand .47
clutch size in July and August	% silt/clay .17, median grain size .32, moisture .43, beach slope .29, cobble on sand .38
% of females 8-13 mm producing another clutch of eggs in August	water phaeophytin .77, median grain size .69
phosphoglucomutase activity in August	sediment phaeophytin .29, water phaeophytin .65, grain size dispersion .51

Table 3-7. Results of Cook's D analyses for all beach sites included in each "parsimonious" multiple regression. Note that significant Cook's D's were found only in the regression on percent of Total Females with Spent Egg Cases. For this regression beach sites at 6.5 S and 0.4 N had significant Cook's D's of 19.3 and 18.2 respectively. See text section 3.2.3.1.5 and Table 3-11 for further detail.

Biological Variable	Minimum	Median	Maximum	Value* of Significant Cook's D
weighted mean abundance of sand crabs of all sizes in June (recruitment/colonization)	0.000	0.035	0.796	4.99
weighted mean abundance of sand crabs 6-9 mm in June, July, and August (recruitment)	0.000	0.007	0.458	2.82
% of all females with eggs or spent egg cases in July and August	0.002	0.020	0.268	3.09
% of females > 13 mm with eggs or spent egg cases in July and August	0.000	0.022	0.618	3.34
% of females > 10 mm and < 13 mm with eggs or spent egg cases in July and August	0.000	0.008	0.546	3.01
% of all females with eggs in July and August	0.000	0.008	1.699	3.09
% of females > 13 mm with eggs in July and August	0.000	0.035	0.648	3.34
% of females > 10 mm and < 13 mm with eggs in July and August	0.000	0.014	1.874	3.09
% of all females with spent egg cases in August	0.004	0.054	19.298	4.99
% of females > 13 mm with spent egg cases in August	0.001	0.354	11.147	14.70
% of females > 10 mm and < 13 mm with spent egg cases in August	0.002	0.048	2.292	5.12
clutch size in July and August	0.000	0.009	0.438	3.28
% of spent females 8-13 mm producing another clutch of eggs in August	0.026	0.140	0.414	7.76
phosphoglucomutase activity in August	0.000	0.059	4.471	5.05

* F statistic (p, n-p, 1- ; where n = number of observations, p = number of independent variables + 1, and = .95 two tails) from Draper and Smith, 1981, p. 170.

Table 3-8. Cook's D determinations of whether the relationship between the biological and environmental variables developed from beach sites > 1.5 km from SONGS could predict the biology at beach sites near SONGS. Significantly high Cook's D values (underlined) signify poor predictions. See Appendix D (section D.4) for details of interpretation. Multiple Cook's D values at a beach site occur because data from June, July and August, or from July and August were included in some multiple regressions. Dots indicate that too few sand crabs in that particular category were available to reasonably estimate the biological variable from that beach site and survey(s).

Biological Measurements	Regression on all beaches except 1.5 km S & 0.4 km N Cook's D at 1.5 km N	Regression on all beaches except 1.5 km N & 1.5 km S Cook's D at 0.4 km N	Regression on all beaches except 1.5 km N & 0.4 km N Cook's D at 1.5 km S	Value* of significant Cook's D
weighted mean abundance of sand crabs of all sizes in June (recruitment/colonization)	0.028	0.003	0.349	6.85
weighted mean abundance of sand crabs 6-9 mm in June, July, and August (recruitment)	0.022 0.004 0.006	0.030 0.002 0.484	0.075 0.002 0.002	2.82
% of all females with eggs or spent egg cases in July and August	0.005 0.015	0.002 0.028	0.017 0.001	3.28
% of females > 13 mm with eggs of spent egg cases in July and August	. .	.	0.050 0.045	3.60
% of females > 10 mm and < 13 mm with eggs or spent egg cases in July and August	1.769 0.007	0.000 4.399	0.011 0.010	3.22
% of all females with eggs in July and August	0.000 0.000	0.002 0.029	0.012 0.002	3.28
% of females > 13 mm with eggs in July and August	. .	. 0.000	0.039 0.032	3.60
% of females > 10 mm and < 13 mm with eggs in July and August	0.052 0.001	0.005 0.000	0.007 0.006	3.28
% of all females with spent egg cases in August	0.006	12.051	0.003	6.85
% of females > 13 mm with spent egg cases in August	.	.	0.255	14.70
% of females > 10 mm and < 13 mm with spent egg cases in August	0.002	0.492	0.062	6.98
clutch size in July and August	0.002 0.028	. 0.000	. 0.120	3.41
% of spent females 8-13 mm producing another clutch of eggs in August	.	0.214	0.184	9.98
phosphoglucomutase activity in August	.	0.190	0.084	6.23

*F statistic (p, n-p, 1- ; where n = number of observations, p = number of independent variables plus 1, and = .95 two tails) from Draper and Smith, 1981, p. 170.

Table 3-9. Summary of size frequency distribution of male sand crabs at beach sites surveyed in June, July, and August 1983.

Beach site	JUNE				JULY				AUGUST			
	Range of sieves with male sand crabs	Number of size modes	Sieves with peak abundance	% of males in sieves with peak abundance	Range of sieves with male sand crabs	Number of size modes	Sieves with peak abundance	% of males in sieves with peak abundance	Range of sieves with male sand crabs	Number of size modes	Sieves with peak abundance	% of males in sieves with peak abundance
450 km N		not sampled				not sampled			5-15	3	7-8; 10-12	40; 35
115 km N	5-10	2	5-6	81	5-10	2	6-7; 5-7	75; 97	5-8	1	6-7	83
100 km N	5-11	3	5-7	95	5-11	2	5-7	96	5-12	2	6-7; 5-7	69; 80
79 km N	5-10	2	5	93	5-9	2	5	91	5-7	1	5	80
15.5 km N	5-7	1	5-7	100	5-6	1	5-6	100	5-7	1	5-7	100
12 km N	5-7	1	5-7	100	5-7	1	5	81	5-8	2	5-6	79
6.5 km N	5-9	2	5-6	90	5-10	2	5-6	89	5-9	2	5-7	97
1.5 km N	5-6	1	5	99	5-7	1	5-7	100	5-7	1	5-7	100
0.4 km N	5-6	1	5-6	100	5-7	1	5	85	5-7	1	5	89
1.5 km S	5-8	2	5-7	83	5-9	2	5-6	89	5-10	2	6-7	80
6.5 km S	5-11	3	6; 5-7	60; 86	5-10	2	5-6	92	5-11	2	6-7	87
12 km S	5-9	2	5-6	92	5-9	2	5-6	91	5-8	1	6; 5-7	57; 99
18 km S	5-8	1	6; 5-7	70; 99	5-10	2	5-6	98		not sampled		
25 km S	5-9	2	5-6	95	5-10	2	5-7	98	5-12	2	6-7	82
45 km S	5-10	3	5	82	5-9	2	5-6	94	5-8	1	5-6	99
65 km S	5-9	2	5-6	93	5-9	1	5-7	95	5-10	2	5-7	88

Table 3-10. Results of ANOVA and SNK analyses that compared beach sites with respect to the fraction of the female populations that were reproductive. Females with eggs or spent egg cases were defined as reproductive. The three size classes were analyzed separately. Sites within 12 km of SONGS were identified as near-SONGS sites on this table.

SIZE CLASS	SURVEY JUNE	JULY	AUGUST
> 13mm	non-SONGS sites not different from others (Figure 3-23a)	no females at near-SONGS sites (see Figure 3-24a)	sites with females, near-SONGS sites significantly lower (Figure 3-25a)
> 10mm-13mm	no reproductive females (not tested) (Figure 3-23b)	near-SONGS sites not different from others (Figure 3-24b)	near-SONGS sites significantly lower except 0.4 km N (Figure 3-25b)
7mm-10mm	no reproductive females (not tested)	no reproductive females at most sites (not tested)	near-SONGS sites tend to be lower, except 0.4 km N (Figure 3-25c)

Table 3-11. Results of excluding influential observations (significant Cook's D) from the "parsimonious" regression equation of the percent of all females with spent egg cases in August.

	Regression Equations			
	Parsimonious	Without 0.4 km N	Without 6.5 km S	Without 0.4 km N and 6.5 km S
Statistics				
n/error df	7/7	7/6	7/6	7/5
R^2	0.90	0.92	0.90	0.91
adjusted R^2	0.81	0.84	0.79	0.81
P > F	0.0036	0.0048	0.01	0.015
F for Cook's D	4.99	5.70	5.70	6.85
Cook's D > F	19.30(6.5km S) 18.22(0.4km N)	6.88(6.5km S)	15.03(0.4km N)	-
Regression Coefficients*				
sediment carbon	-2117.4	-2071.3	-1700.0	-1843.7
July water chlorophyll	-10.8	-11.4	-9.5	-10.7
July water phaeophytin	-21.2	-21.5	-25.2	-23.7
median grain size	-22.7	-20.8	-23.2	-21.2
cobble on sand	2.2	2.1	3.8	3.0
weighted cobble coverage on sand	-0.6	-1.8	-1.2	-2.1

* regression coefficients = "parameter estimates" shown on regression outputs in Appendix D.

Table 3-12. The occurrence of spent egg cases among bright-orange eggs in egg masses examined for the analysis of clutch size. Site groupings used in the analysis are shown. Data shown are pooled for all three surveys.

Beach site	Number of egg masses examined	Number of egg masses with spent egg cases: several*	few**	very few	none
450 km N***	39	0	0	0	39
NORTH					
115 km N	16	4	3	0	9
100 km N	59	11	1	11	36
79 km N	3	0	0	0	3
NEAR					
15.5 km N	0	-	-	-	-
12 km N	14	3	4	1	6
6.5 km N	10	2	1	2	5
1.5 km N	2	0	2	0	0
0.4 km N	29	1	16	9	3
1.5 km S	4	0	2	2	0
6.5 km S	7	0	4	1	2
12 km S	29	1	5	5	18
SOUTH					
18 km S	47	1	0	1	45
25 km S	97	1	0	2	94
45 km S	83	0	0	1	82
65 km S	75	0	0	0	75

* egg masses with several spent egg cases were not included in the analysis of clutch size.
** groups "several" and "few" were combined in the contingency analysis of clutch size versus beach group
*** 450 km N was excluded from the contingency analysis

Table 3-13. Summary of the total percent of female sand crabs with spent egg cases at beach sites examined June - October, 1983. A blank indicates that the beach was not sampled on that date.

Survey	Beach study Sites (Distance from SONGS in km)														
	65S	45S	25S	18S	12S	6.5S	1.5S	0.4N	1.5N	6.5N	12N	15.5N	79N	100N	115N	450N
June 11-15	0.0	0.0	0.4	0.0	7.7	38.8	25.0**	0.0**	0.0	4.8	0.0	0.0	0.2	1.4	0.3	
July 2-5	0.3	0.3	0.4	0.1	0.5	0.3	2.1	1.9	2.2	0.6	1.0	0.0	0.0	2.0	1.8	
August 2-6	1.8	1.9	6.9	0.0**	35.4	30.3	42.5	33.5	16.3	26.1	31.1	8.3	0.0	17.1	25.0***	1.5
August 30 - Sept. 3		7.7					15.4*	25.4		25.5				51.8		
Sept. 9-10	11.1	13.3				12.0		0.0		36.0				11.9	32.4	
Sept. 23-24	7.0	1.6				5.9				10.2				10.5	20.9	
October 5-6	0.0	0.0														
October 19		0.0														

* Only 26 sand crabs were found on August 31, 1983. The beach remained narrow, steep and was comprised of a high percentage of cobble. Since it was unlikely that we would subsequently find sufficient sand crabs at this site our efforts were shifted instead to 6.5 km south.

** Fewer than 10 females were collected on the beach.

*** Fewer than 10 females were collected on the beach by MEC; however Wenner and Siegel collected greater numbers at this time on this beach and reported percentages higher than 5%.

Table 3-14. The percentage of females larger and smaller than 13 mm in the reproductive population according to the developmental stage of their egg masses for June, July, and August 1983.

Beach site	June				July				August				August			
	Females > 13 mm				Females > 13 mm				Females > 13 mm				Females > 10 mm to 13 mm			
	Developmental Stage of Eggs				Developmental Stage of Eggs				Developmental Stage of Eggs				Developmental Stage of Eggs			
	Bright-Orange	Burnt-Orange	Gray	Spent	Bright-Orange	Burnt-Orange	Gray	Spent	Bright-Orange	Burnt-Orange	Gray	Spent	Bright-Orange	Burnt-Orange	Gray	Spent
450 km N	NS	NS	NS	NS	NS	NS	NS	NS	78	15	3	4	-	-	-	-
115 km N	0	0	0	100*	19	0	14	66	+	+	+	+	+	+	+	+
100 km N	38	4	0	58	47	4	0	49	52	17	12	19	63	0	25	13
79 km N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15.5 km N	-	-	-	-	-	-	-	-	-	-	-	-	80	0	0	20
12 km N	-	-	-	-	-	-	-	-	-	-	-	-	6	6	0	88
6.5 km N	13*	0	0	88*	-	-	-	-	9	0	0	91	1	0	0	99
1.5 km N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.4 km N	-	-	-	-	-	-	-	-	-	-	-	-	28	3	0	69
1.5 km S	-	-	-	-	-	-	-	-	4	0	0	96	1	0	0	99
6.5 km S	0	0	0	100	-	-	-	-	-1	0	-1	99	0	0	0	100
12 km S	-	-	-	-	-	-	-	-	33	0	4	63	22	0	2	76
18 km S	100*	-	-	-	93	7	-1	0	+	+	+	+	+	+	+	+
25 km S	78	16	2	5	92	4	3	1	67	25	3	5	51	36	3	11
45 km S	80	12	8	0	90	9	1	1	75	19	4	2	83	13	3	1
65 km S	83	17	0	0	82	16	0	2	87	5	6	2	77	11	10	2

NS = not sampled

+ = not fully sampled because of weather or beach disturbance (see section 2.1.3.1)

* = percentage based on less than 10 reproductive females

Note: females between 10 mm and 13 mm in June and July were not shown here because fewer than 10 reproductive females were collected at all sites near and north of SONGS (see Appendix F, Table F-1).

Table 3-15. External egg condition and corresponding internal histological ovarian condition in female sand crabs with repeated egg production.

	External Egg Condition	Histological Condition
1)	Bright, newly extruded immature egg	Ovaries contain primary oocytes, yolk deposition may be in progress
2)	Burnt, more developed, eyespots becoming visible	Developing vitellogenic oocytes
3)	Greyish-burnt, between burnt and grey	Developing vitellogenic oocytes
4)	Grey (or brown) more developed than burnt, eyespots very apparent	Developing vitellogenic oocytes
5)	Spent egg cases	Yolk-filled mature oocytes, may be ready to be released

Table 3-16. Adjusted ranks of beach sites for selected biological variables. Asterisks (*) denote variables that were identified as being different at beach sites near SONGS than at other beach sites. Because of the question of the validity of PGM activity as a variable, results are given with and without its inclusion.

Biological Variable	Survey	Adjustment Factor	Distance from SONGS 115N	100N	79N	15.5N	12N	6.5N	1.5N	0.4N	1.5S	6.5S	12S	18S	25S	45S	65S
Weighted mean abundance total crabs > sieve 4	June	15/15	14.0	13.0	8.0	3.0	4.0	12.0	7.0	1.0	2.0	9.0	6.0	11.0	15.0	10.0	5.0
	July	15/15	14.0	10.0	1.0	2.0	9.0	13.0	3.0	8.0	6.0	12.0	7.0	5.0	15.0	11.0	4.0
	August	15/15	6.0	5.0	2.0	3.0	8.0	13.0	4.0	14.0	11.0	15.0	7.0	1.0	12.0	10.0	9.0
Size																	
mean maximum mode males	June	15/14	15.0	11.3	4.3	1.1	2.1	10.7	3.2		9.6	13.9	6.4	5.4	12.9	7.5	8.6
	July	15/15	14.0	13.0	7.0	3.0	2.0	9.0	4.0	1.0	5.0	11.0	10.0	6.0	12.0	15.0	8.0
	August	15/14	8.6	13.9	2.1		4.3	7.5	1.1	5.4	12.9	11.8	6.4		9.6	3.2	10.7
median length reproductive females	August	15/11		15.0		4.1	2.7	6.8		1.4	9.5	12.3	8.2		10.9	5.5	13.6
Reproduction																	
% females with eggs > 13 mm	August	15/ 8*		9.4				5.6			3.8	1.9	7.5		11.2	15.0	13.3
10-13 mm	July	15/13	2.3	5.8			8.1	2.3	10.4	6.9	4.6	2.3	12.7	13.8	9.2	15.0	11.5
10-13 mm	August	15/11*		9.5		10.9	5.5	4.1		8.2	2.7	1.4	6.8		13.6	15.0	12.3
7-10 mm	August	15/12			1.3	13.8	8.8	5.0	6.3	10.0	7.5	3.8	2.5		12.5	15.0	11.3
% females with spent egg cases > 13 mm	August	15/ 8*		9.4				5.6			3.8	1.9	7.5		11.2	13.3	15.0
10-13 mm	July	15/13	10.4	6.9			2.3	9.2	1.2	3.5	4.6	5.8	13.8	13.8	8.1	11.5	13.8
10-13 mm	August	15/11*		12.3		9.5	4.1	6.8		1.4	5.5	8.2	2.7		10.9	15.0	13.6
7-10 mm	August	15/12			15.0	3.8	2.5	8.8	6.3	1.3	5.0	11.3	10.0		13.8	12.5	7.5
eggs/clutch	July	15/11	6.8	2.0			10.9	10.9	2.0			4.1	6.8	10.9	14.3	14.3	6.8
	August	15/12*	6.9	15.0			1.3	11.3	6.9	3.1	3.1	6.9	6.9		13.1	10.0	13.1
% spent females with internal eggs 8-13 mm	August	15/ 9*		11.7			6.7	8.3		2.5	2.5	5.0	10.0		13.3	15.0	
Phosphoglucomutase (PGM) enzyme activity	August	15/12*		15.0	2.5	1.3	10.0	8.8		3.8	5.0	7.5	6.3		11.3	12.5	13.8
Median Rank without PGM			9.5	10.7	3.2	3.4	4.2	8.6	4.0	3.3	5.0	7.6	7.0	8.4	12.3	12.9	11.3
Median Rank with PGM			9.5	11.3	2.5	3.0	4.3	8.8	4.0	3.5	5.0	7.5	7.0	8.4	12.0	12.5	11.4

Table 3-17. SONGS water circulation* for the period April-August 1977, 1980-1983.

Month	1977	1980	1981	1982	1983
April	5.06	2.27	4.38	7.71	6.89
May	5.22	0.94	5.61	5.91	17.66
June	5.07	3.01	7.11	6.38	18.86
July	5.36	2.75	3.49	11.82	22.41
August	5.41	1.00	3.11	12.54	23.49
Σ volume for Units 1, 2, & 3 (April-August)	26.12	9.97	23.70	44.36	89.31
Σ volume for Unit 1 (April-August)	26.12	9.97	15.27	5.14	7.92
Σ volume of Units 1, 2, & 3 expressed as a fraction of the Units' full capacity**	0.16	0.06	0.14	0.27	0.54
Σ volume of Unit 1 expressed as a fraction of Unit 1's full capacity***	0.95	0.36	0.56	0.19	0.29

* Volumes are $10^7 m^3$

** Units 1, 2, and 3 full capacity = $1.09 \times 10^7 m^3$/day or
$166.8 \times 10^7 m^3$/April-August

*** Unit 1 full capacity = $1.8 \times 10^6 m^3$/day or
$27.5 \times 10^7 m^3$/April-August

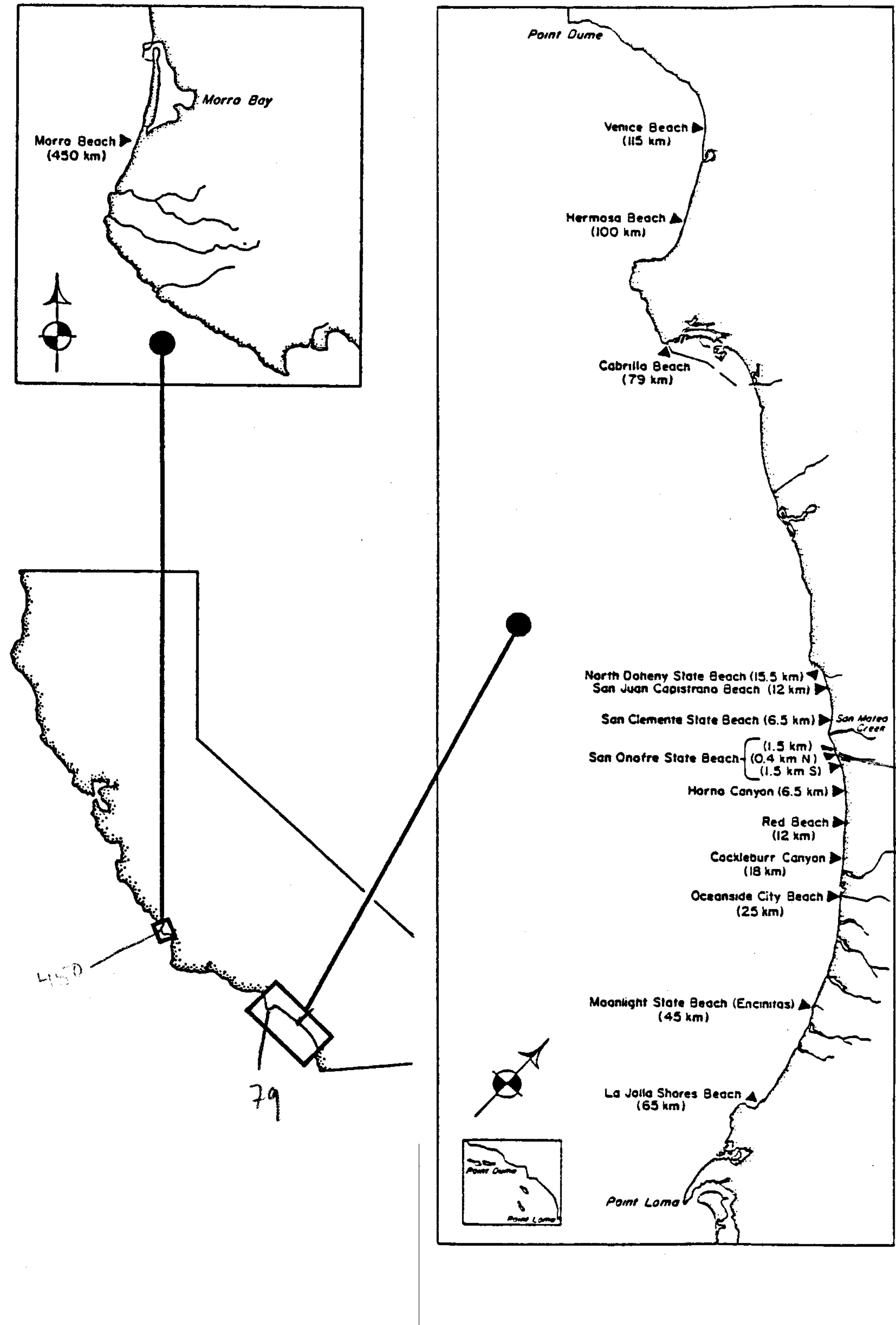


Figure 2-1. Map of the 16 sand crab survey beach sites relative to SONGS. The Morro Bay site was only sampled in August. The position of SONGS is indicated by the arrow.

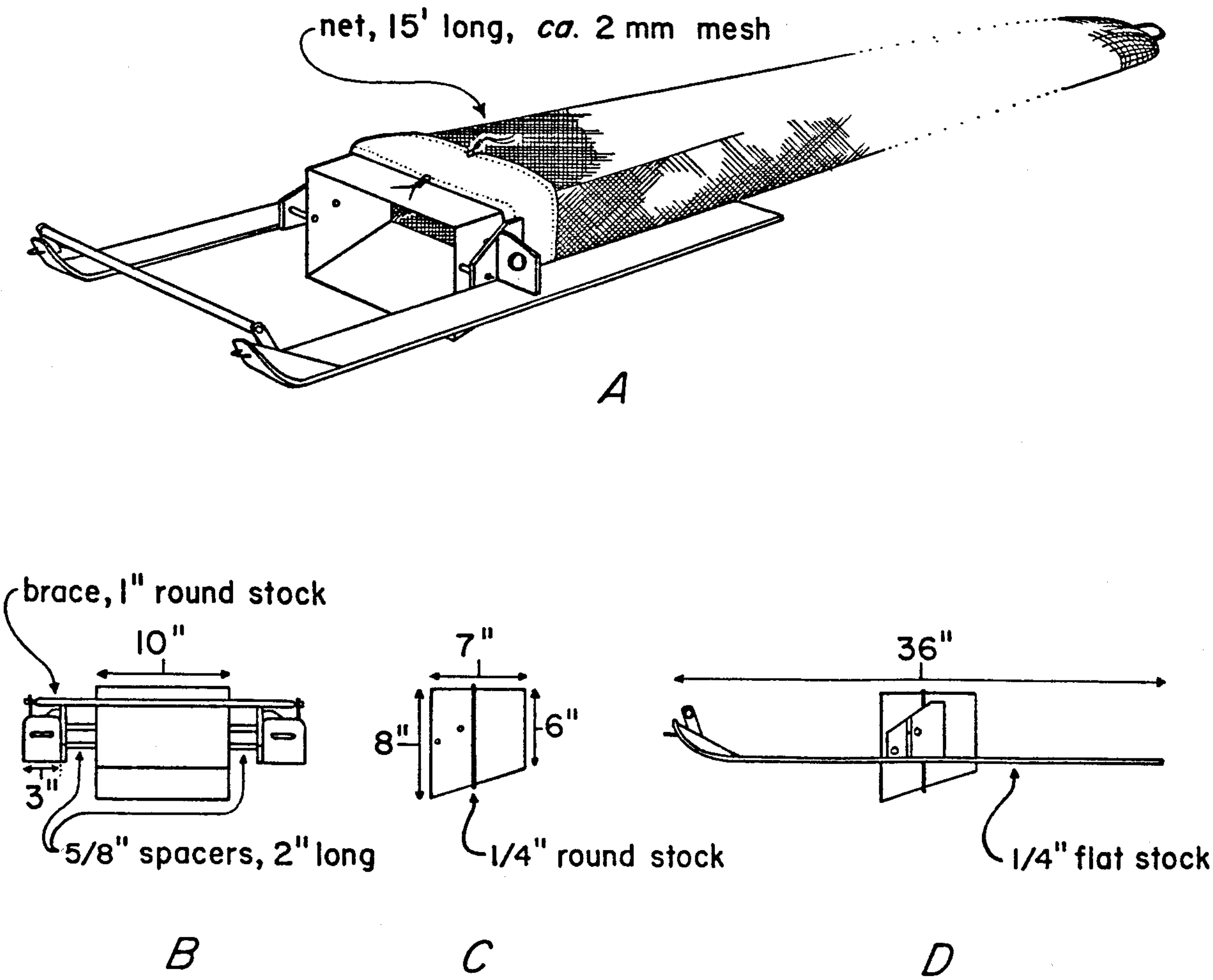


Figure 2-2. Final design of the sand crab sampling sled.

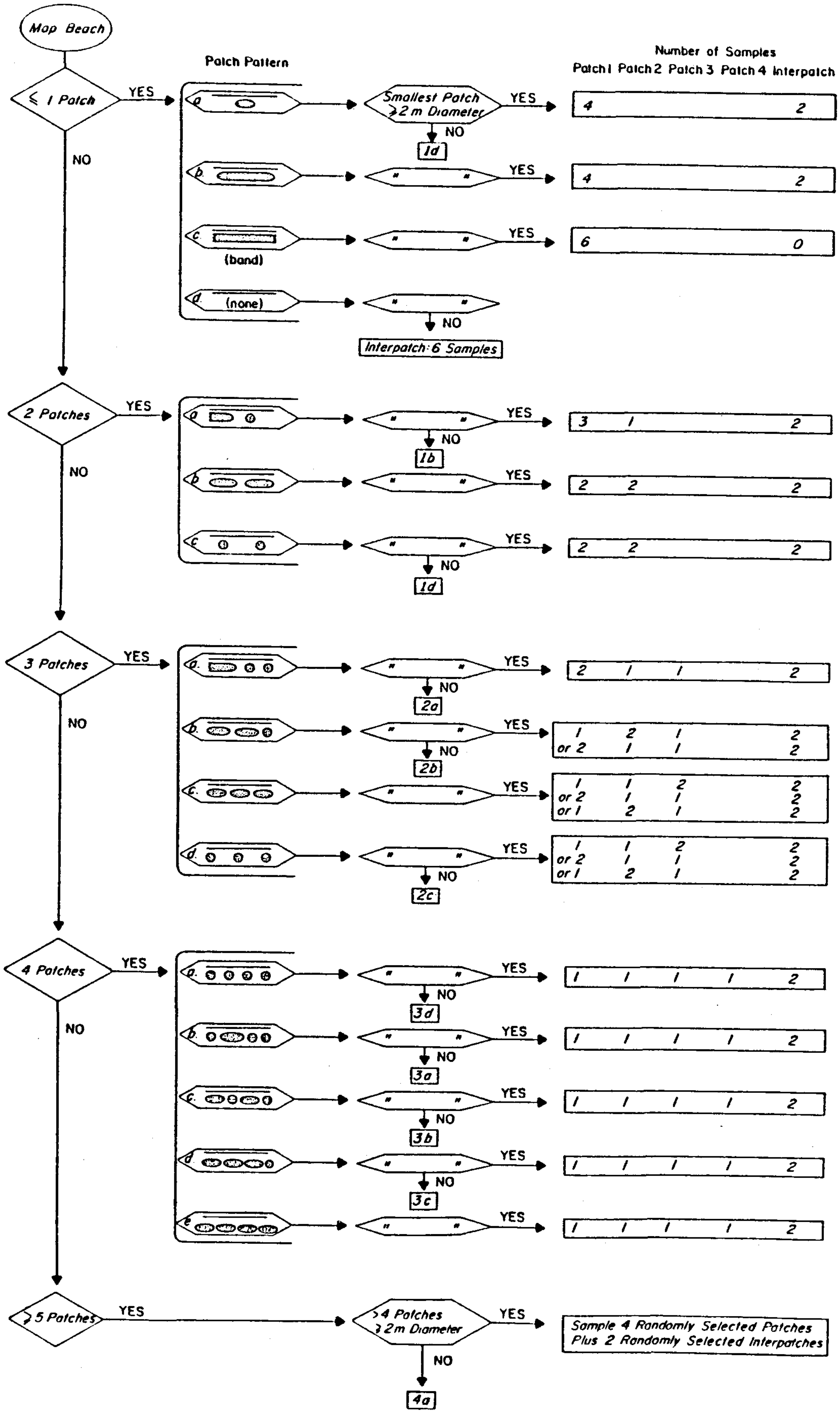
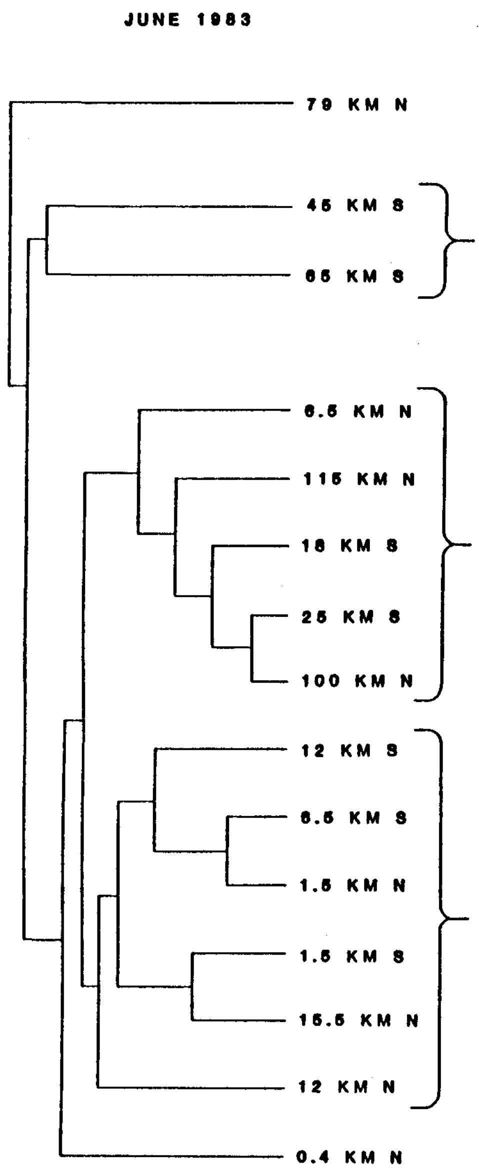


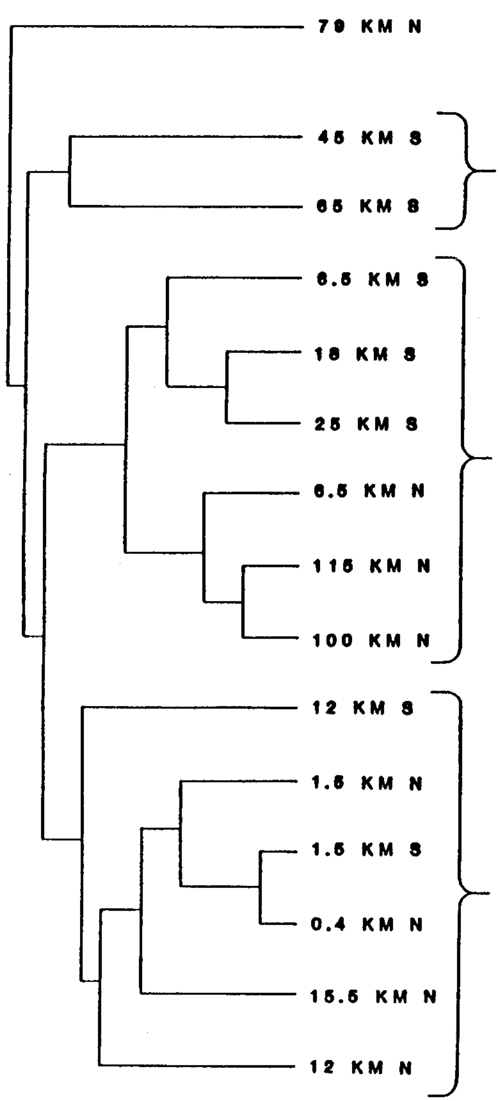
Figure 2-3. Selection contingencies for the determination of which patches are sampled on a beach.



SEDIMENT TYPE	SEDIMENT FOOD	WATER FOOD	WATER SESTON
fine grains, low dispersion, high moisture, moderate cobble,	moderate chlorophyll, high phaeophytin, very high carbon	moderate chlorophyll, moderate phaeophytin	moderate-high
fine grains, low dispersion, high moisture, low-moderate cobble	high chlorophyll, moderate-high phaeophytin	high chlorophyll and phaeophytin at 45 km S; low at 65 km S	moderate-high at 45 km S, low at 65 km S
moderate-fine grains, low-moderate dispersion, high moisture, no cobble, (except very low cobble at 6.5 km N)	low-moderate chlorophyll and phaeophytin	low chlorophyll and high phaeophytin at 6.5 km N; moderate chlorophyll and low phaeophytin at 18 km S, 25 km S, 115 km S; low chlorophyll and phaeophytin at 100 km N	low-moderate
coarse grains, moderate-high dispersion, low-moderate moisture, moderate-high cobble (except no cobble at 12 km S)	low chlorophyll and phaeophytin	moderate chlorophyll and low phaeophytin at 12 km S, 6.5 km S, 1.5 km N; low chlorophyll and phaeophytin at 12 km N, 15.5 km N, 1.5 km S	moderate-high
coarse grains, high dispersion, low moisture, high cobble	low chlorophyll and phaeophytin	moderate chlorophyll and high phaeophytin	moderate-high

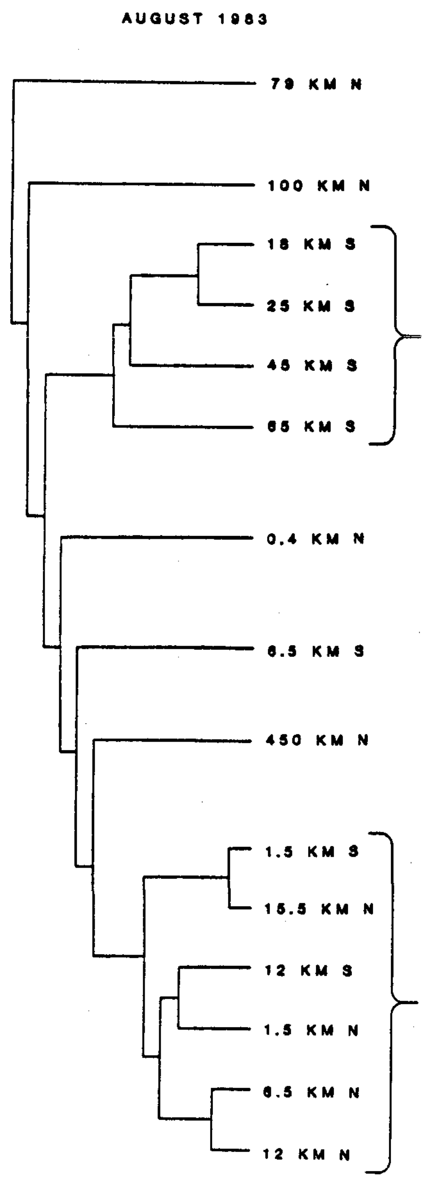
Figure 3-1. Summary of cluster analysis of *beach* sites in June based on selected physical and chemical measurements of the environment.

JULY 1983



SEDIMENT TYPE	SEDIMENT FOOD	WATER FOOD	WATER SESTON
fine grains, low dispersion, high moisture, high cobble	low-moderate chlorophyll, high phaeophytin, very high carbon	low chlorophyll, moderate phaeophytin	moderate-high
fine grains, low dispersion, moderate-high moisture, moderate-high cobble	high chlorophyll, moderate-high phaeophytin	low-moderate chlorophyll and phaeophytin	low
moderate-fine grains, low-moderate dispersion, moderate-high moisture, very little cobble (except high cobble at 6.5 km S)	low-moderate chlorophyll and phaeophytin	moderate-high chlorophyll, low-moderate phaeophytin	low at 100 km N, 18 km S, 25 km S; moderate at 115 km N, 6.5 km N, 6.5 km S
coarse grains, high dispersion, moderate moisture, moderate-high cobble	low chlorophyll and phaeophytin	moderate-high chlorophyll, moderate-high phaeophytin at 12 km S, 15.5 km N, 1.5 km N, 0.4 km N; low phaeophytin at 12 km N, 1.5 km S	moderate-high

Figure 3-2. Summary of cluster analysis of beach sites in July based on selected physical and chemical measurements of the environment.



SEDIMENT TYPE	SEDIMENT FOOD	WATER FOOD	WATER SESTON
fine grains, low dispersion, high moisture, moderate cobble	high chlorophyll and phaeophytin, very high carbon	low chlorophyll, high phaeophytin	low-moderate
moderate grains, low dispersion, high moisture, no cobble	moderate-high chlorophyll and phaeophytin	high chlorophyll and phaeophytin	low
fine-moderate grains, low dispersion, high moisture, low cobble	moderate chlorophyll and phaeophytin at 18 and 25 km S; very high chlorophyll and phaeophytin at 45 and 65 km S	low chlorophyll, moderate phaeophytin	low (except moderate at 45 km S)
coarse grains, high dispersion, moderate moisture, high cobble	low chlorophyll and phaeophytin	low chlorophyll, high phaeophytin	low
coarse grains, moderate dispersion, moderate moisture, high cobble	low chlorophyll and phaeophytin	low chlorophyll, moderate phaeophytin	moderate
very coarse grains, high dispersion, low moisture, pea gravel	low chlorophyll and phaeophytin	moderate chlorophyll, high phaeophytin	low
coarse grains, moderate-high dispersion, moderate moisture, no cobble at 6.5 and 12 km N, high cobble at 1.5 km N, 1.5 km S, 12 km S, 15.5 km N	low chlorophyll and phaeophytin (except moderate at 6.5 km N)	low chlorophyll, moderate-high phaeophytin	low at 1.5 km N, 6.5 km N, 12 km S, moderate at 12 km N, 15.5 km N, 1.5 km S

Figure 3-3. Summary of cluster analysis of beach sites in August based on selected physical and chemical measurements on the environment.

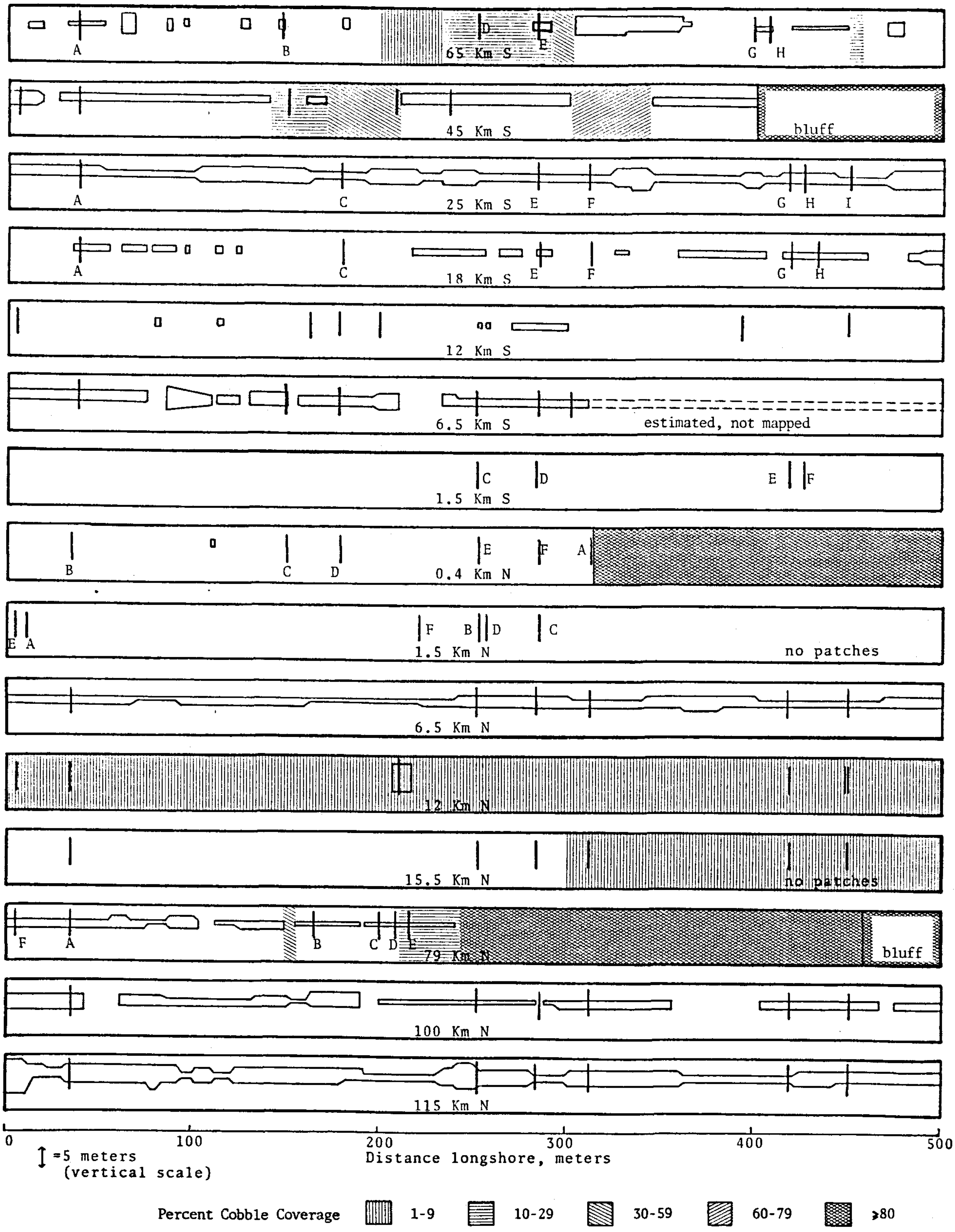


Figure 3-4. Beach map of sand crab patches (enclosed areas), cobble areas (shaded areas), and sled tow locations (vertical lines) for beach sites sampled in June 1983. Sled tow locations were designated by letters A-F, which read left to right unless otherwise indicated.

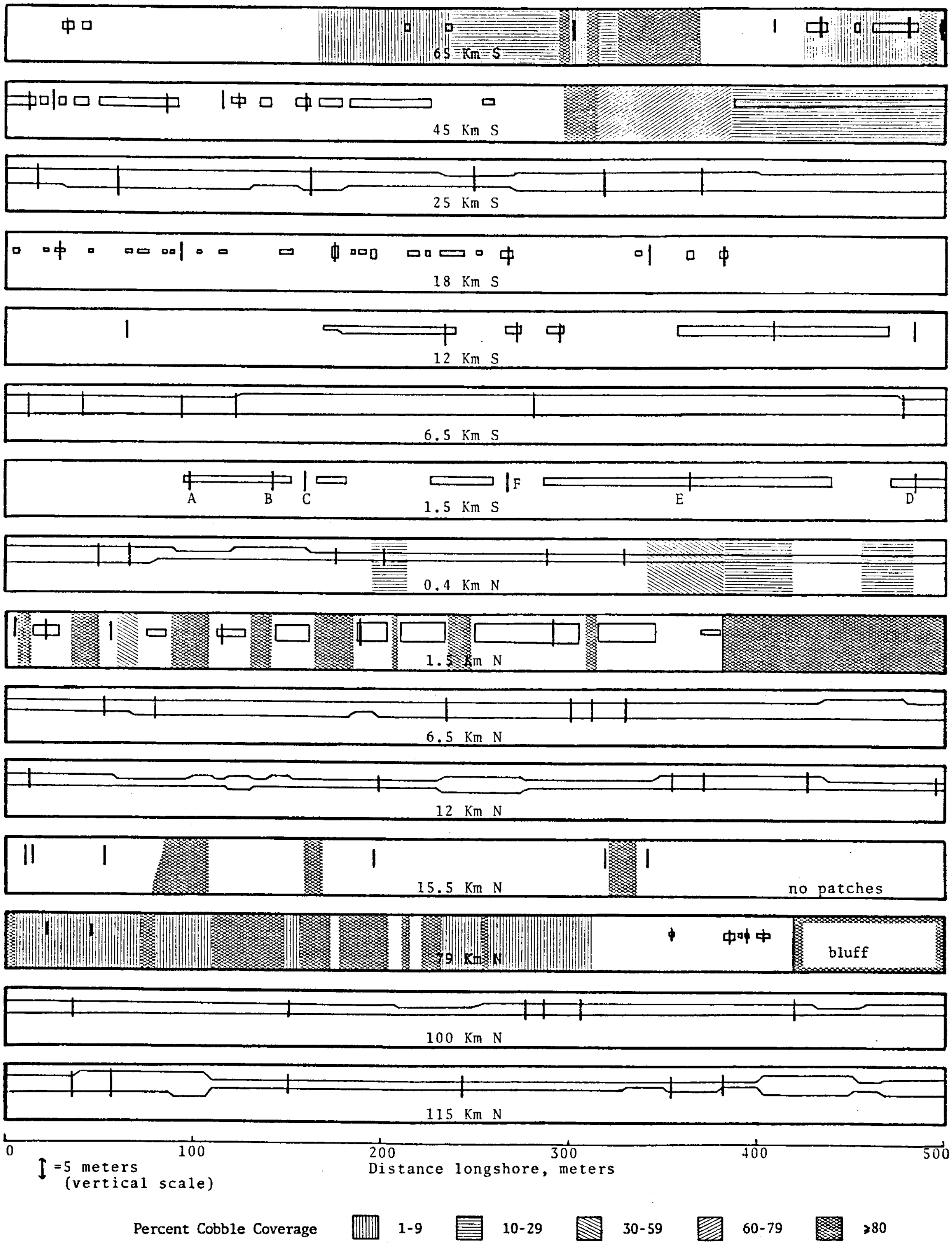


Figure 3-5. Beach map of sand crab patches (enclosed areas), cobble areas (shaded areas), and sled tow locations (vertical lines) for beach sites sampled in July 1983. Sled tow locations were designated by letters A-F, which read left to right unless otherwise indicated.

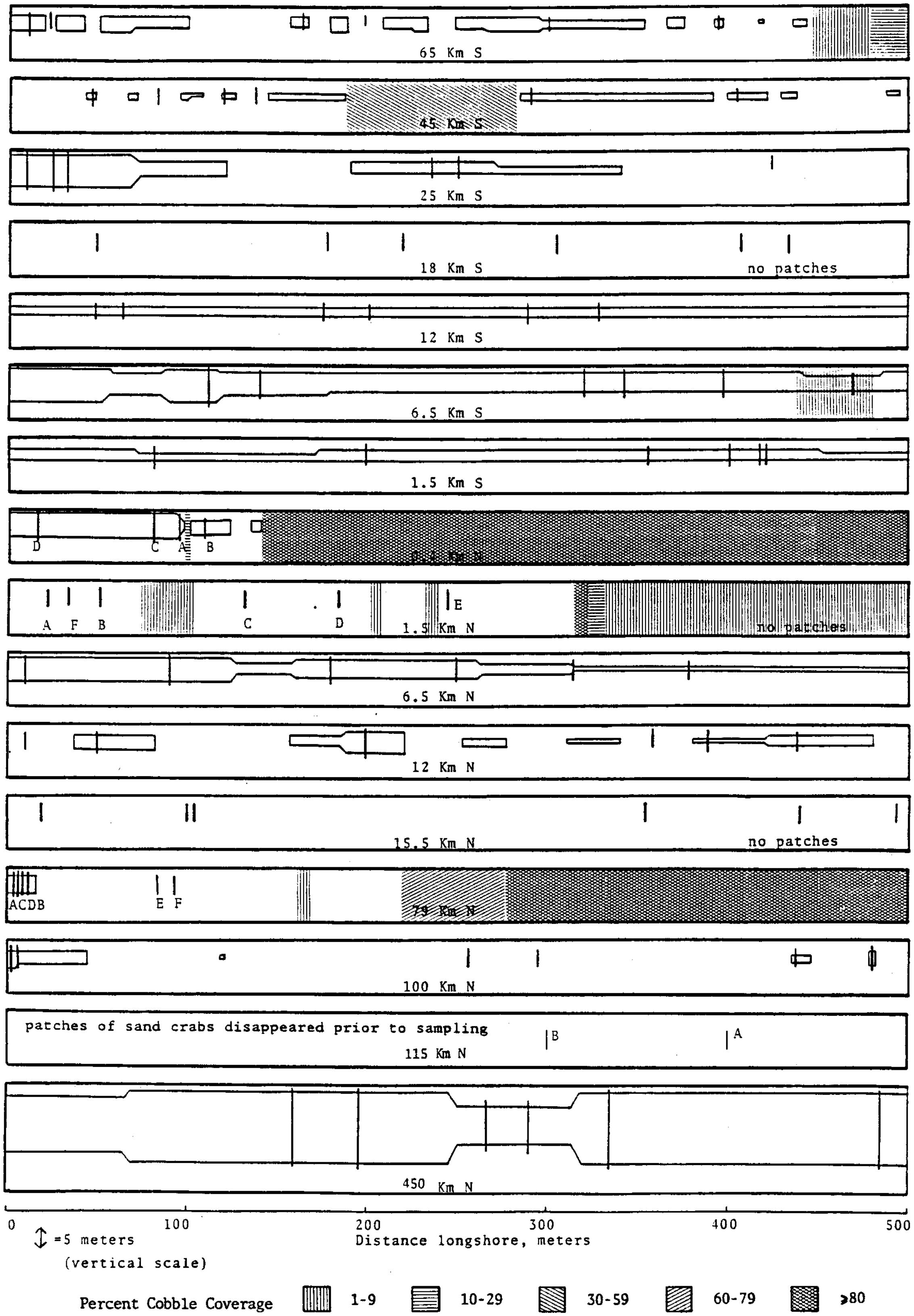
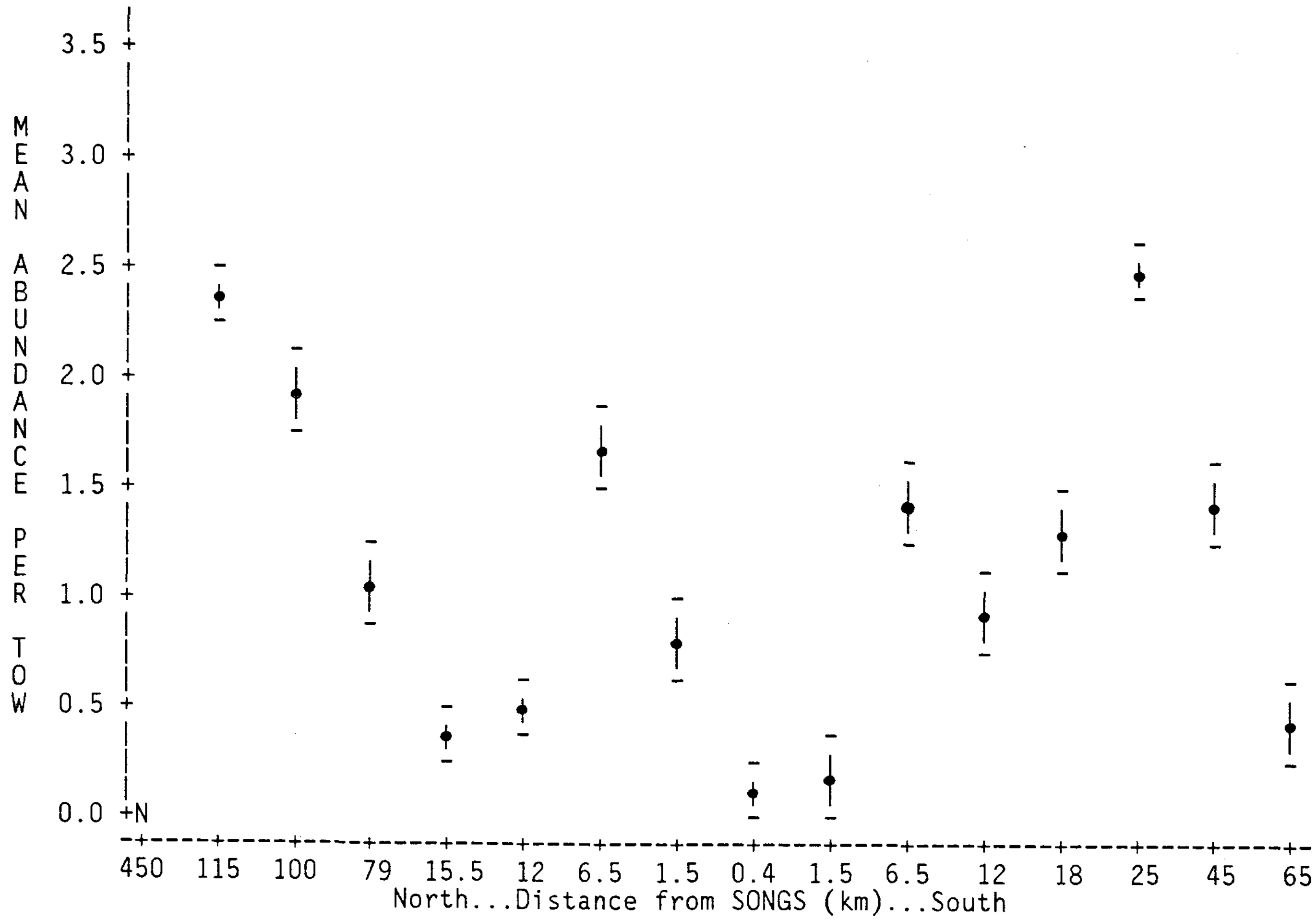


Figure 3-6. Beach map of sand crab patches (enclosed areas), cobble areas (shaded areas), and sled tow locations (vertical lines) for beach sites sampled in August 1983. Sled tow locations were designated by letters A-F, which read left to right unless otherwise indicated.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF MALE SAND CRABS
JUNE 1983



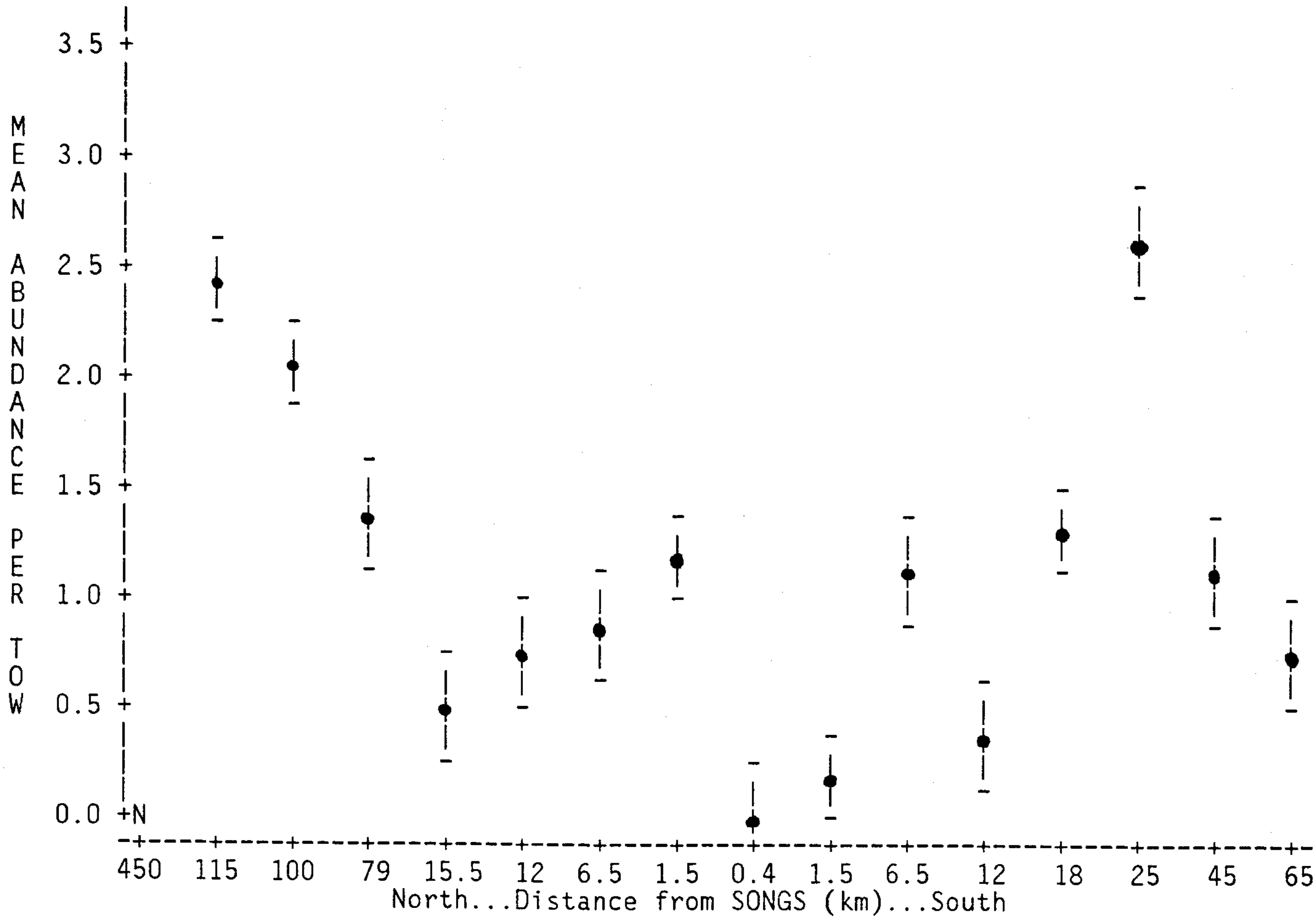
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING		MEAN	BEACH
A		2.495	25 km S
A		2.374	115 km N
B		1.956	100 km N
C		1.650	6.5 km N
C	D	1.446	45 km S
C	D	1.390	6.5 km S
	D	1.285	18 km S
E		1.038	79 km N
E		0.964	12 km S
E		0.843	1.5 km N
F		0.497	12 km N
F		0.452	65 km S
F	G	0.381	15.5 km N
F	G	0.211	1.5 km S
	G	0.100	0.4 km N

Figure 3-7a. Weighted mean abundance (log transformed) of male sand crabs in June 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF FEMALE SAND CRABS
JUNE 1983



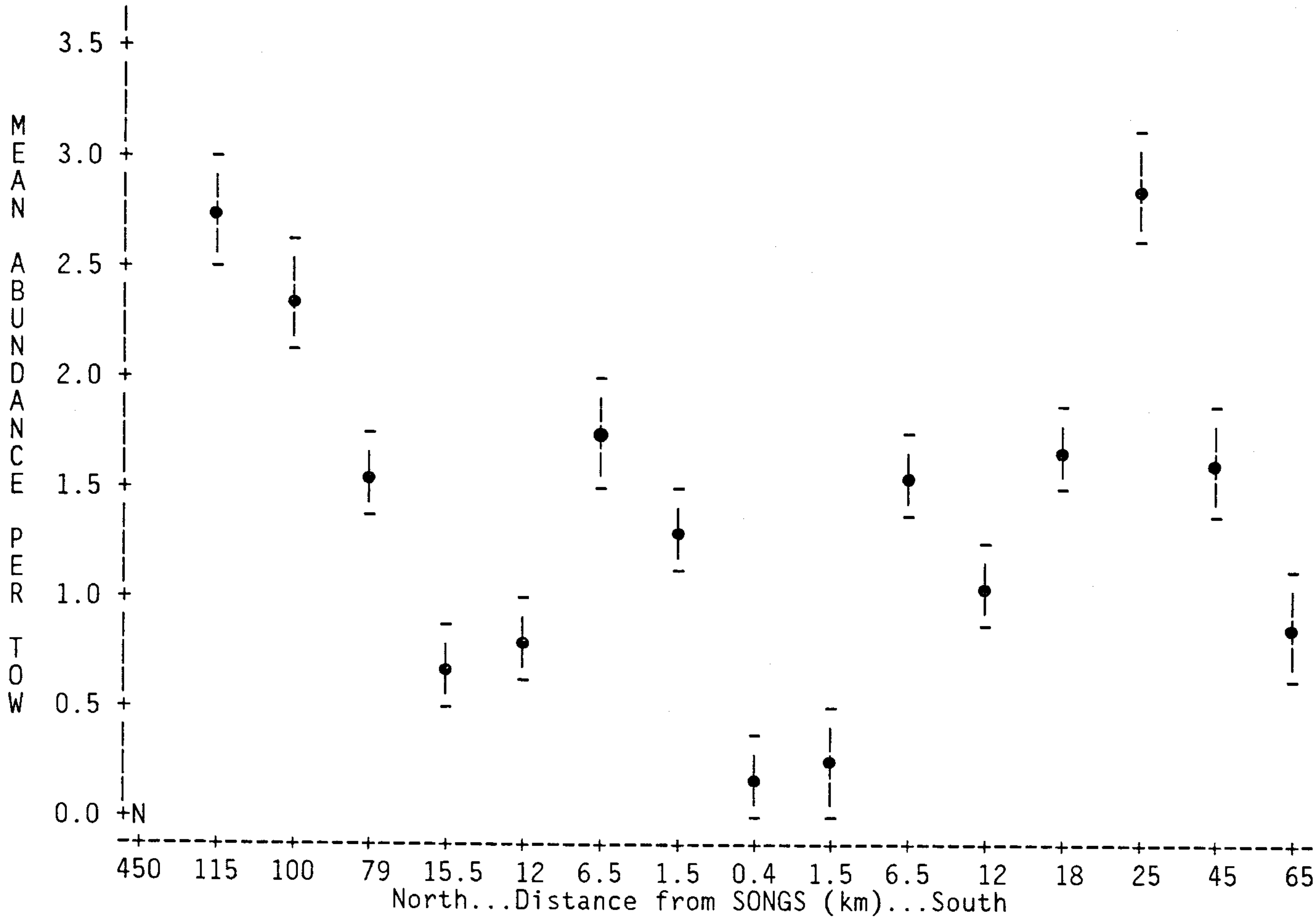
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING			MEAN	BEACH
A			2.658	25 km S
A			2.451	115 km N
B			2.079	100 km N
C			1.391	79 km N
C			1.311	18 km S
C	D		1.173	1.5 km N
C	D		1.159	45 km S
C	D		1.113	6.5 km S
	D	E	0.894	6.5 km N
	D	E	0.763	65 km S
	D	E	0.761	12 km N
F		E	0.533	15.5 km N
F	G		0.368	12 km S
	G		0.175	1.5 km S
	G		0.050	0.4 km N

Figure 3-7b. Weighted mean abundance (log transformed) of female sand crabs in June 1983 and the SNK results on these values. Site means (dots) $\pm$ 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF SAND CRABS
JUNE 1983



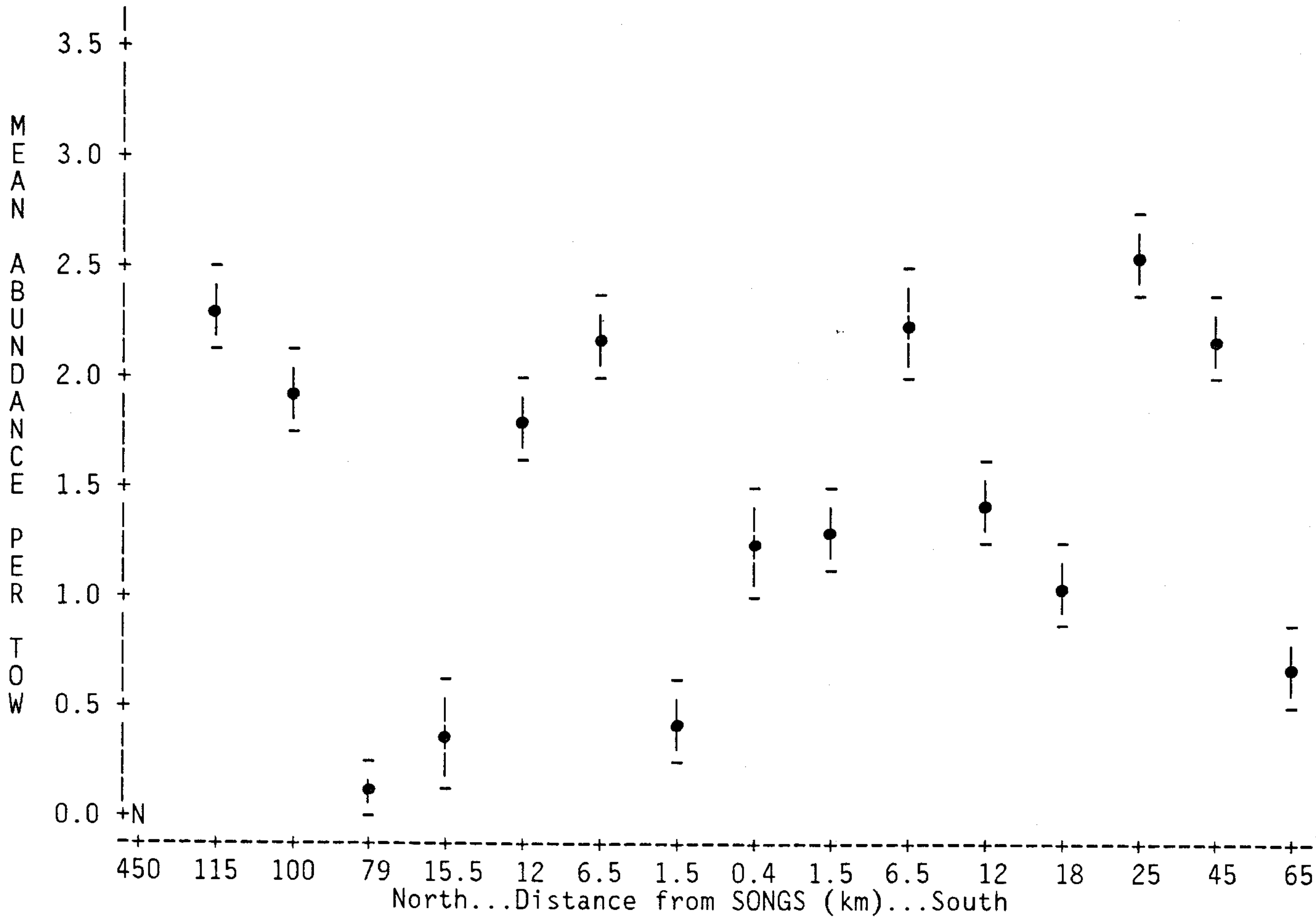
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING		MEAN	BEACH
A		2.891	25 km S
A		2.735	115 km N
B		2.367	100 km N
C		1.743	6.5 km N
C		1.704	18 km S
C	D	1.646	45 km S
C	D	1.591	6.5 km S
C	D	1.551	79 km N
	D	1.312	1.5 km N
E		1.030	12 km S
E		0.852	65 km S
E		0.843	12 km N
E		0.677	15.5 km N
F		0.260	1.5 km S
F		0.130	0.4 km N

Figure 3-7c. Weighted mean abundance (log transformed) of all sand crabs in June 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF MALE SAND CRABS
JULY 1983



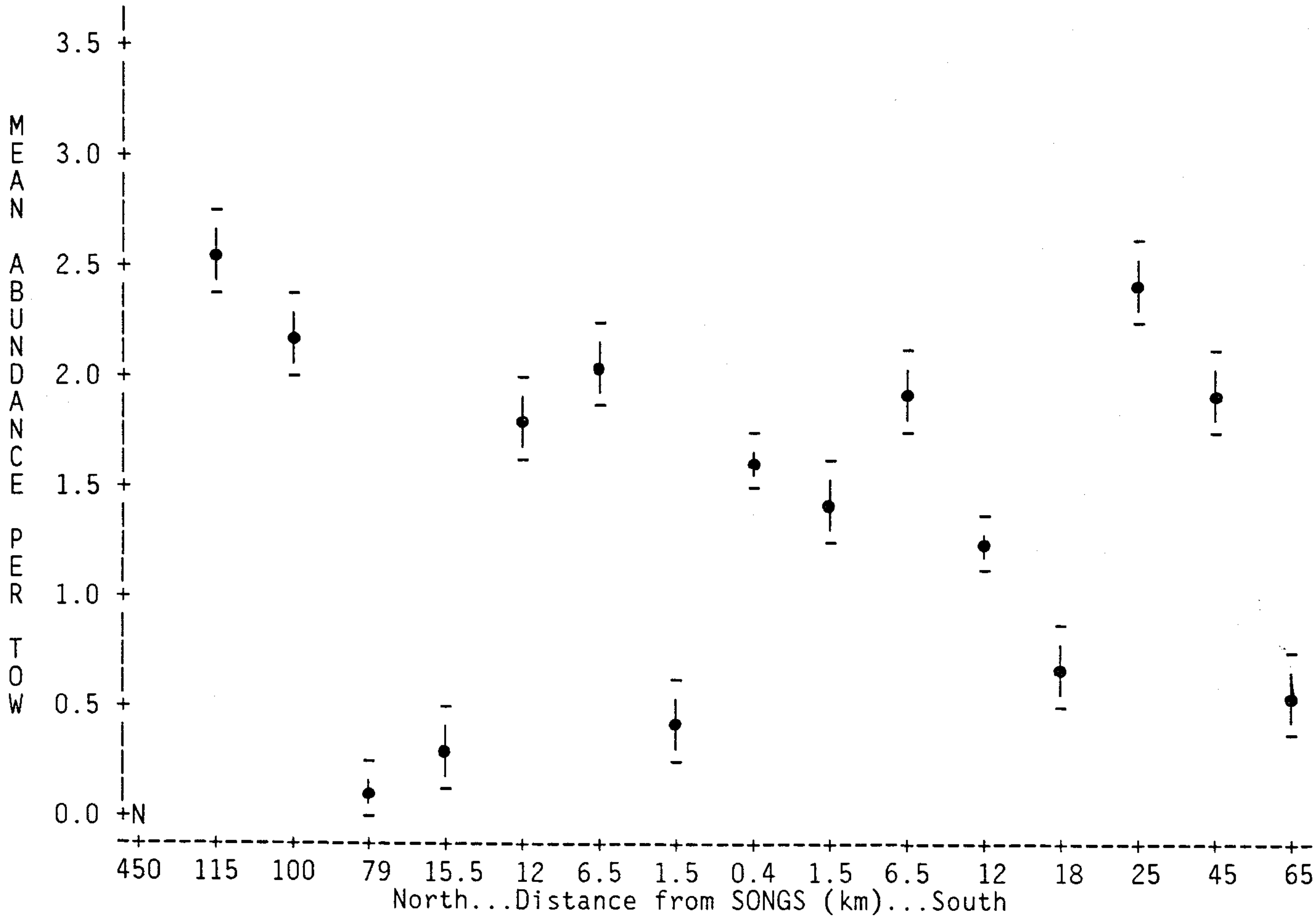
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING			MEAN	BEACH
A			2.590	25 km S
A	B		2.347	115 km N
A	B		2.245	6.5 km S
	B	C	2.168	45 km S
	B	C	2.144	6.5 km N
	B	C	1.930	100 km N
		C	1.786	12 km N
	D		1.436	12 km S
	D		1.301	1.5 km S
	D		1.243	0.4 km N
	D		1.051	18 km S
	E		0.680	65 km S
	E	F	0.425	1.5 km N
	E	F	0.371	15.5 km N
		F	0.081	79 km N

Figure 3-8a. Weighted mean abundance (log transformed) of male sand crabs in July 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF FEMALE SAND CRABS
JULY 1983



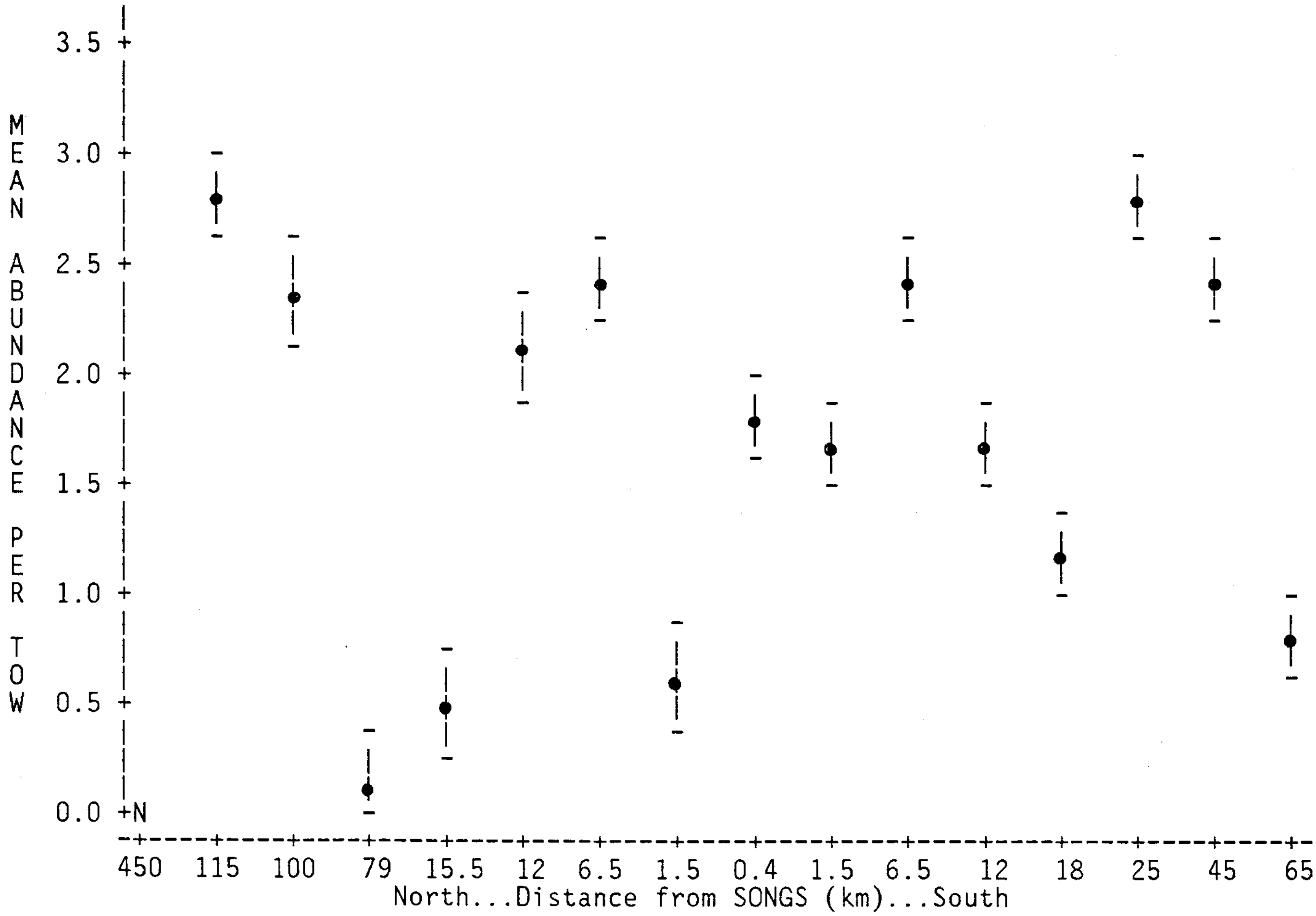
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING			MEAN	BEACH
A			2.579	115 km N
A	B		2.418	25 km S
C	B		2.155	100 km N
C	B		2.113	6.5 km N
C		D	1.970	6.5 km S
C		D	1.911	45 km S
C		D	1.798	12 km N
	E	D	1.628	0.4 km N
F	E		1.432	1.5 km S
F			1.253	12 km S
	G		0.735	18 km S
H	G		0.556	65 km S
H	G		0.467	1.5 km N
H		I	0.308	15.5 km N
		I	0.116	79 km N

Figure 3-8b. Weighted mean abundance (log transformed) of female sand crabs in July 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF SAND CRABS
JULY 1983

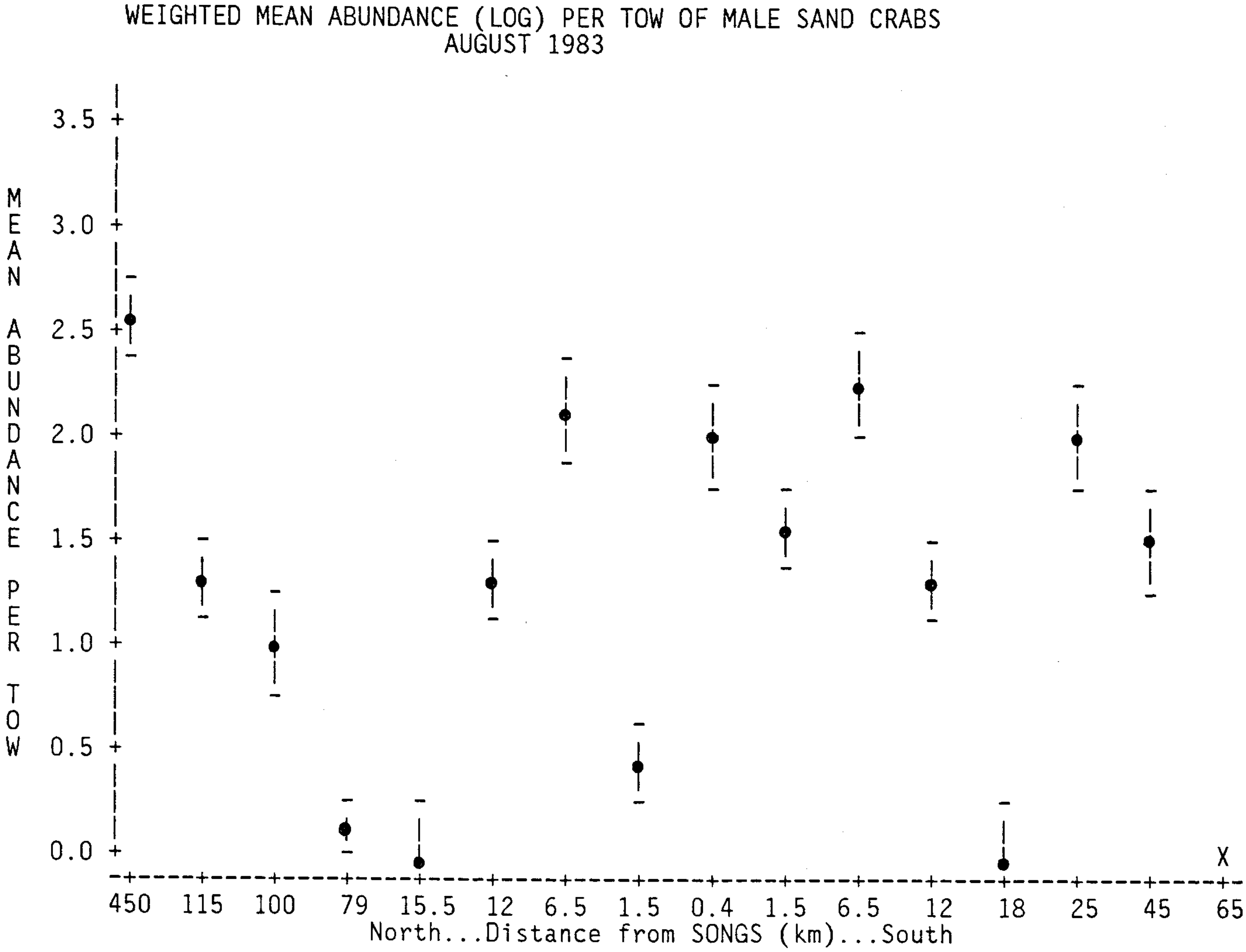


N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING		MEAN	BEACH
A		2.824	25 km S
A		2.791	115 km N
A	B	2.464	6.5 km N
A	B	2.455	6.5 km S
A	B	2.427	45 km S
A	B	2.368	100 km N
	B	2.138	12 km N
C		1.794	0.4 km N
C		1.686	12 km S
C		1.661	1.5 km S
D		1.203	18 km S
E		0.814	65 km S
E		0.600	1.5 km N
E		0.515	15.5 km N
F		0.127	79 km N

Figure 3-8c. Weighted mean abundance (log transformed) of all sand crabs in July 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

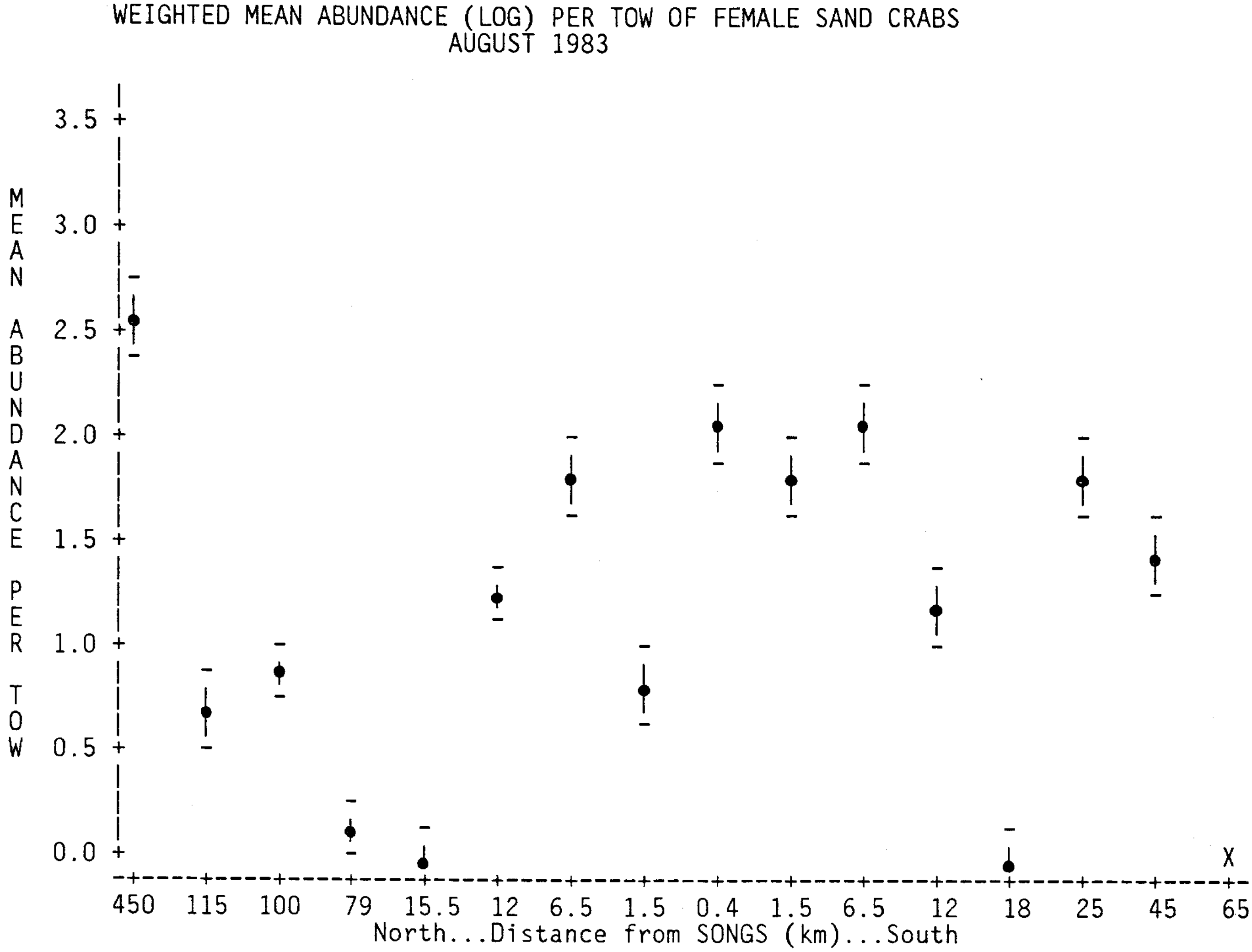


X = not sexed due to damage from lack of formalin

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING		MEAN	BEACH
A		2.572	450 km N
B		2.231	6.5 km S
B		2.112	6.5 km N
B		2.014	0.4 km N
B		1.996	25 km S
C		1.525	1.5 km S
C		1.515	45 km S
C	D	1.347	115 km N
C	D	1.336	12 km N
C	D	1.289	12 km S
	D	1.002	100 km N
E		0.431	1.5 km N
E		0.094	79 km N
E		0.000	15.5 km N
E		0.000	65 km S
E		0.000	18 km S

Figure 3-9a. Weighted mean abundance (log transformed) of male sand crabs in August 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



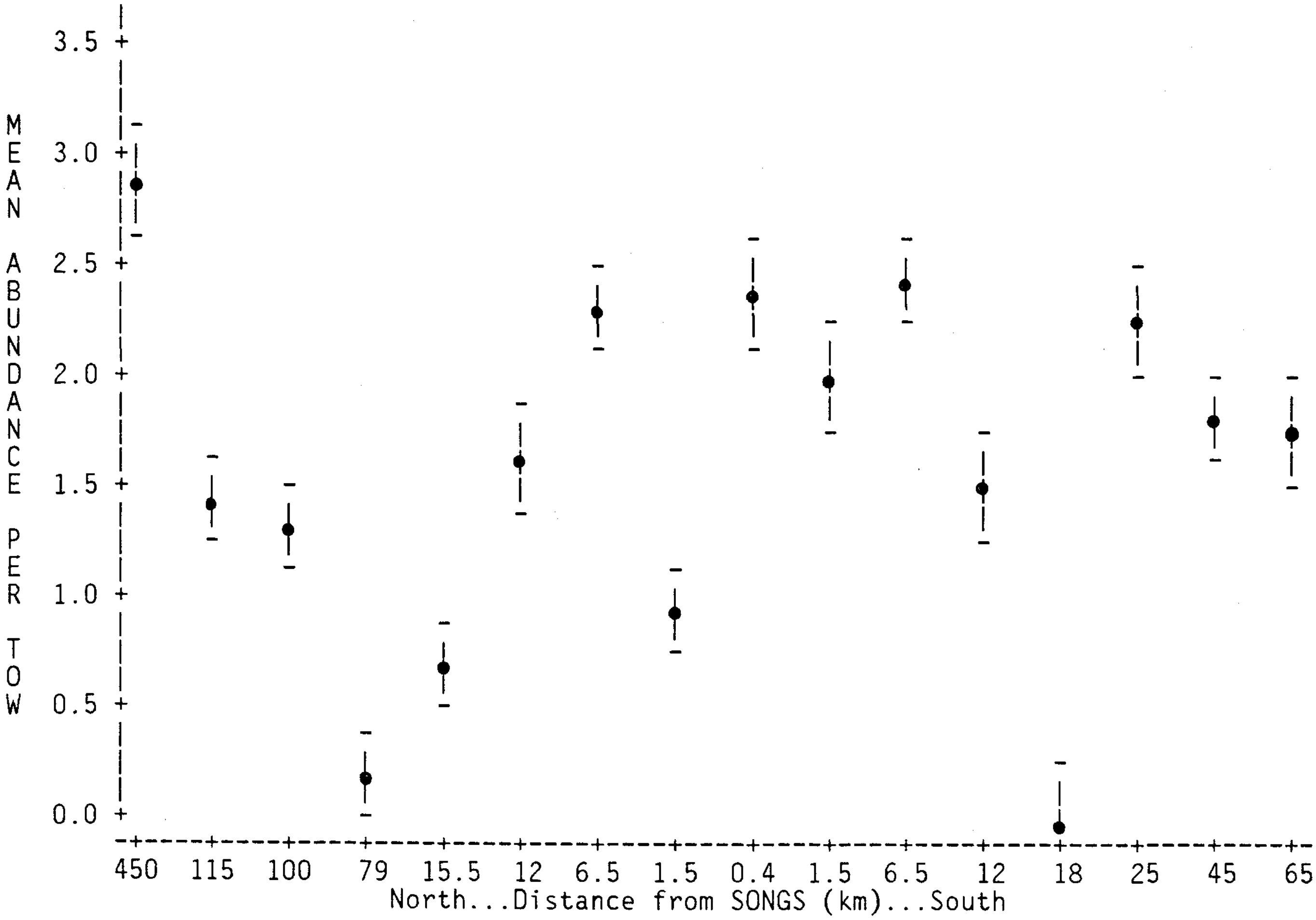
X = not sexed due to damage from lack of formalin

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING	MEAN	BEACH
A	2.544	450 km N
B	2.094	0.4 km N
B	2.074	6.5 km S
B	1.849	1.5 km S
B	1.817	25 km S
B	1.816	6.5 km N
C	1.468	45 km S
C	1.272	12 km N
C	1.167	12 km S
D	0.884	100 km N
D	0.779	1.5 km N
D	0.661	115 km N
E	0.113	79 km N
E	0.000	15.5 km N
E	0.000	65 km S
E	0.000	18 km S

Figure 3-9b. Weighted mean abundance (log transformed) of female sand crabs in August 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

WEIGHTED MEAN ABUNDANCE (LOG) PER TOW OF SAND CRABS
AUGUST 1983

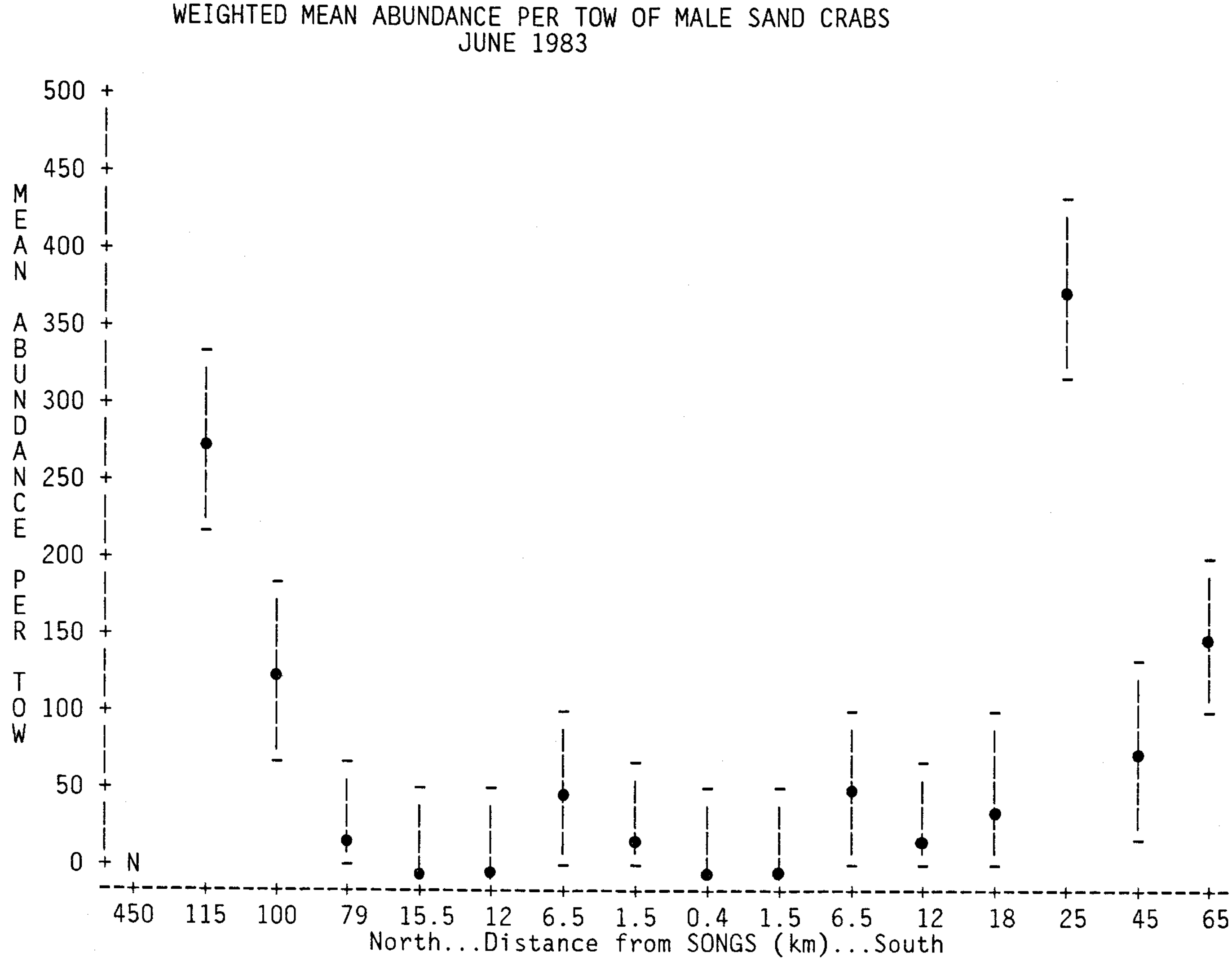


X = not sexed due to damage from lack of formalin

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

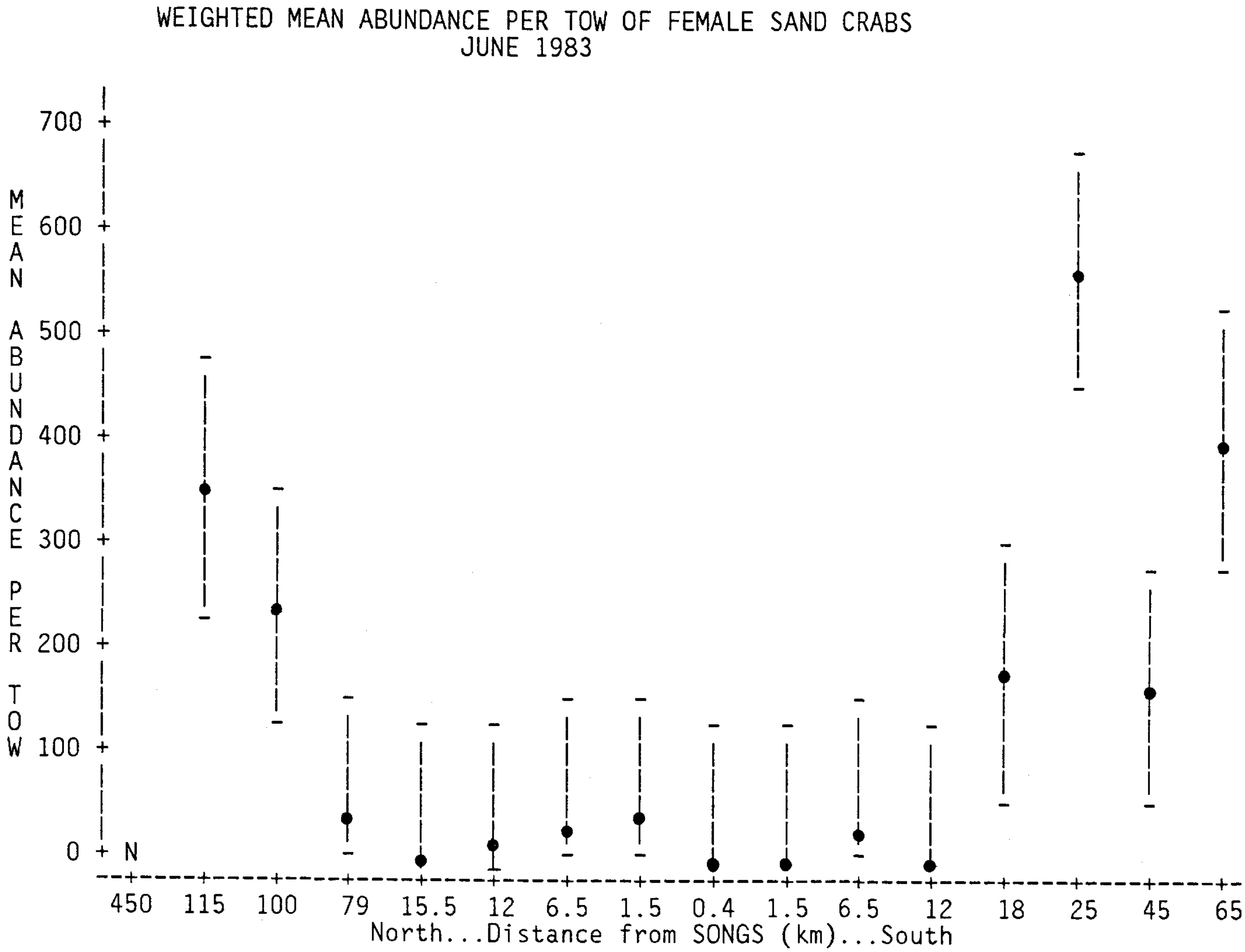
GROUPING		MEAN	BEACH
A		2.891	450 km N
B		2.465	6.5 km S
B		2.349	0.4 km N
B		2.311	6.5 km N
B		2.261	25 km S
B	C	2.019	1.5 km S
D	C	1.806	45 km S
D	C	1.735	65 km S
D	C	1.602	12 km N
D		1.519	12 km S
D		1.411	115 km N
D		1.326	100 km N
E		0.911	1.5 km N
E		0.711	15.5 km N
F		0.123	79 km N
F		0.000	18 km S

Figure 3-9c. Weighted mean abundance (log transformed) of all sand crabs in August 1983 and the SNK results on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



N = not sampled

Figure 3-10a. Weighted mean abundance of male sand crabs in June 1983. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



N = not sampled

Figure 3-10b. Weighted mean abundance of female sand crabs in June 1983. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

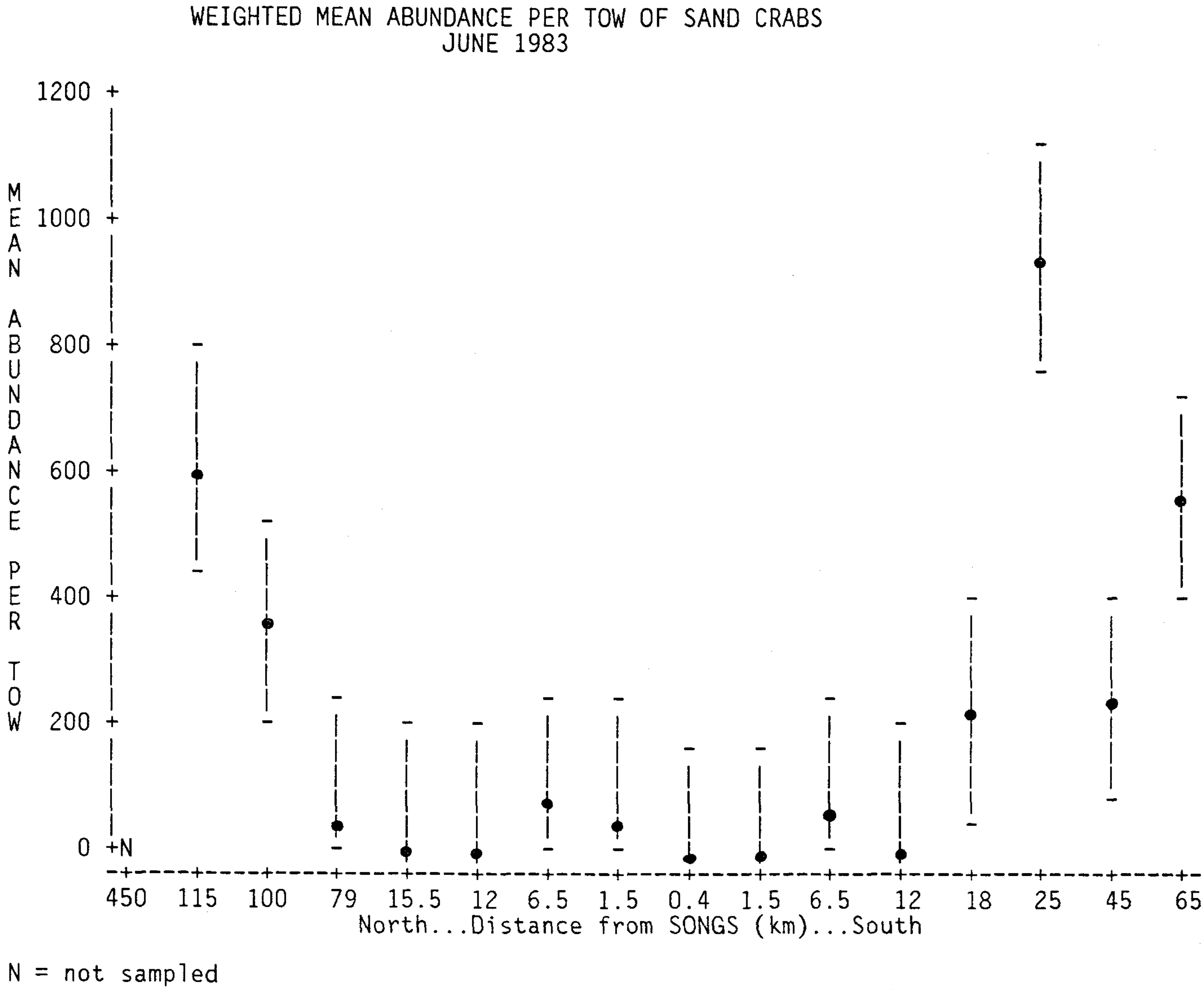


Figure 3-10c. Weighted mean abundance of all sand crabs in June 1983. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

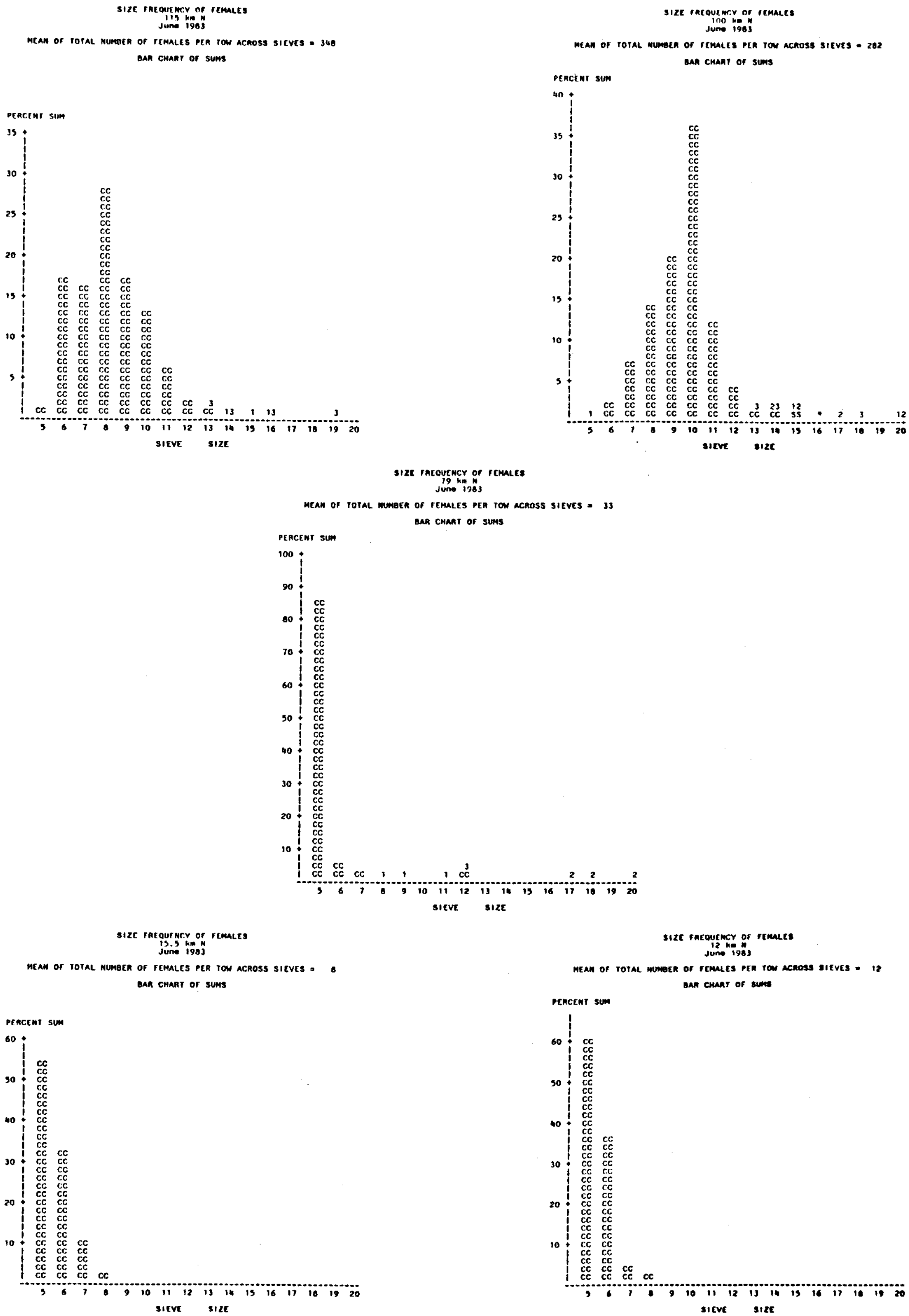


Figure 3-11a. Size frequency distributions of females in June at sites 115 km N to 12 km N.

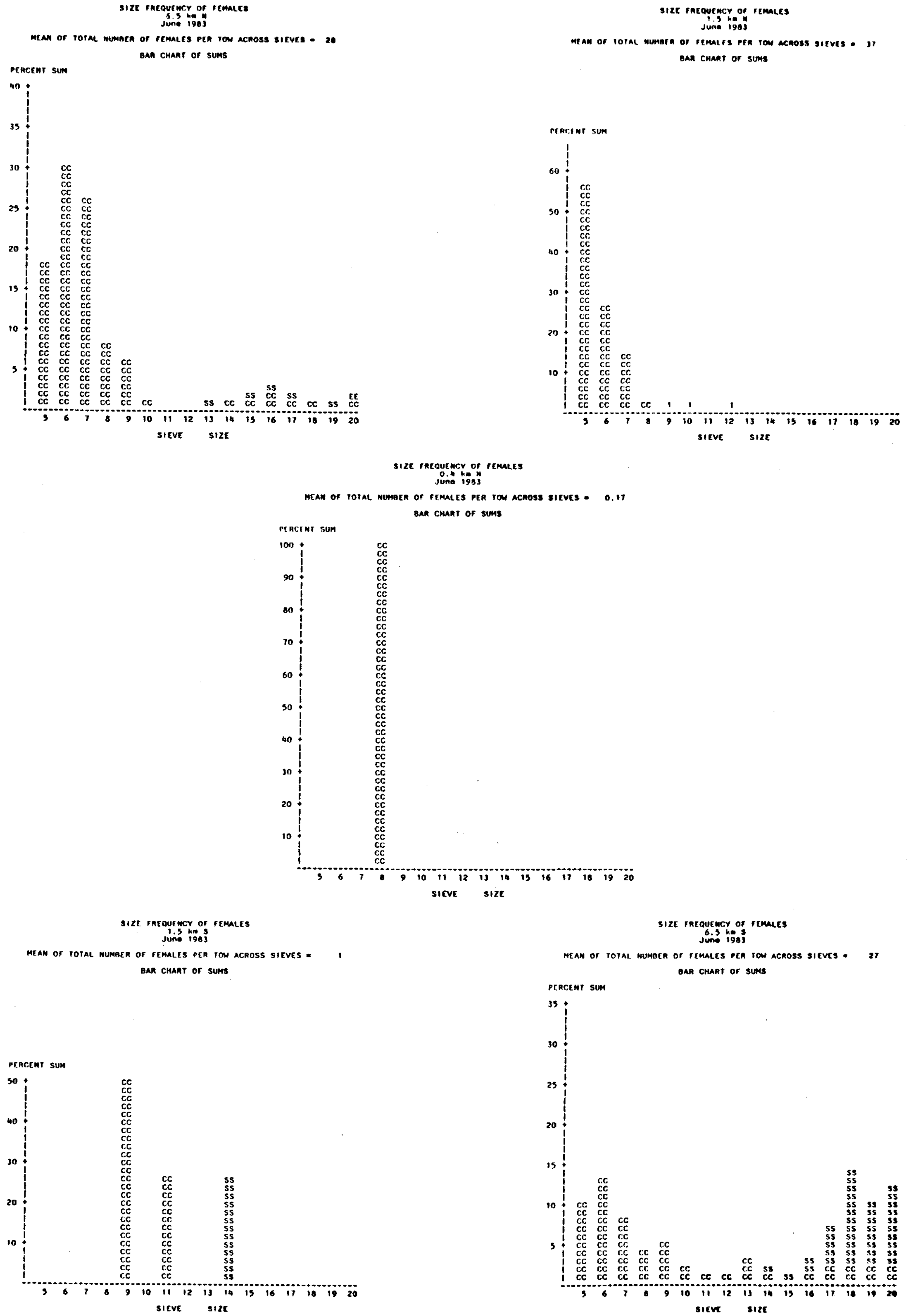


Figure 3-11b. Size frequency distributions of females in June at sites 6.5 km N to 6.5 km S.

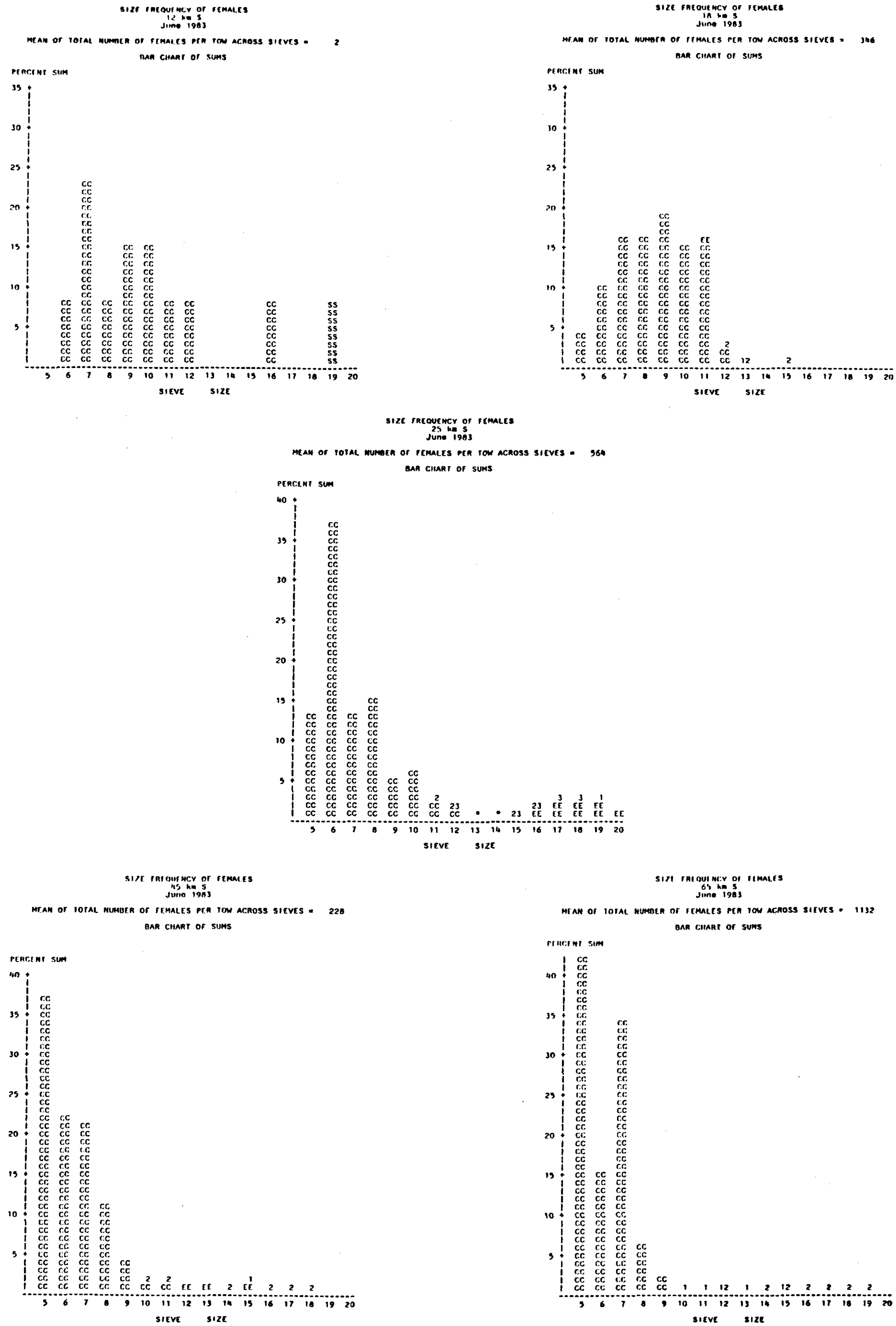
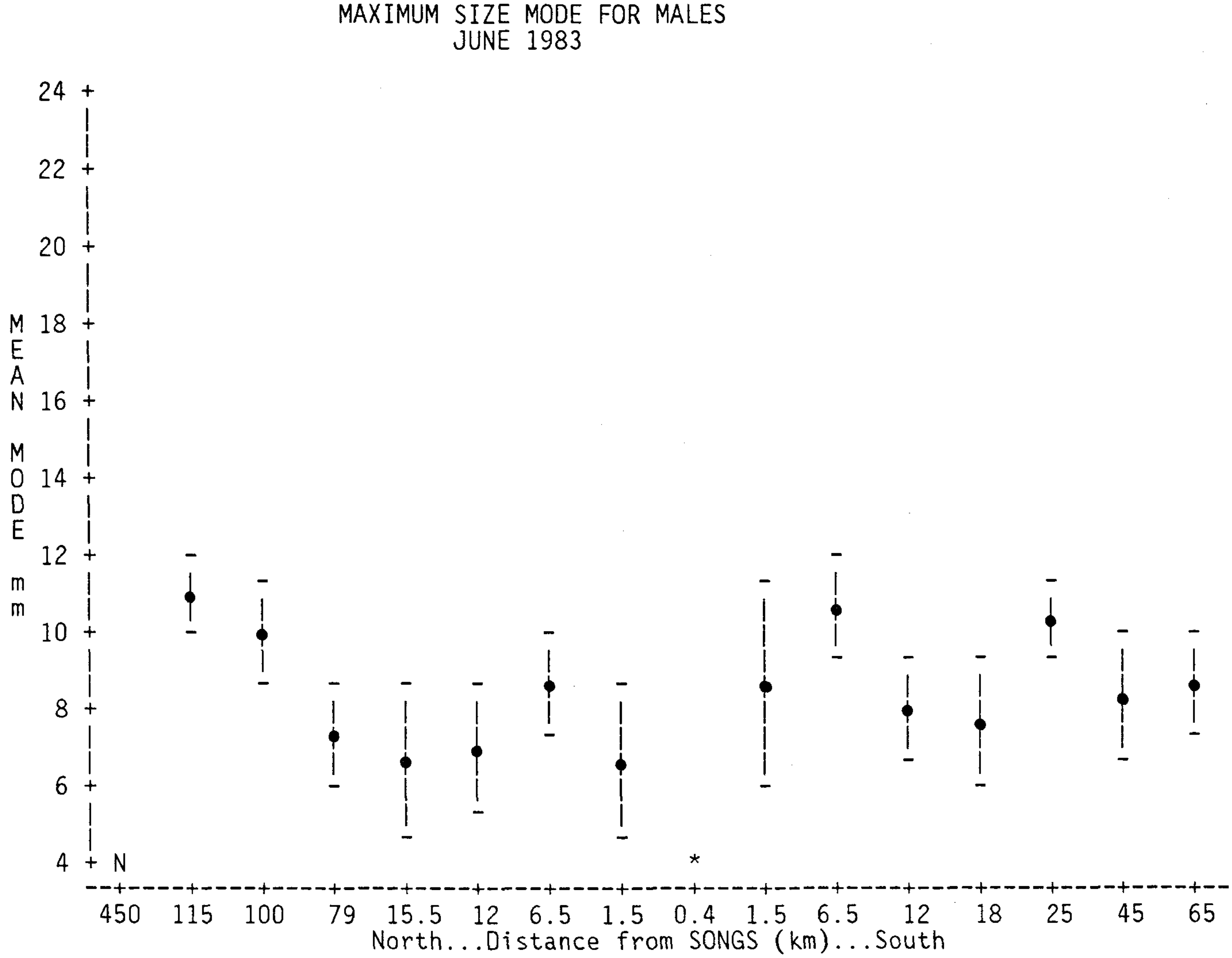


Figure 3-11c. Size frequency distributions of females in June at sites 12 km S to 65 km S.



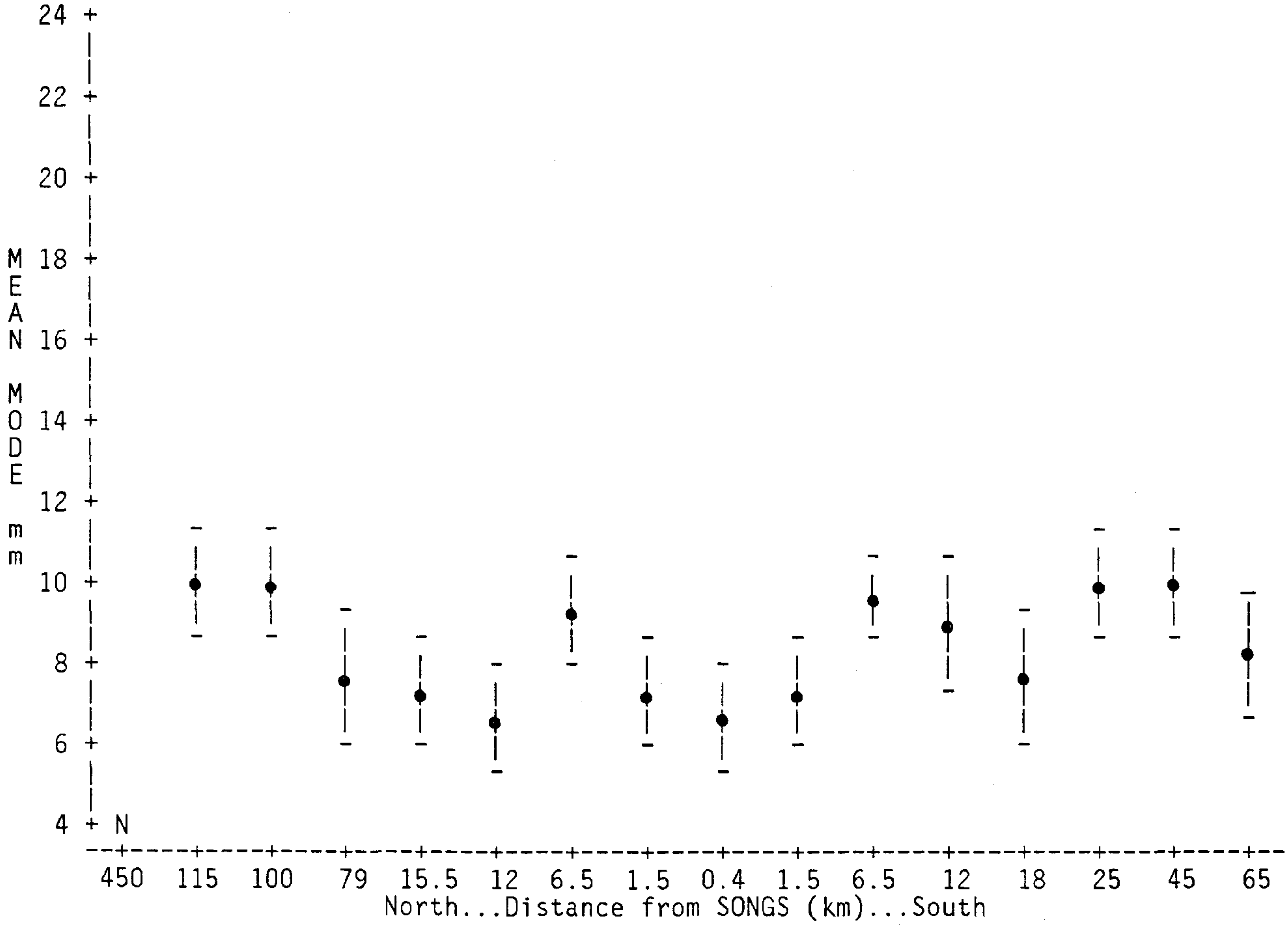
* = less than 5 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING			MEAN	REPS	BEACH
	A		11.150	6	115 km N
B	A		10.583	6	6.5 km S
B	A	C	10.183	6	25 km S
B	A	C	9.700	4	100 km N
B	A	C	8.767	6	6.5 km N
B	A	C	8.500	1	1.5 km S
B	A	C	8.400	4	65 km S
B	A	C	8.267	3	45 km S
B	A	C	8.225	4	12 km S
B	A	C	7.433	3	18 km S
B	A	C	7.375	4	79 km N
B		C	6.800	2	1.5 km N
B		C	6.767	3	12 km N
		C	6.650	2	15.5 km N

Figure 3-12. Mean of the maximum size mode of males in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MAXIMUM SIZE MODE FOR MALES
JULY 1983

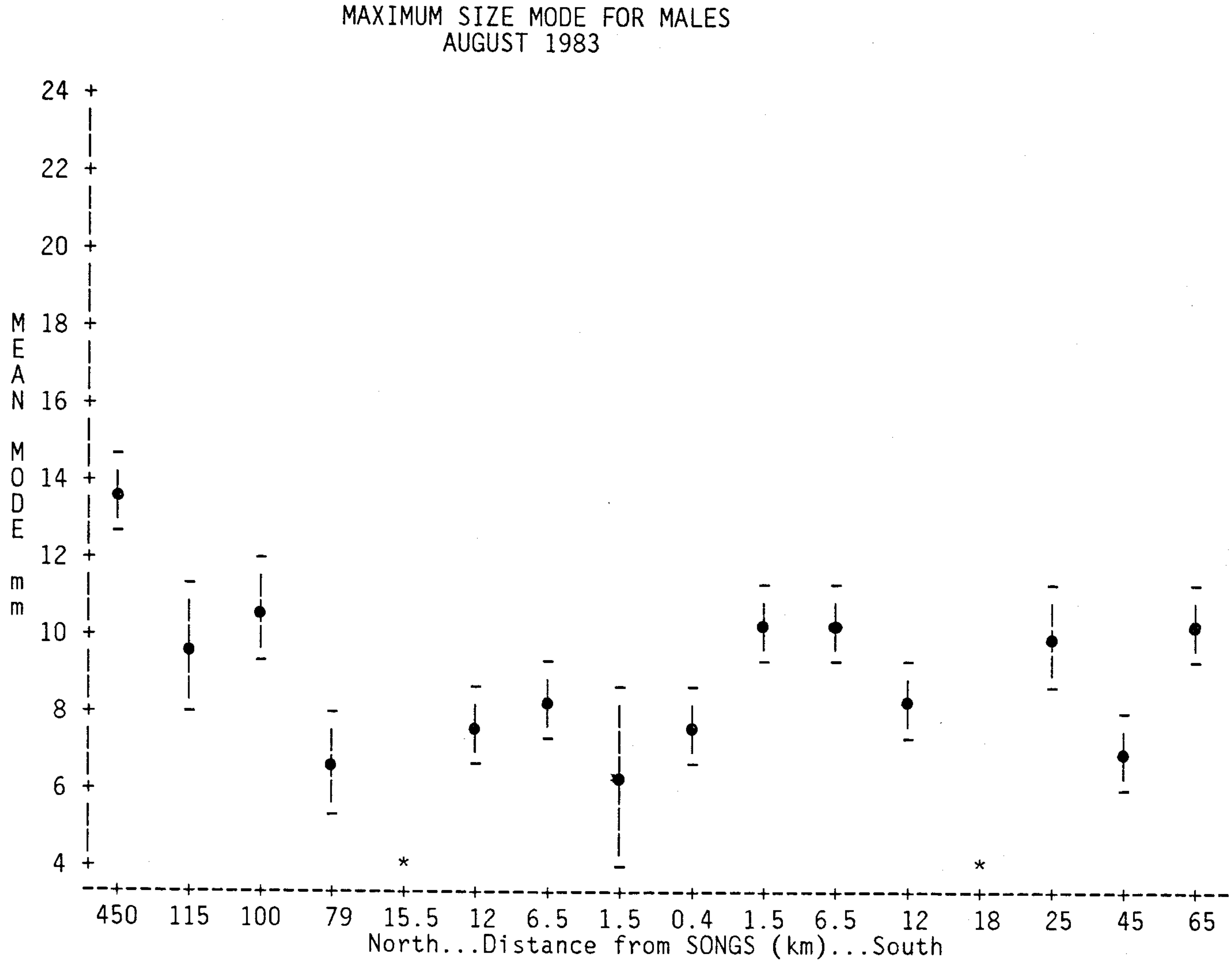


* = less than 5 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	10.050	4	45 km S
	A	10.050	6	115 km N
	A	9.983	6	100 km N
	A	9.867	6	25 km S
B	A	9.567	6	6.5 km S
B	A	9.300	3	12 km S
B	A	9.300	6	6.5 km N
B	A	8.350	4	65 km S
B	A	7.967	3	79 km N
B	A	7.725	4	18 km S
B	A	7.525	4	1.5 km S
B	A	7.200	4	1.5 km N
B	A	7.125	4	15.5 km N
B		6.600	6	12 km N
B		6.480	5	0.4 km N

Figure 3-13. Mean of the maximum size mode of males in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



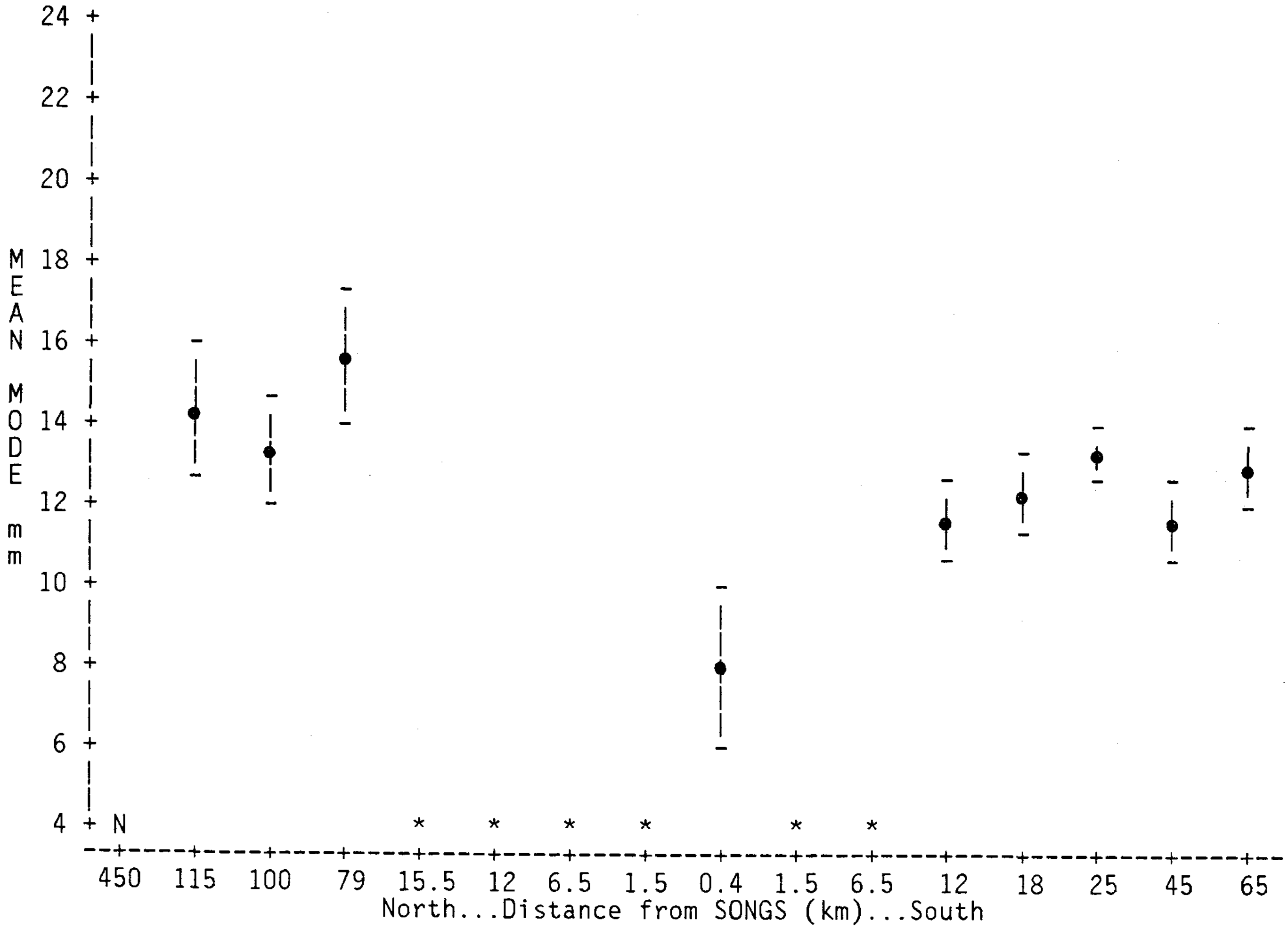
* = less than 5 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	13.517	6	450 km N
	B	10.700	4	100 km N
	B	10.480	5	1.5 km S
	B	10.367	6	6.5 km S
	B	10.200	4	65 km S
	B	10.175	4	25 km S
	B	9.800	2	115 km N
C	B	8.467	6	6.5 km N
C	B	8.317	6	12 km S
C	B	7.725	4	0.4 km N
C	B	7.675	4	12 km N
C		6.950	4	45 km S
C		6.775	4	79 km N
C		6.600	1	1.5 km N

Figure 3-14. Mean of the maximum size mode of males in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MINIMUM SIZE MODE FOR FEMALES WITH EGGS
JULY 1983

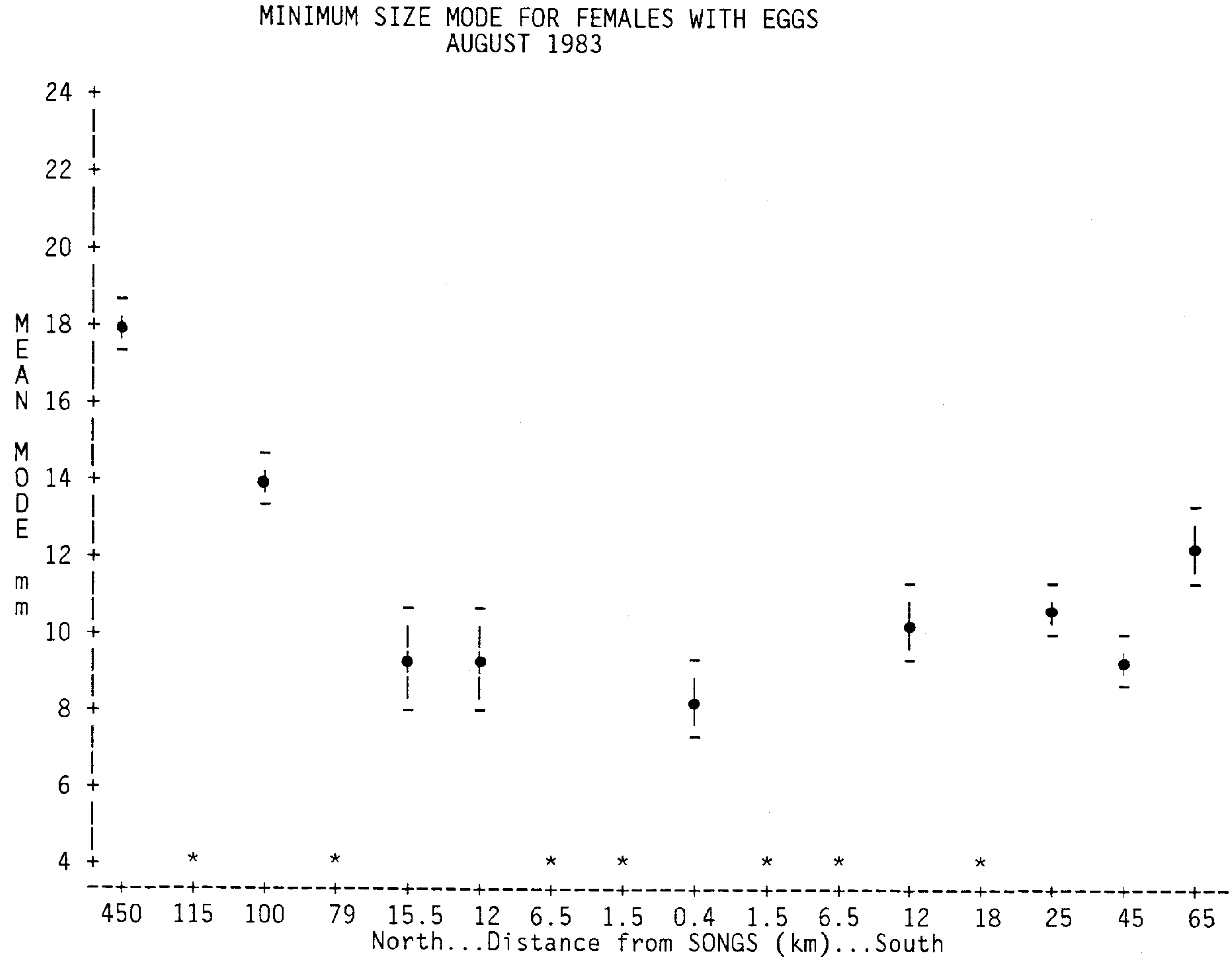


* = less than 5 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	N	BEACH
	A	15.600	1	79 km N
B	A	14.345	1	115 km N
B	A	13.462	2	100 km N
B	A	13.272	6	25 km S
B	A	12.829	3	65 km S
B	A	12.578	3	18 km S
B		11.575	3	12 km S
B		11.557	4	45 km S
	C	8.000	1	0.4 km N

Figure 3-15. Mean of the minimum size mode of females with eggs in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



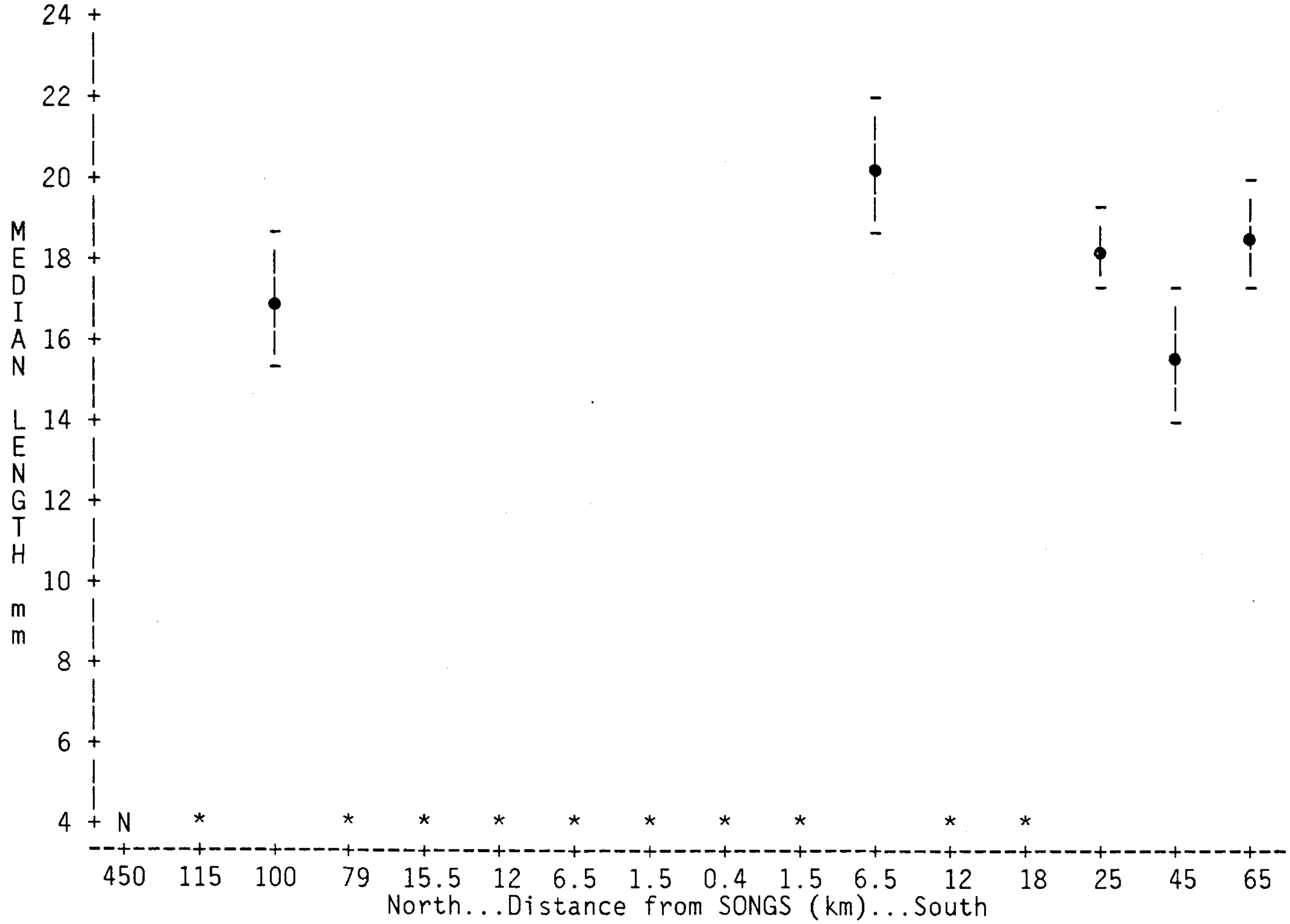
* = less than 5 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	N	BEACH
	A	17.759	6	450 km N
	B	14.170	4	100 km N
	C	12.263	3	65 km S
	D	10.753	4	25 km S
	D	10.455	2	12 km S
E	D	9.250	2	12 km N
E	D	9.207	4	45 km S
E	D	9.188	2	15.5 km N
E		8.395	4	0.4 km N

Figure 3-16. Mean of the minimum size mode of females with eggs in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES WITH EGGS OR SPENT EGG CASES
JUNE 1983



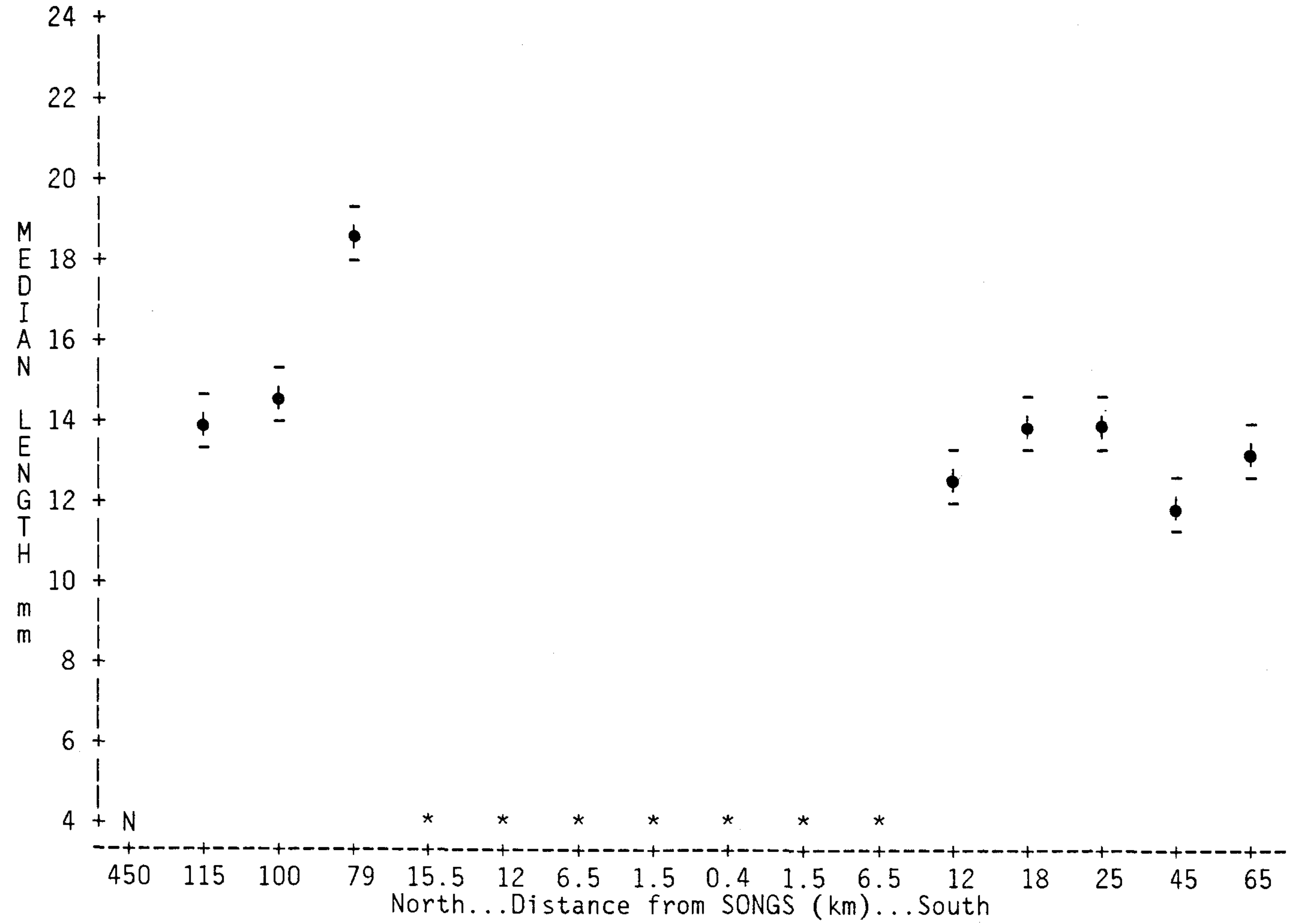
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	20.200	1	6.5 km S
A	18.700	1	65 km S
A	18.467	3	25 km S
A	16.900	1	100 km N
A	15.650	1	45 km S

Figure 3-17. Median carapace length (mm) of females with eggs or spent egg cases in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES WITH EGGS OR SPENT EGG CASES
JULY 1983



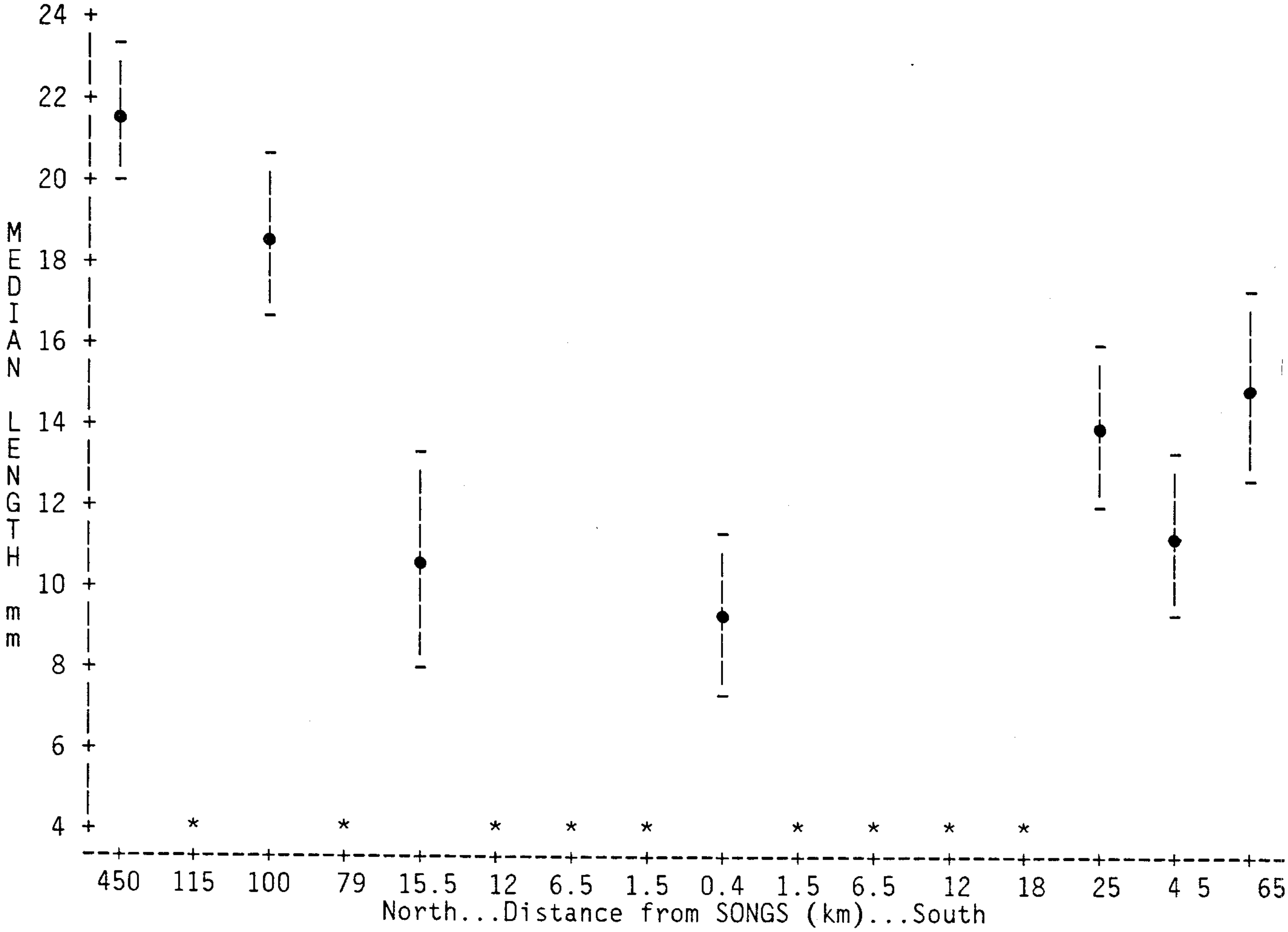
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	18.600	1	79 km N
	B	14.600	2	100 km N
C	B	14.325	4	115 km N
C	B	14.150	3	18 km S
C	B	13.933	6	25 km S
C	D	13.200	3	65 km S
E	D	12.600	2	12 km S
E		11.950	4	45 km S

Figure 3-18. Median carapace length (mm) of females with eggs or spent egg cases in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES WITH EGGS
AUGUST 1983



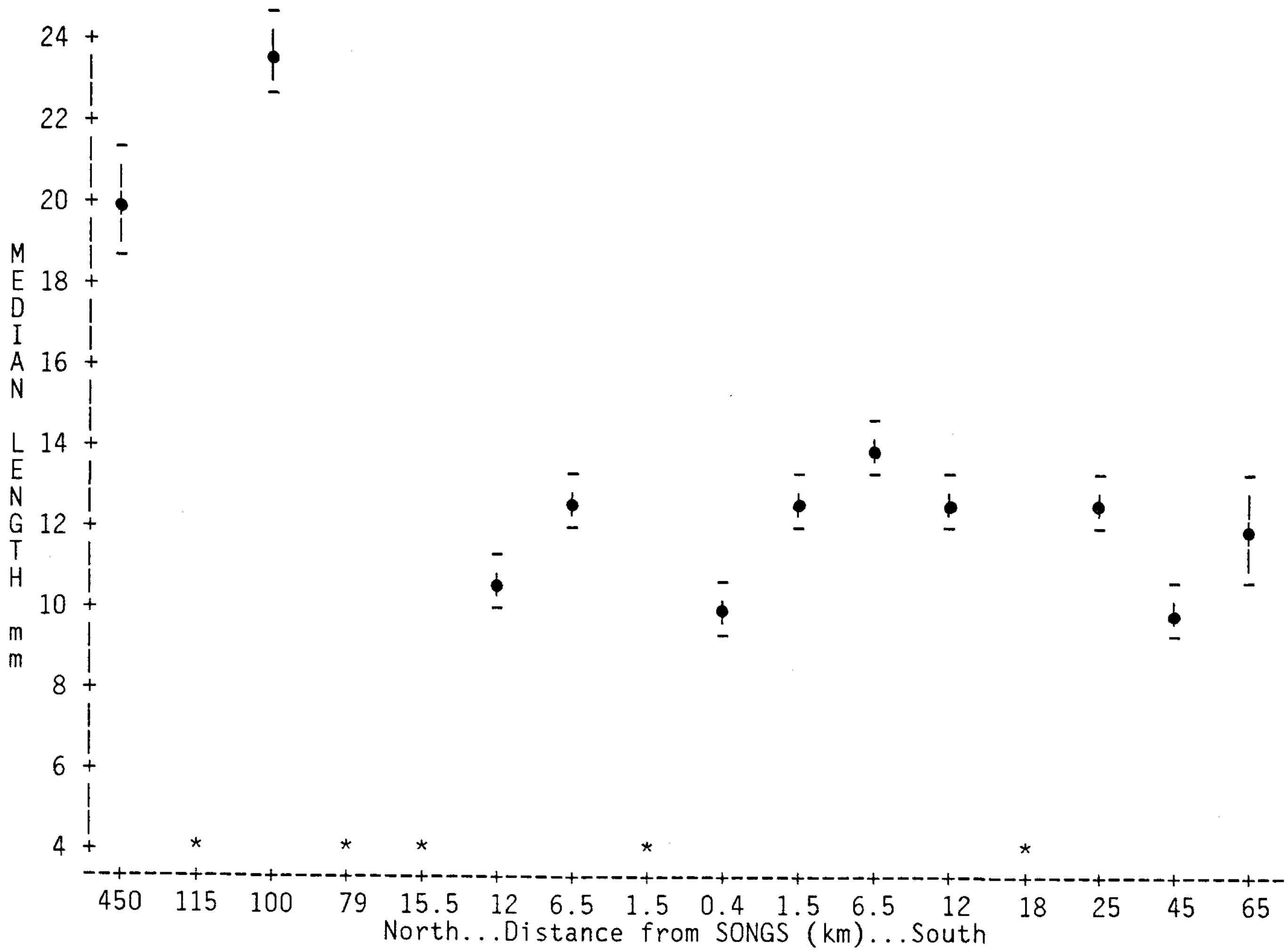
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SNK	GROUPING		MEAN	N	BEACH
		A	21.733	6	450 km N
		A	18.675	4	100 km N
		B	15.012	4	65 km S
	C	B	13.725	4	25 km S
	C		11.225	4	45 km S
	C		10.750	2	15.5 km N
	C		9.575	4	0.4 km N

Figure 3-19a. Median carapace length (mm) of females with eggs in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES WITH SPENT EGG CASES
AUGUST 1983



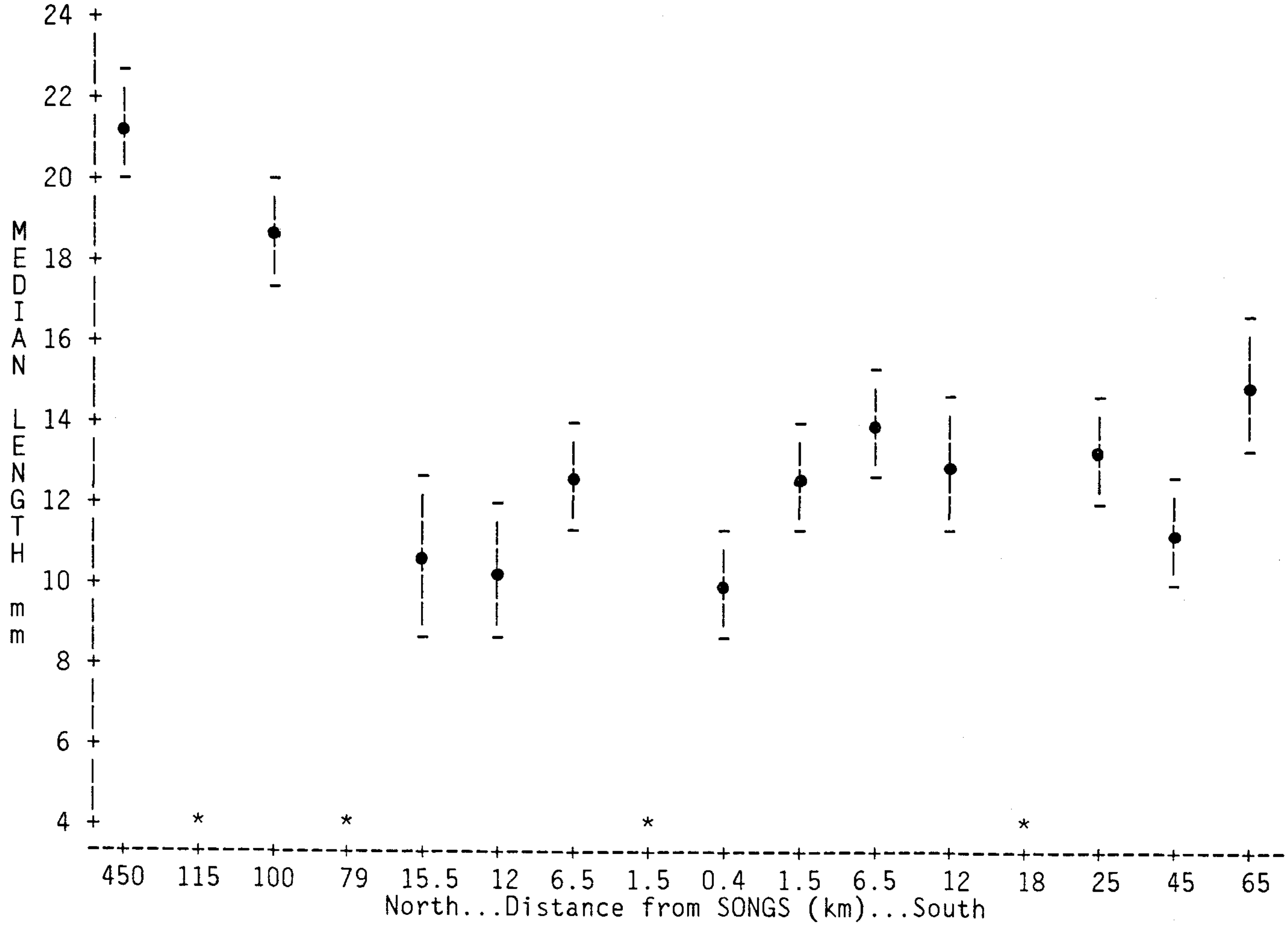
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	23.700	2	100 km N
	B	20.200	1	450 km N
	C	14.050	6	6.5 km S
D	C	12.975	4	25 km S
D	C	12.900	5	1.5 km S
D	C	12.900	3	12 km S
D	C	12.500	6	6.5 km N
D		11.800	1	65 km S
	E	10.567	3	12 km N
	E	9.900	4	0.4 km N
	E	9.717	3	45 km S

Figure 3-19b. Median carapace length (mm) of females with spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES WITH EGGS OR SPENT EGG CASES
AUGUST 1983



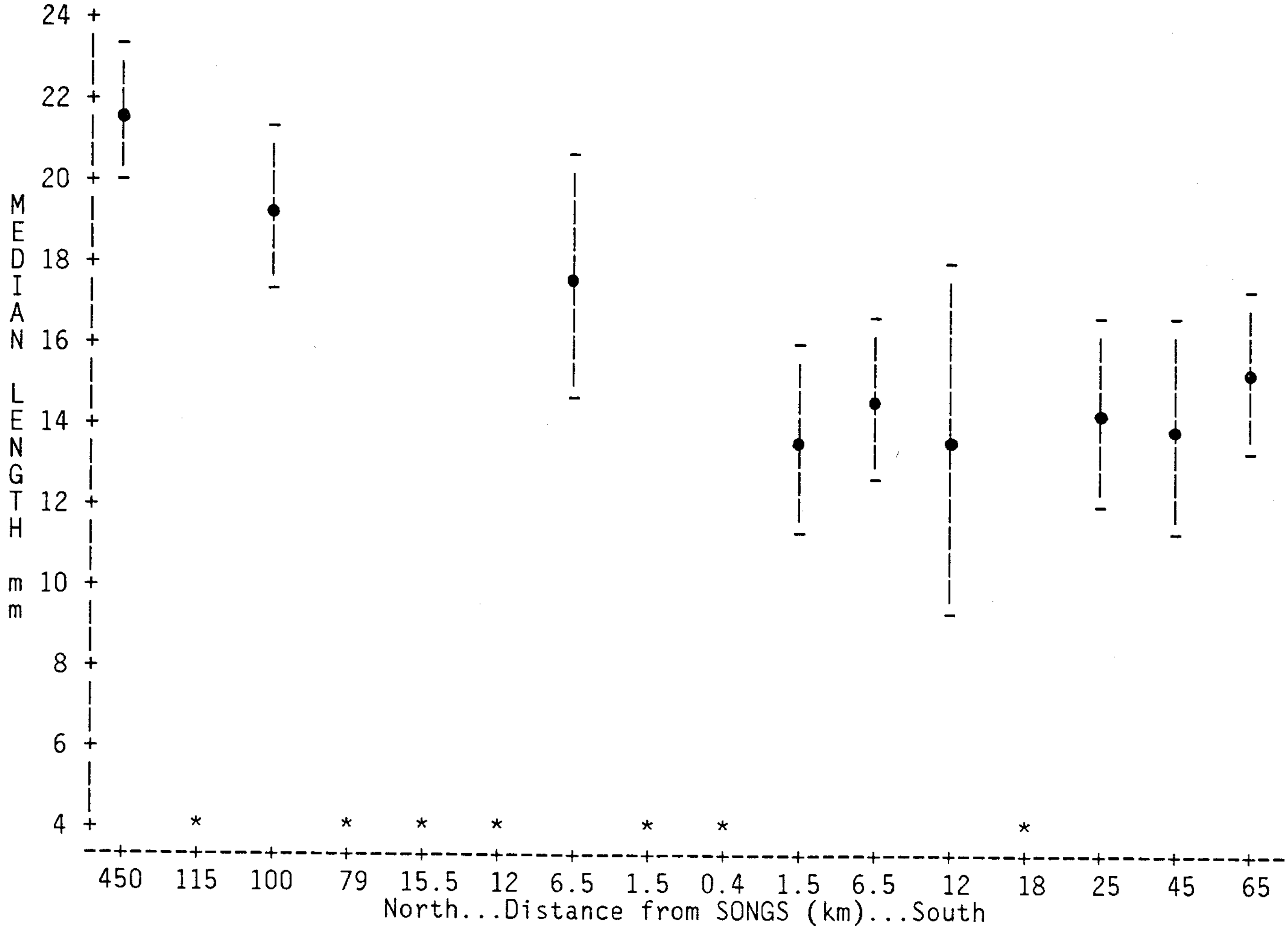
* = less than 10 animals per replicate

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING				MEAN	REPS	BEACH
		A		21.567	6	450 km N
		B		18.675	4	100 km N
		C		15.012	4	65 km S
D		C		14.050	6	6.5 km S
D		C	E	13.450	4	25 km S
D	F	C	E	12.900	5	1.5 km S
D	F	C	E	12.900	4	12 km S
D	F	C	E	12.500	6	6.5 km N
D	F		E	11.225	4	45 km S
D	F		E	10.750	2	15.5 km N
	F		E	10.567	3	12 km N
	F			9.900	4	0.4 km N

Figure 3-19c. Median carapace length (mm) of females with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES >13 mm WITH EGGS OR SPENT EGG CASES
AUGUST 1983



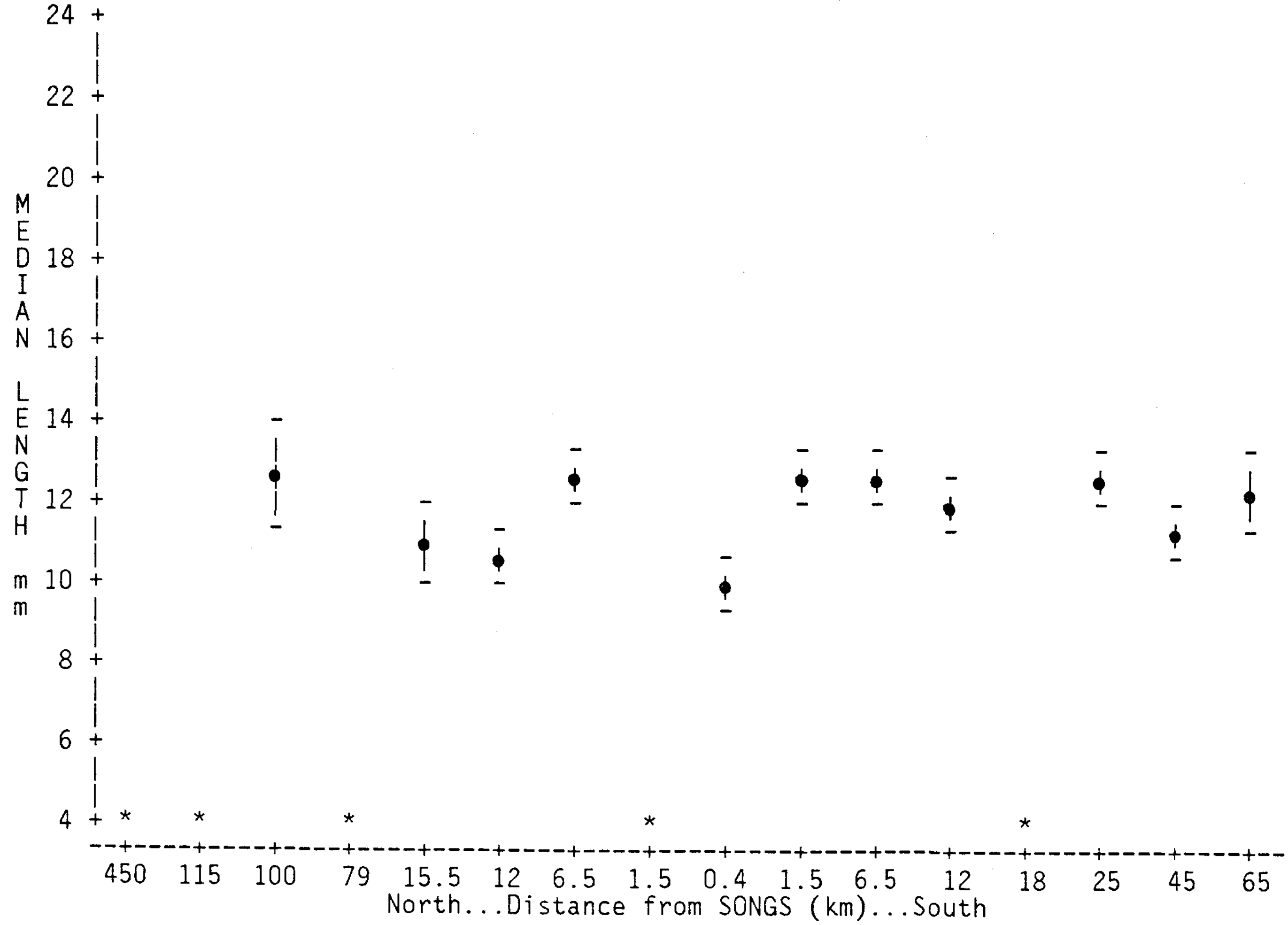
* = less than 10 animals per replicate

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	21.567	6	450 km N
B	A	19.300	4	100 km N
B	A	17.850	2	6.5 km N
B		15.450	4	65 km S
B		14.740	5	6.5 km S
B		14.175	4	25 km S
B		14.033	3	45 km S
B		13.800	4	1.5 km S
B		13.800	1	12 km S

Figure 3-20. Median carapace length (mm) of females larger than 13 mm with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

MEAN OF THE MEDIAN LENGTH FOR FEMALES <13 mm WITH EGGS OR SPENT EGG CASES
AUGUST 1983



* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING			MEAN	REPS	BEACH
	A		12.900	1	100 km N
	A		12.700	4	25 km S
	A		12.700	5	6.5 km S
	A		12.600	2	65 km S
	A		12.500	5	1.5 km S
	A		12.420	5	6.5 km N
B	A		11.900	3	12 km S
B	A	C	11.225	4	45 km S
B		C	10.750	2	15.5 km N
B		C	10.567	3	12 km N
		C	9.900	4	0.4 km N

Figure 3-21. Median carapace length (mm) of females smaller than 13 mm with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

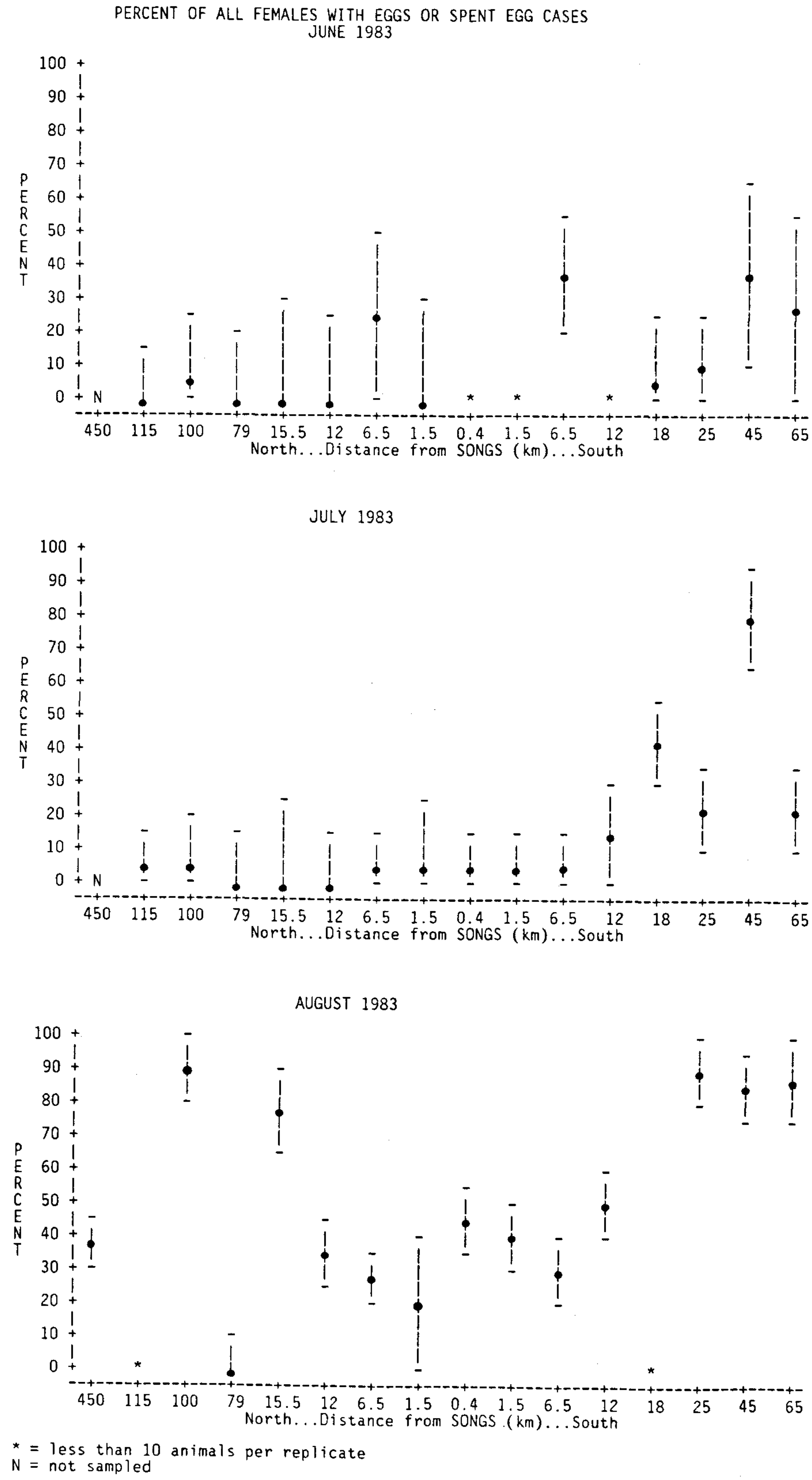
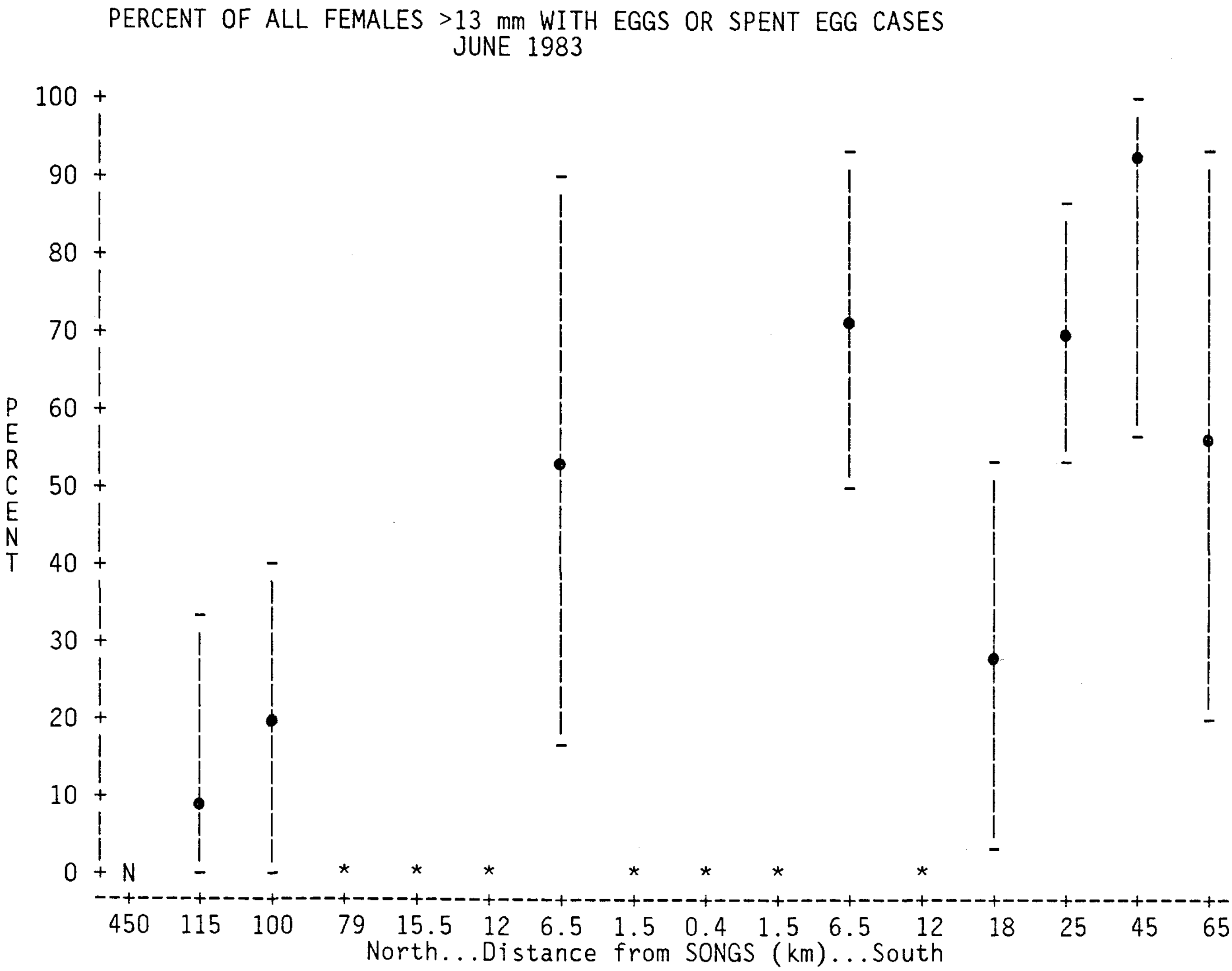


Figure 3-22. Mean percentages, by beach, of all females with eggs or spent egg cases in June, July and August 1983. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



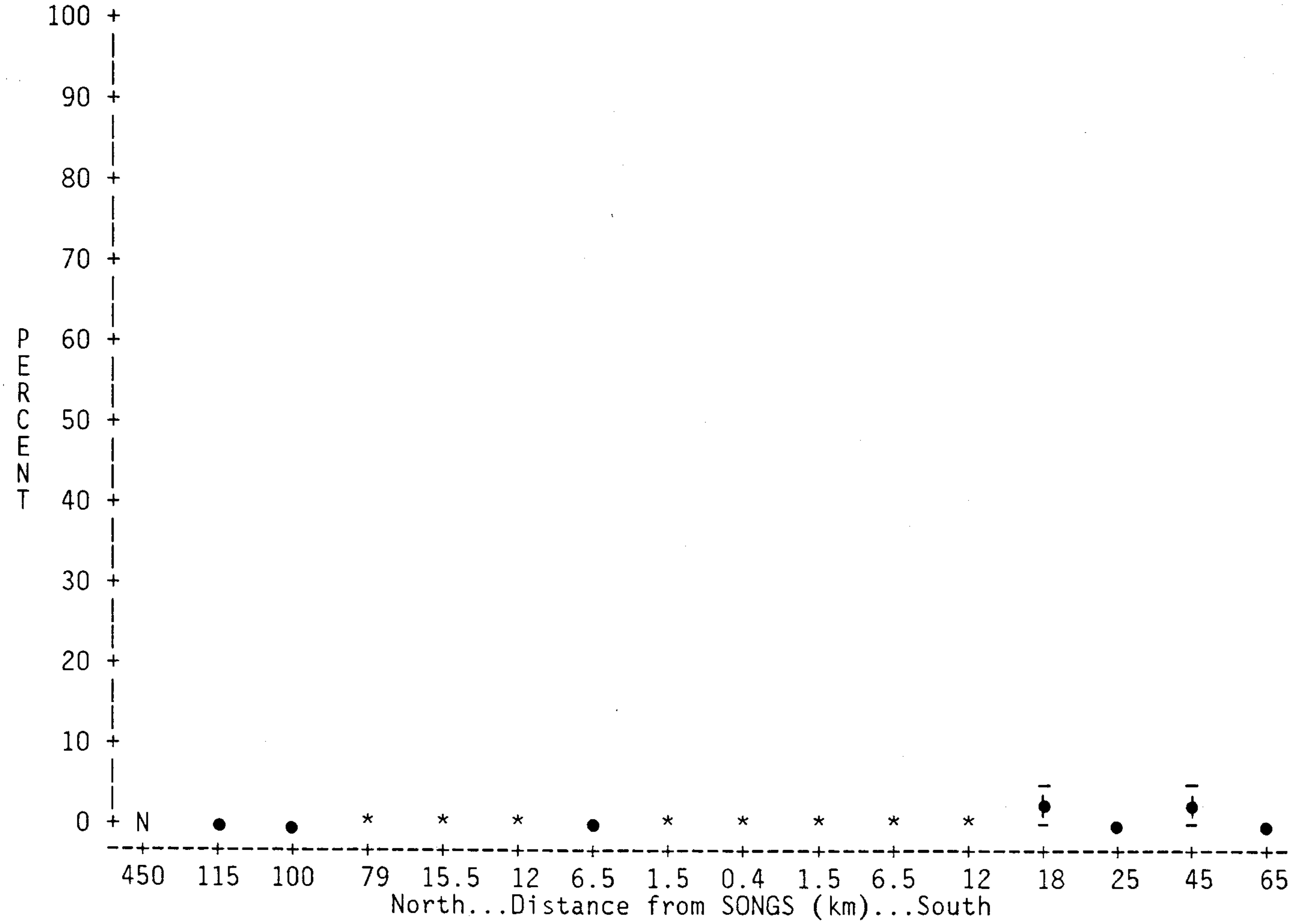
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	92.593	1	45 km S
B	A	70.971	3	6.5 km S
B	A	70.056	4	25 km S
B	A	57.500	1	65 km S
B	A	53.333	1	6.5 km N
B	A	28.571	2	18 km S
B	A	20.794	3	100 km N
B		8.824	2	115 km N

Figure 3-23a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs or spent egg cases in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS OR SPENT EGG CASES
JUNE 1983



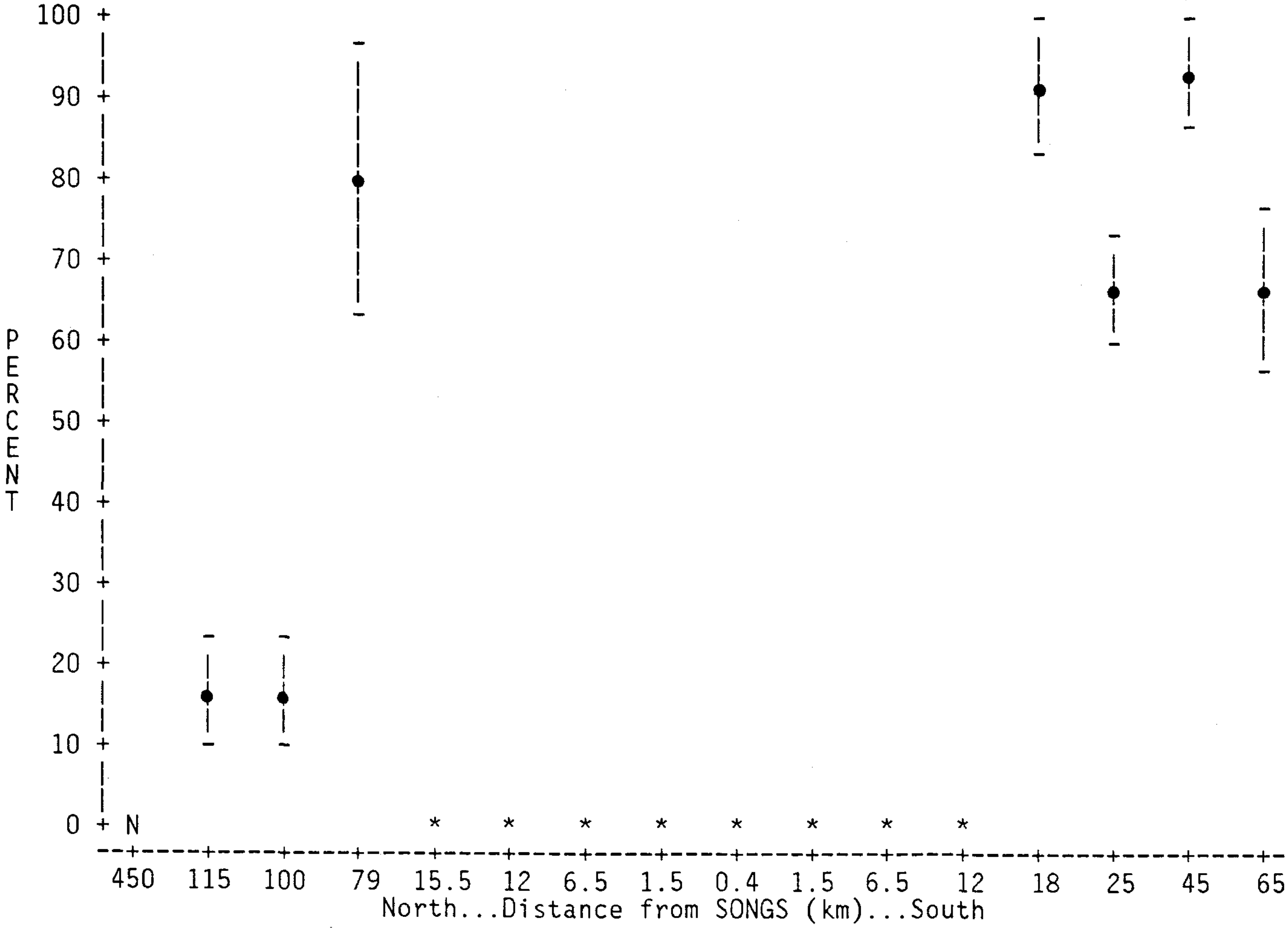
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	2.857	1	45 km S
B	A	1.679	3	18 km S
B		0.278	6	25 km S
B		0.000	4	100 km N
B		0.000	6	115 km N
B		0.000	1	6.5 km N
B		0.000	1	65 km S

Figure 3-23b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs or spent egg cases in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >13 mm WITH EGGS OR SPENT EGG CASES
JULY 1983



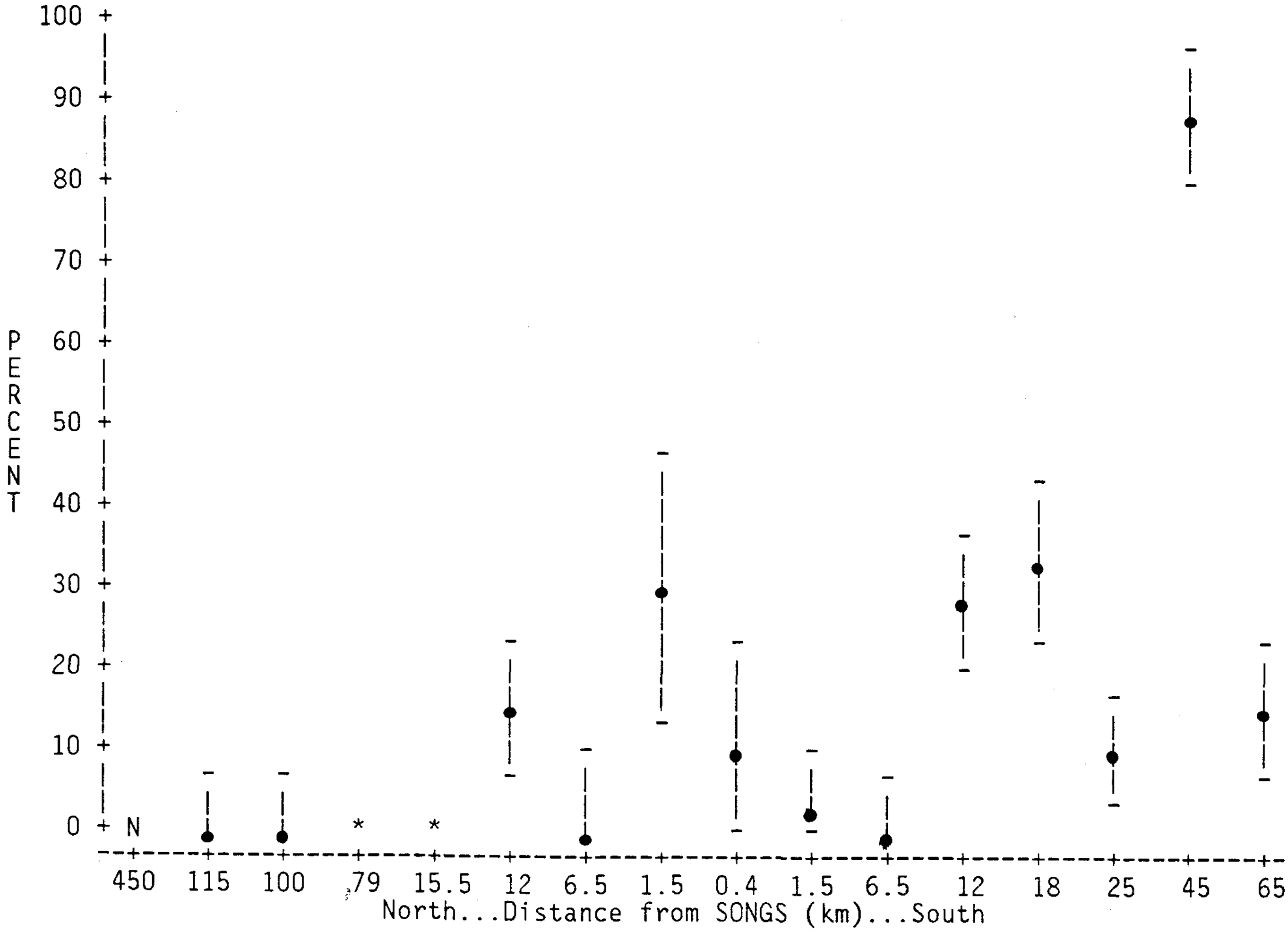
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	96.468	4	45 km S
	A	92.256	3	18 km S
B	A	80.000	1	79 km N
B		67.397	3	65 km S
B		66.945	6	25 km S
	C	16.950	6	100 km N
	C	16.552	6	115 km N

Figure 3-24a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs or spent egg cases in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS OR SPENT EGG CASES
JULY 1983

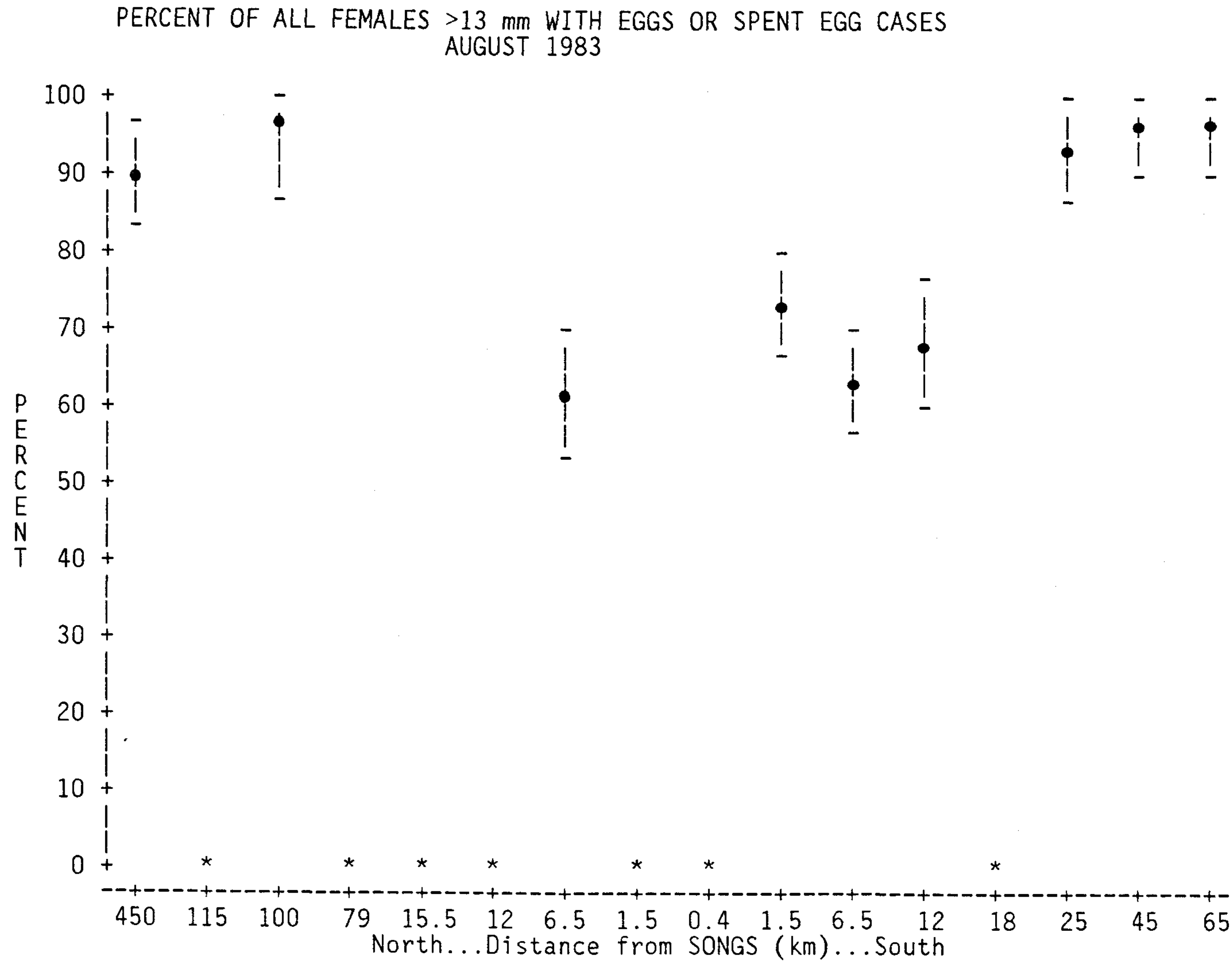


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	87.575	4	45 km S
	B	32.824	3	18 km S
	B	30.769	1	1.5 km N
	B	29.031	4	12 km S
C	B	15.698	4	65 km S
C	B	14.834	4	12 km N
C		9.821	2	0.4 km N
C		9.173	6	25 km S
C		2.258	4	1.5 km S
C		1.082	6	100 km N
C		0.667	5	6.5 km S
C		0.161	4	6.5 km N
C		0.122	6	115 km N

Figure 3-24b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs or spent egg cases in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



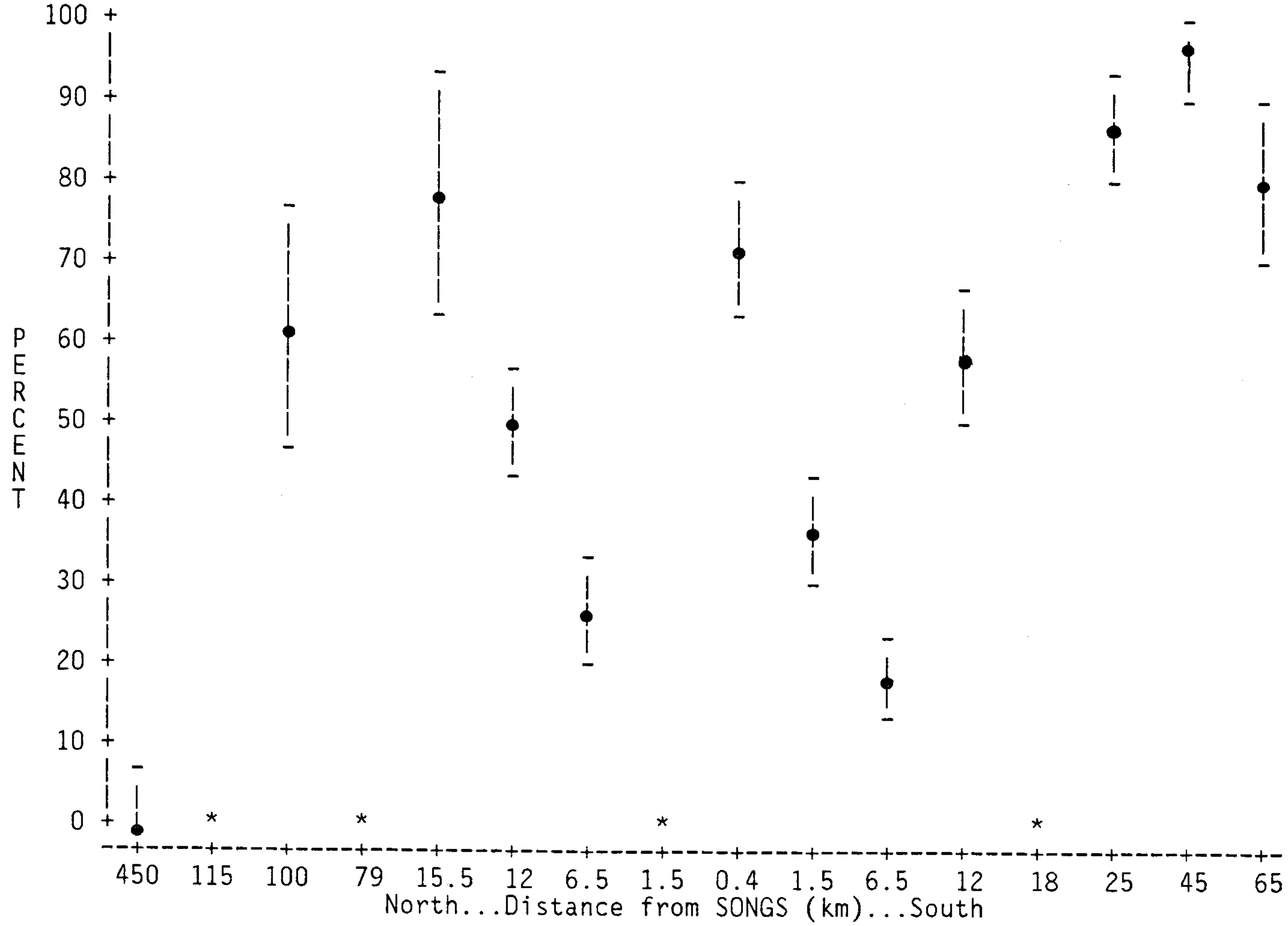
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	98.256	3	45 km S
A	97.557	4	65 km S
A	95.822	4	100 km N
A	92.796	4	25 km S
A	89.470	6	450 km N
B	73.155	4	1.5 km S
B	69.075	3	12 km S
B	63.800	6	6.5 km S
B	62.521	4	6.5 km N

Figure 3-25a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS OR SPENT EGG CASES
AUGUST 1983



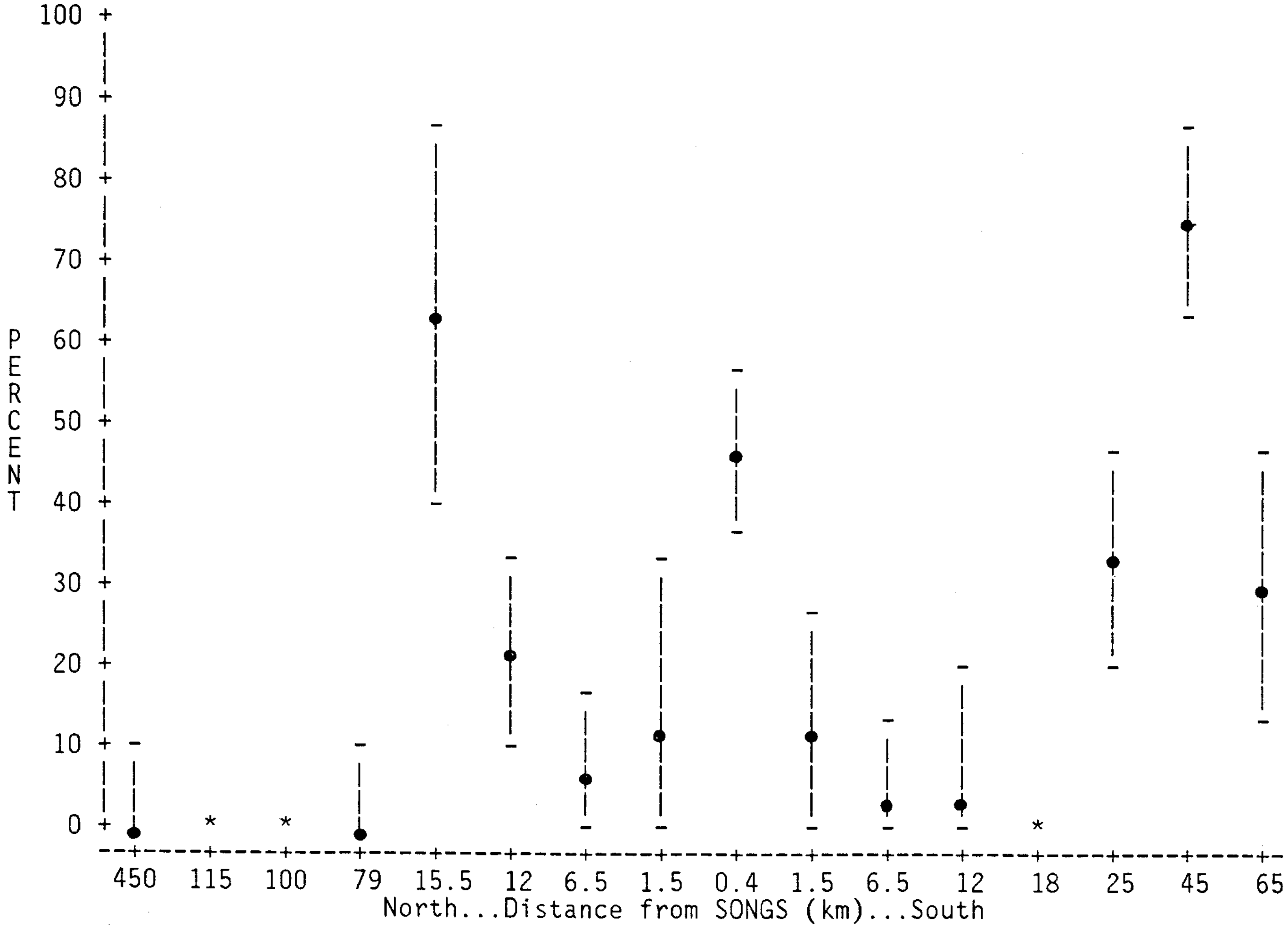
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING			MEAN	REPS	BEACH
	A		96.909	4	45 km S
B	A		86.347	4	25 km S
B			79.639	2	65 km S
B	C		76.923	1	15.5 km N
B	C	D	72.131	4	0.4 km N
E	C	D	61.538	1	100 km N
E		D	58.989	4	12 km S
E			50.864	4	12 km N
	F		35.884	6	1.5 km S
G	F		26.162	6	6.5 km N
G			18.569	6	6.5 km S
	H		0.000	6	450 km N

Figure 3-25b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >7 mm AND <10 mm WITH EGGS OR SPENT EGG CASES
AUGUST 1983

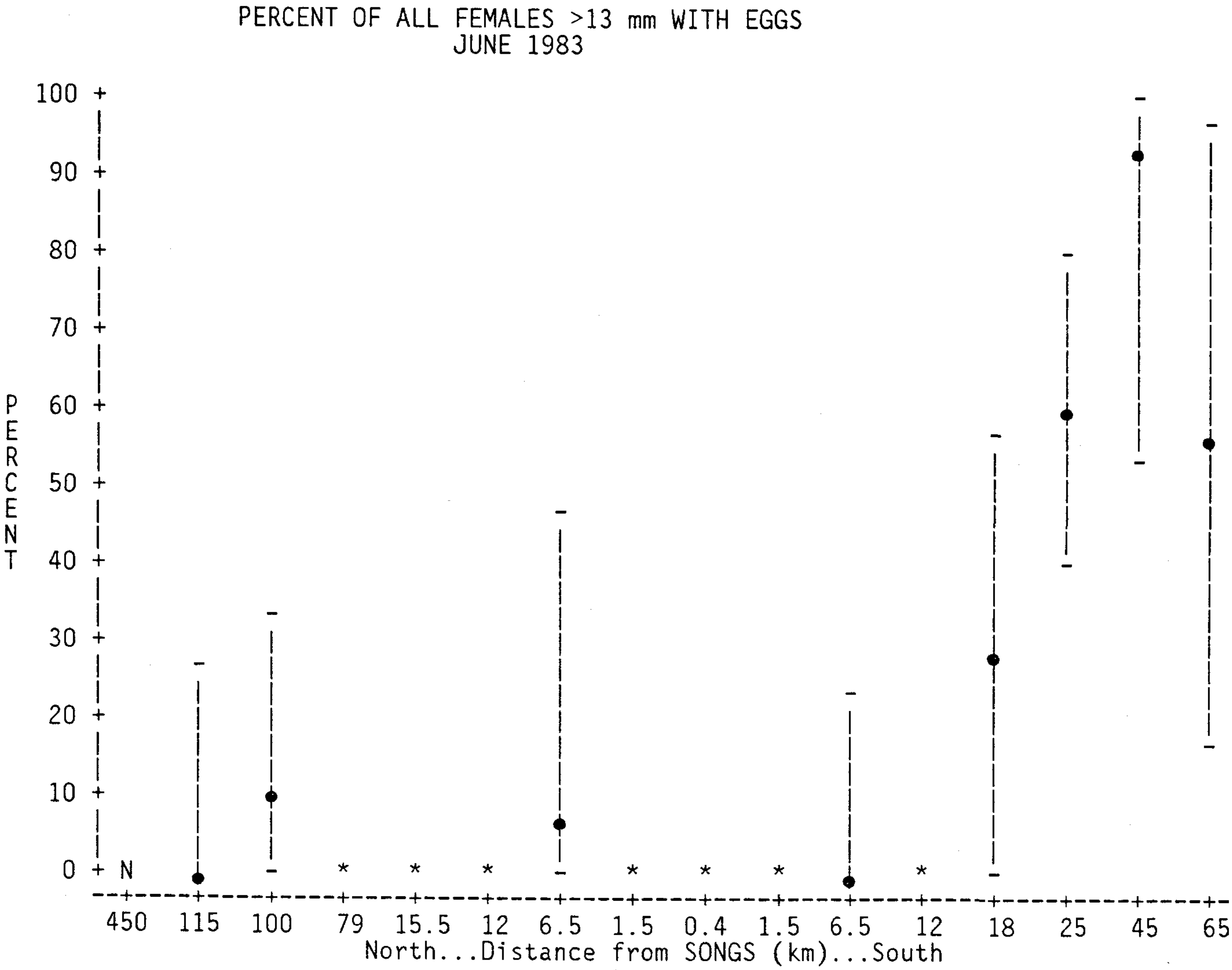


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	75.350	4	45 km S
B	A	64.000	1	15.5 km N
B	C	46.677	4	0.4 km N
D	C	33.916	3	25 km S
D	C	29.167	2	65 km S
D	C	21.312	4	12 km N
D		11.779	3	1.5 km S
D		11.765	1	1.5 km N
D		6.741	6	6.5 km N
D		3.571	2	12 km S
D		3.540	6	6.5 km S
D		0.000	6	450 km N
D		0.000	4	79 km N

Figure 3-25c. Mean percentages, by beach, of females larger than 7 mm and smaller than 10 mm carapace length with eggs or spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



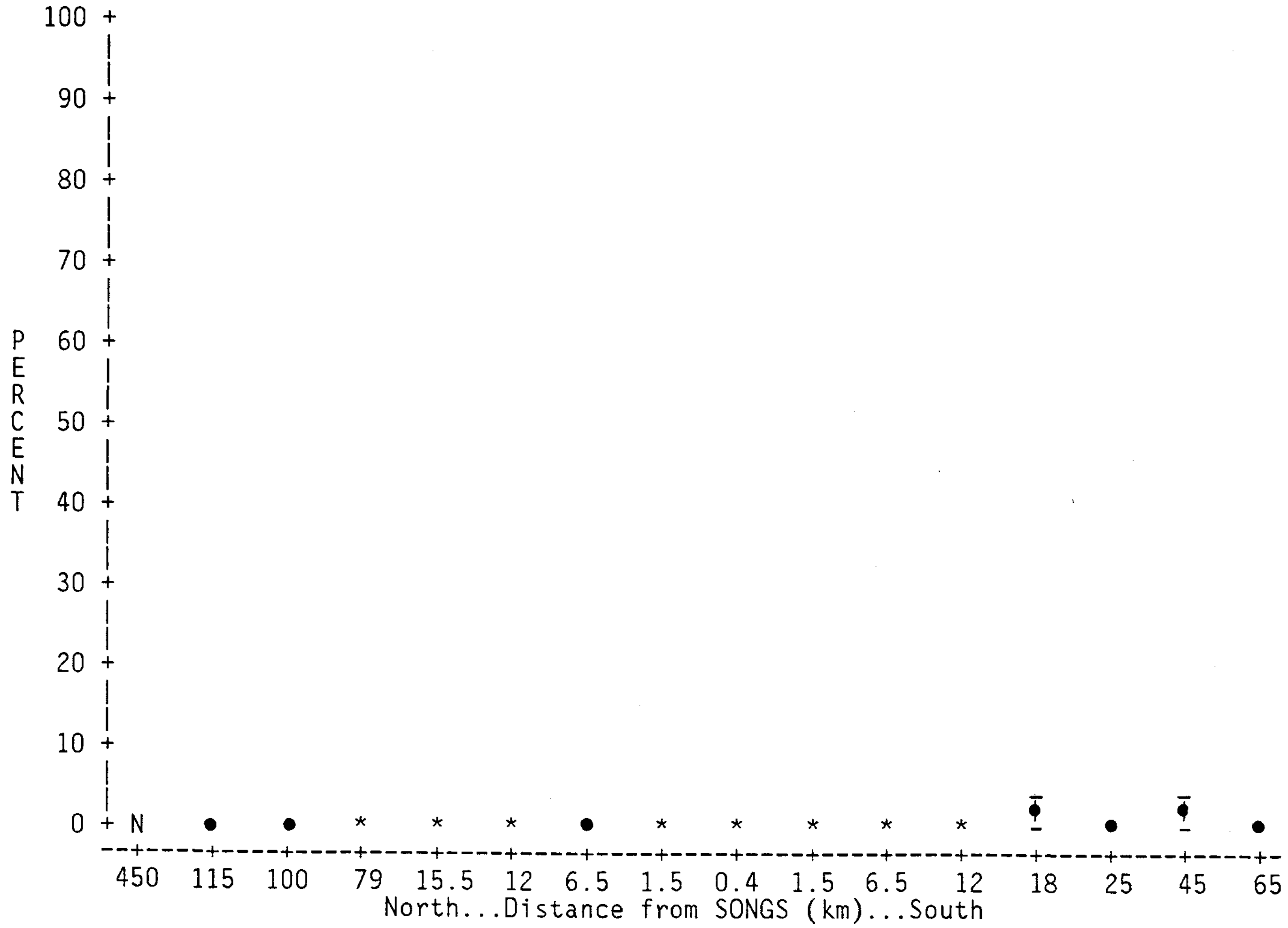
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	92.593	1	45 km S
B	A	61.077	4	25 km S
B	A	57.500	1	65 km S
B	A	28.571	2	18 km S
B		9.295	3	100 km N
B		6.667	1	6.5 km N
B		0.000	3	6.5 km S
B		0.000	2	115 km N

Figure 3-26a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS
JUNE 1983

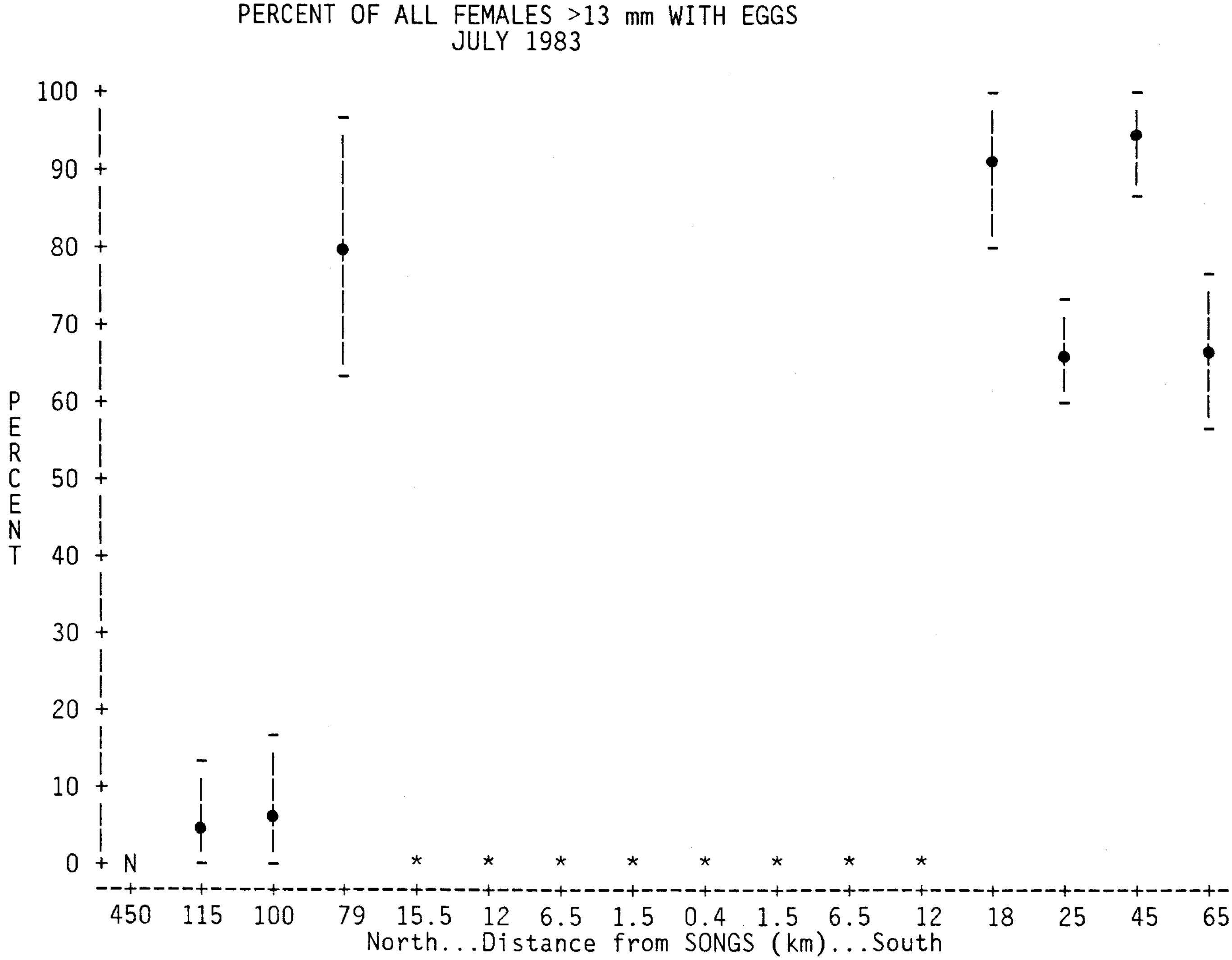


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	2.857	1	45 km S
B	A	1.679	3	18 km S
B		0.278	6	25 km S
B		0.000	4	100 km N
B		0.000	6	115 km N
B		0.000	1	6.5 km N
B		0.000	1	65 km S

Figure 3-26b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



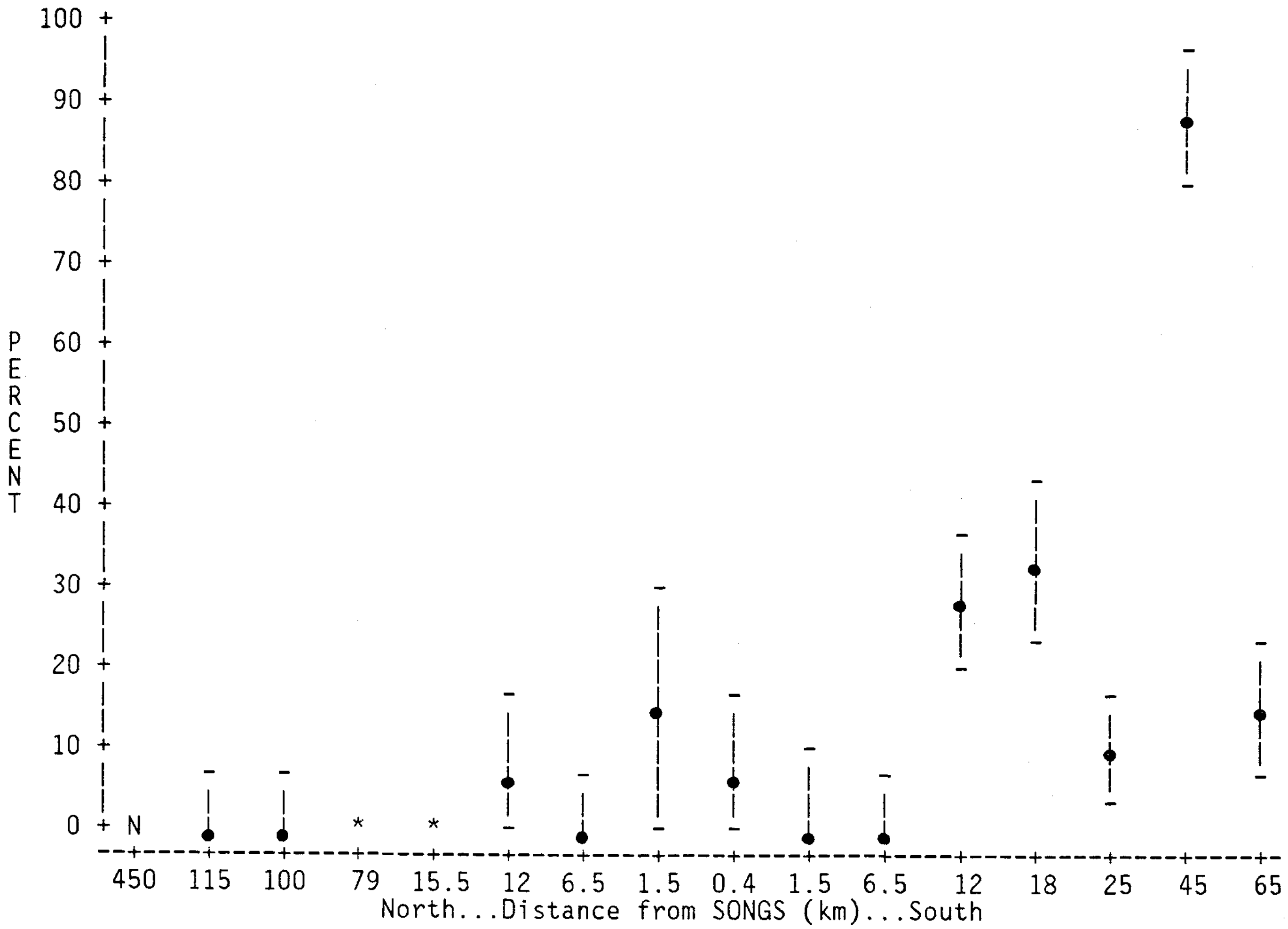
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	95.079	4	45 km S
	A	91.714	3	18 km S
B	A	80.000	1	79 km N
B		66.788	3	65 km S
B		66.301	6	25 km S
	C	7.784	6	100 km N
	C	4.446	6	115 km N

Figure 3-27a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS
JULY 1983



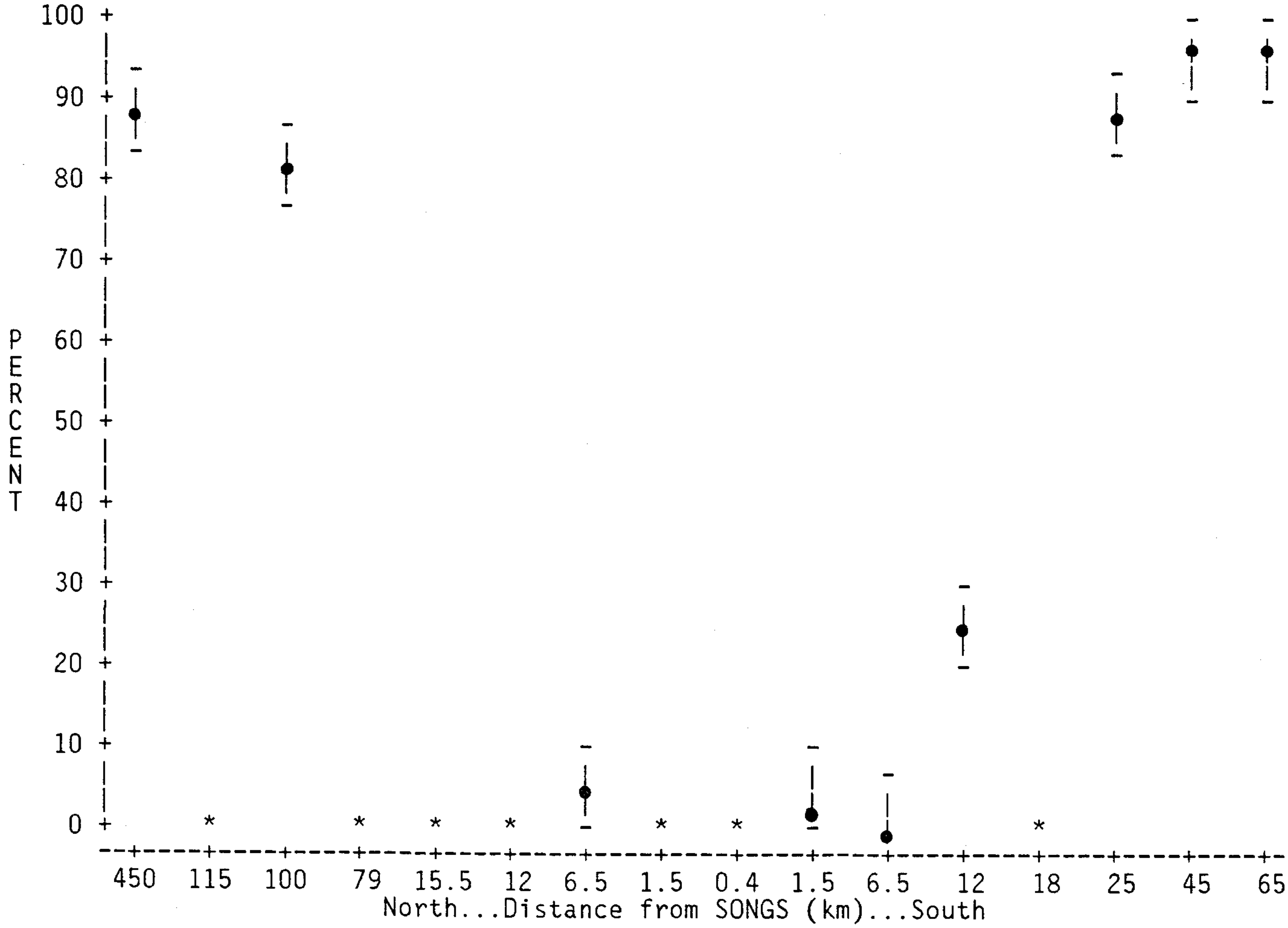
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	87.472	4	45 km S
B	32.824	3	18 km S
B	29.031	4	12 km S
C	15.698	4	65 km S
C	15.385	1	1.5 km N
C	8.905	6	25 km S
C	7.783	4	12 km N
C	6.696	2	0.4 km N
C	0.632	6	100 km N
C	0.446	4	1.5 km S
C	0.000	6	115 km N
C	0.000	4	6.5 km N
C	0.000	5	6.5 km S

Figure 3-27b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >13 mm WITH EGGS
AUGUST 1983



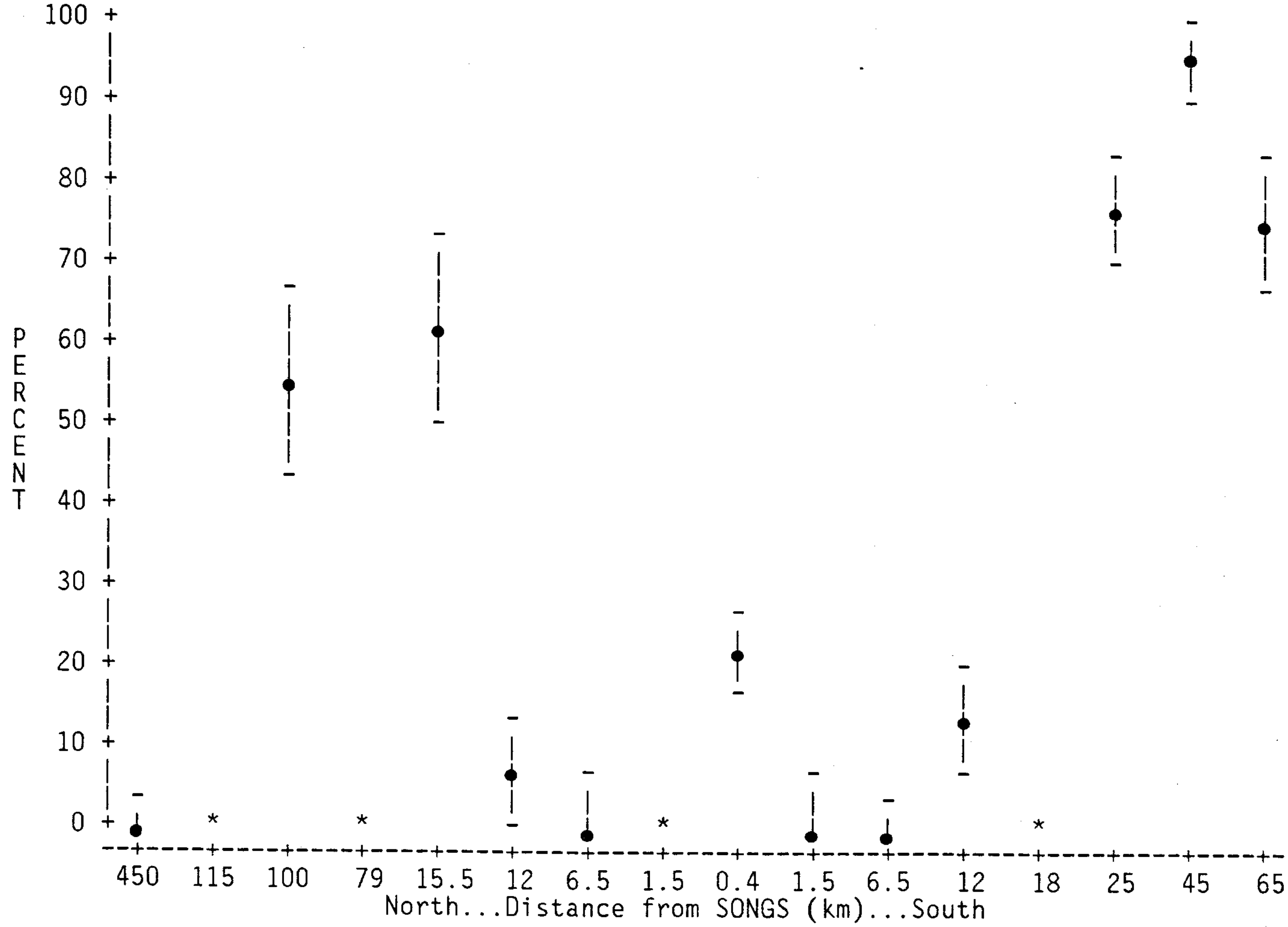
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	96.753	3	45 km S
	A	96.246	4	65 km S
B	A	87.832	4	25 km S
B	A	87.444	6	450 km N
B		82.283	4	100 km N
	C	24.903	3	12 km S
	D	5.699	4	6.5 km N
	D	2.761	4	1.5 km S
	D	0.798	6	6.5 km S

Figure 3-28a. Mean percentages, by beach, of females larger than 13 mm carapace length with eggs in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH EGGS
AUGUST 1983



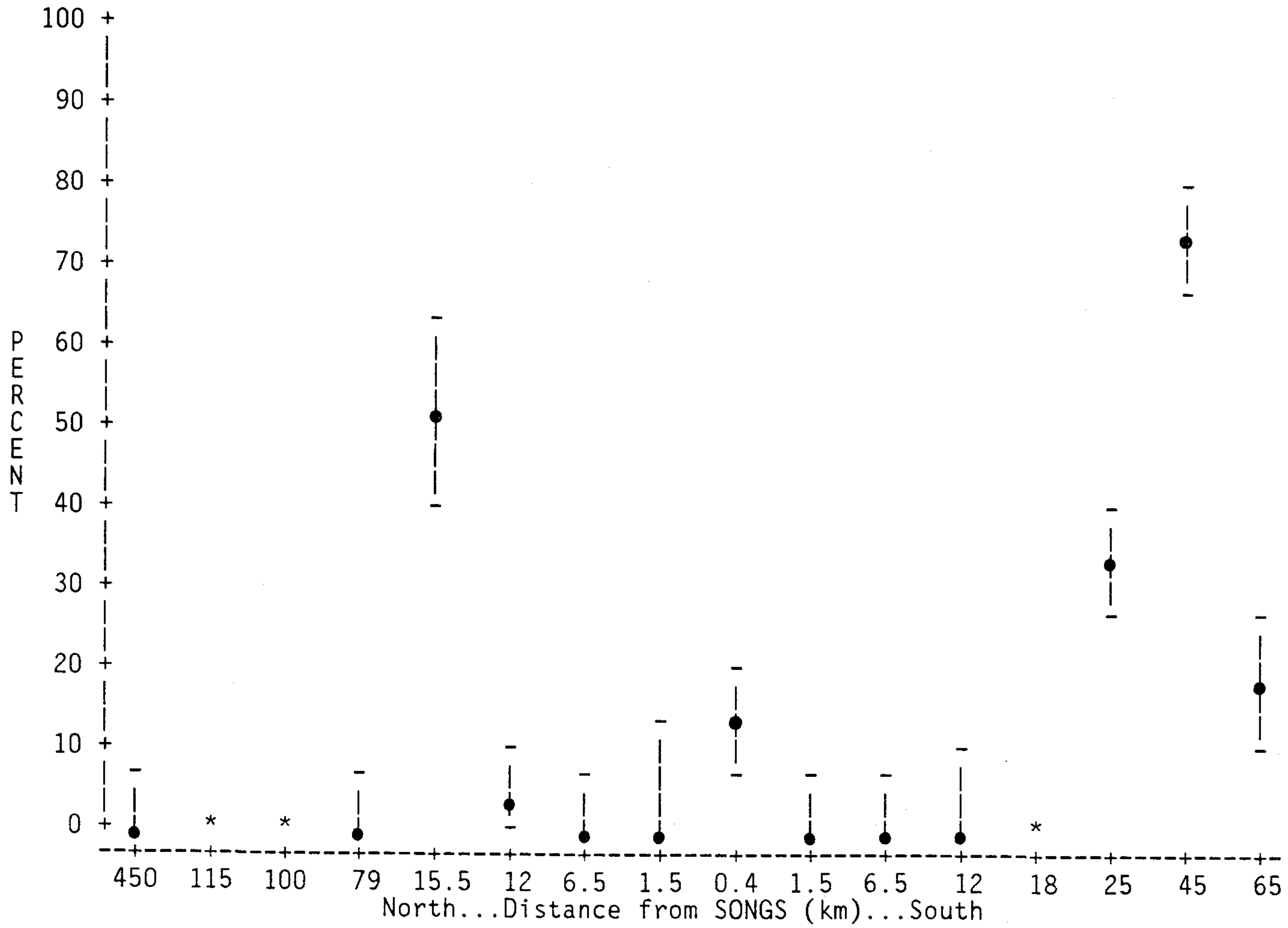
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	95.916	4	45 km S
	B	76.383	4	25 km S
	B	74.828	2	65 km S
	C	61.538	1	15.5 km N
	C	53.846	1	100 km N
	D	21.416	4	0.4 km N
E	D	13.989	4	12 km S
E	F	7.428	4	12 km N
	F	0.450	6	6.5 km N
	F	0.266	6	1.5 km S
	F	0.000	6	6.5 km S
	F	0.000	6	450 km N

Figure 3-28b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with eggs in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >7 mm AND <10 mm WITH EGGS
AUGUST 1983

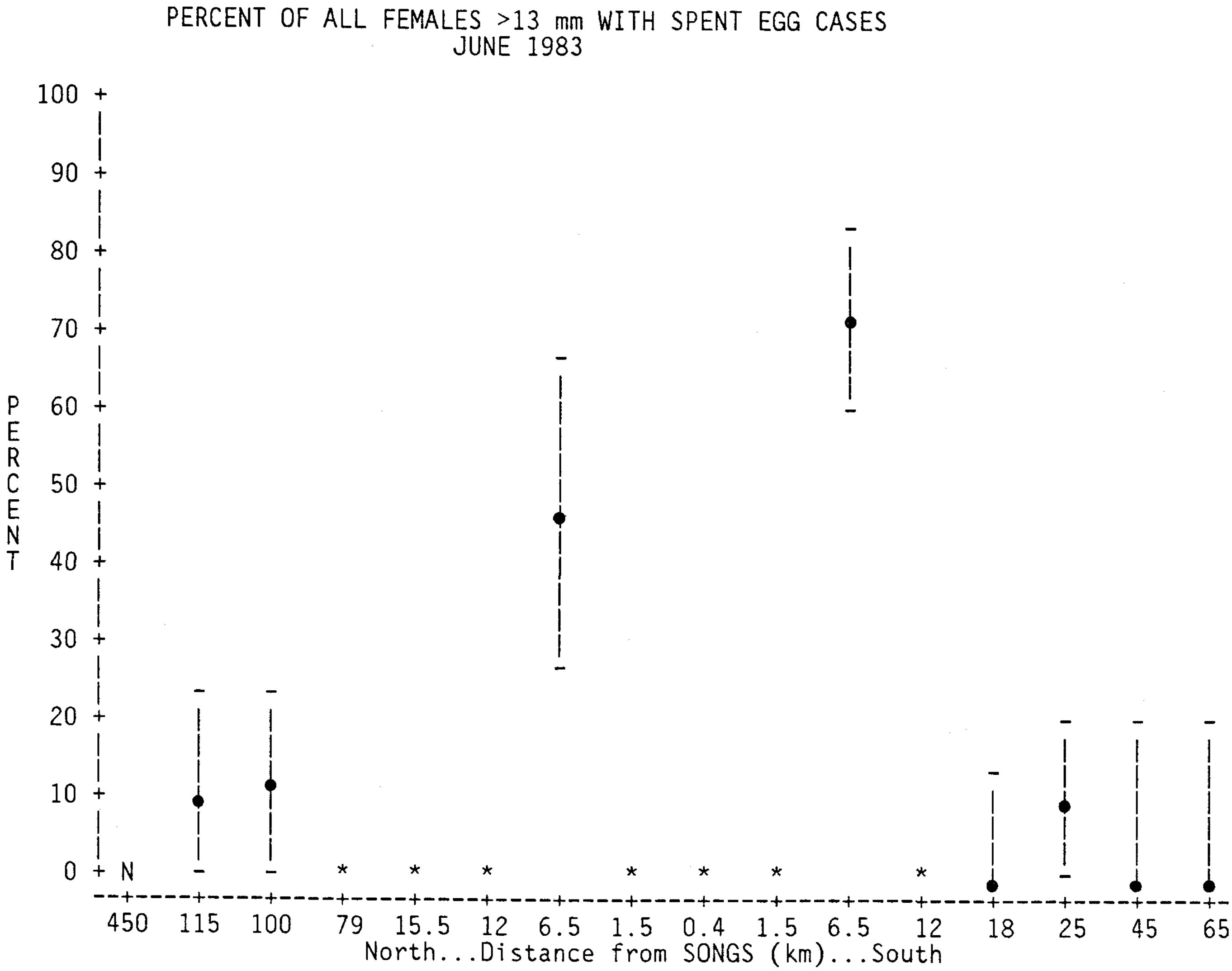


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	72.686	4	45 km S
	B	52.000	1	15.5 km N
	C	33.351	3	25 km S
	D	19.167	2	65 km S
E	D	12.612	4	0.4 km N
E		2.893	4	12 km N
E		0.000	3	1.5 km S
E		0.000	1	1.5 km N
E		0.000	6	450 km N
E		0.000	6	6.5 km N
E		0.000	6	6.5 km S
E		0.000	2	12 km S
E		0.000	4	79 km N

Figure 3-28c. Mean percentages, by beach, of females larger than 7 mm and smaller than 10 mm carapace length with eggs in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



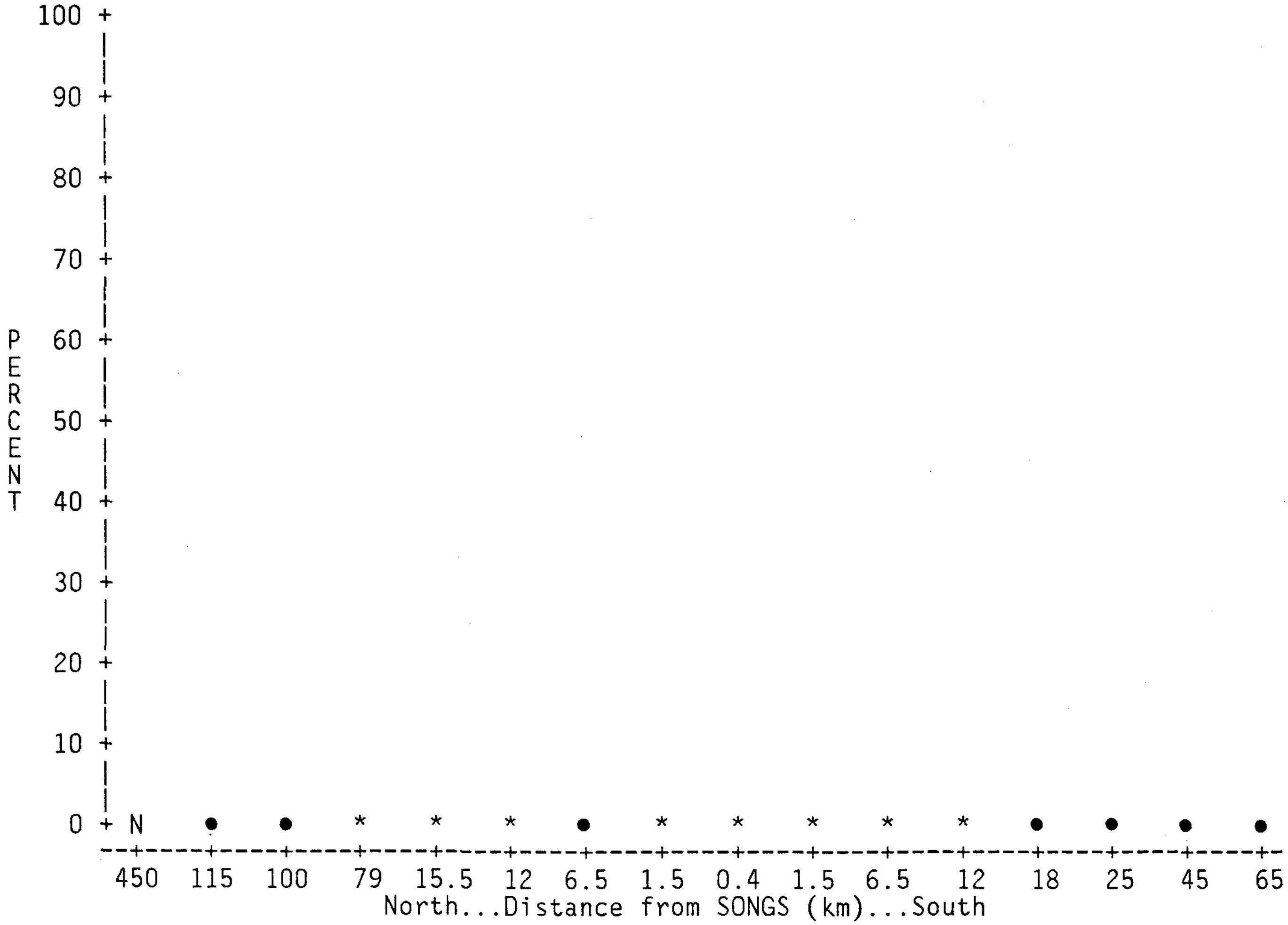
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	70.971	3	6.5 km S
B	46.667	1	6.5 km N
C	11.499	3	100 km N
C	8.978	4	25 km S
C	8.824	2	115 km N
C	0.000	1	45 km S
C	0.000	2	18 km S
C	0.000	1	65 km S

Figure 3-29a. Mean percentages, by beach, of females larger than 13 mm carapace length with spent egg cases in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH SPENT EGG CASES
JUNE 1983

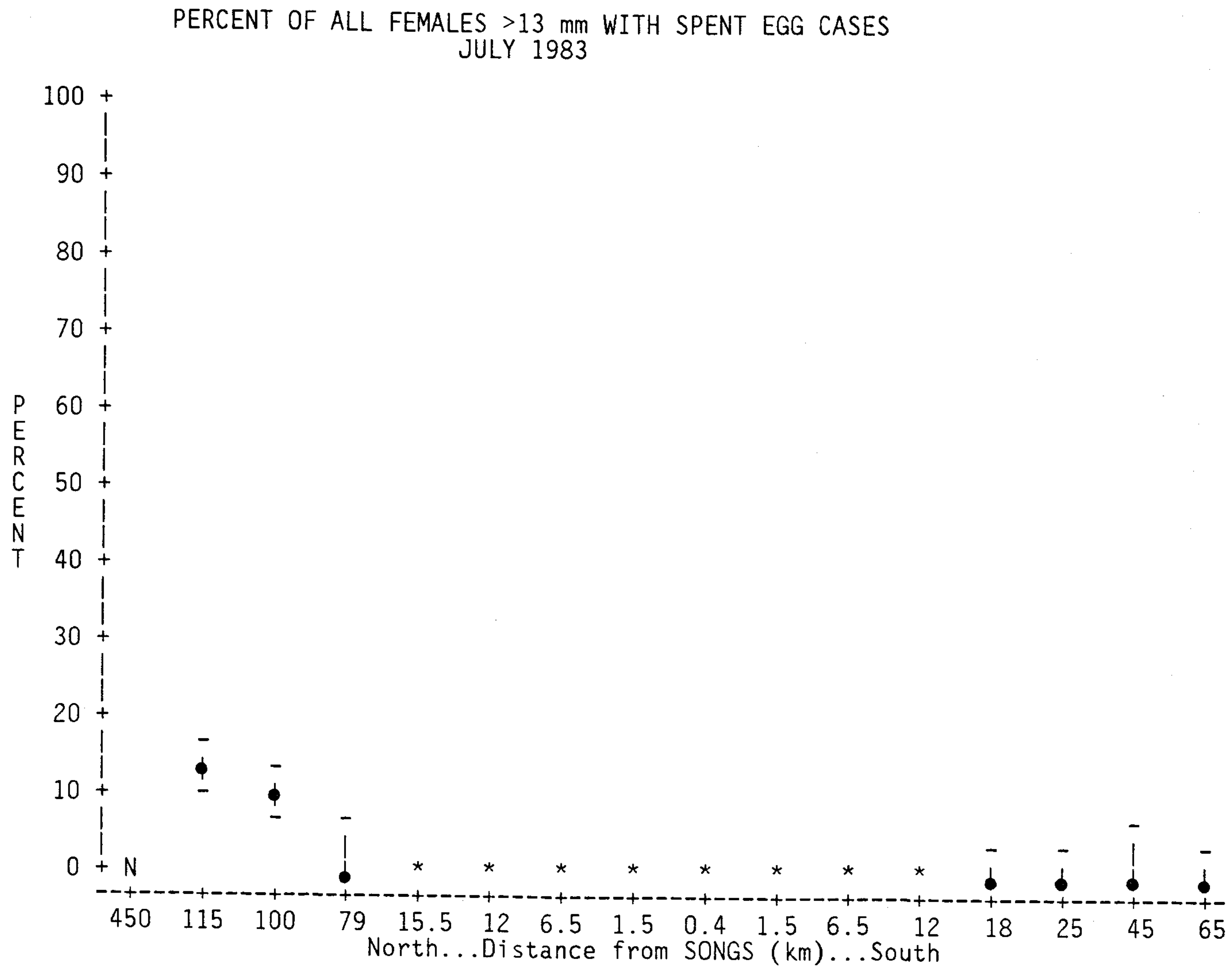


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	0	4	100 km N
A	0	6	115 km N
A	0	3	18 km S
A	0	6	25 km S
A	0	1	45 km S
A	0	1	6.5 km N
A	0	1	65 km S

Figure 3-29b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with spent egg cases in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

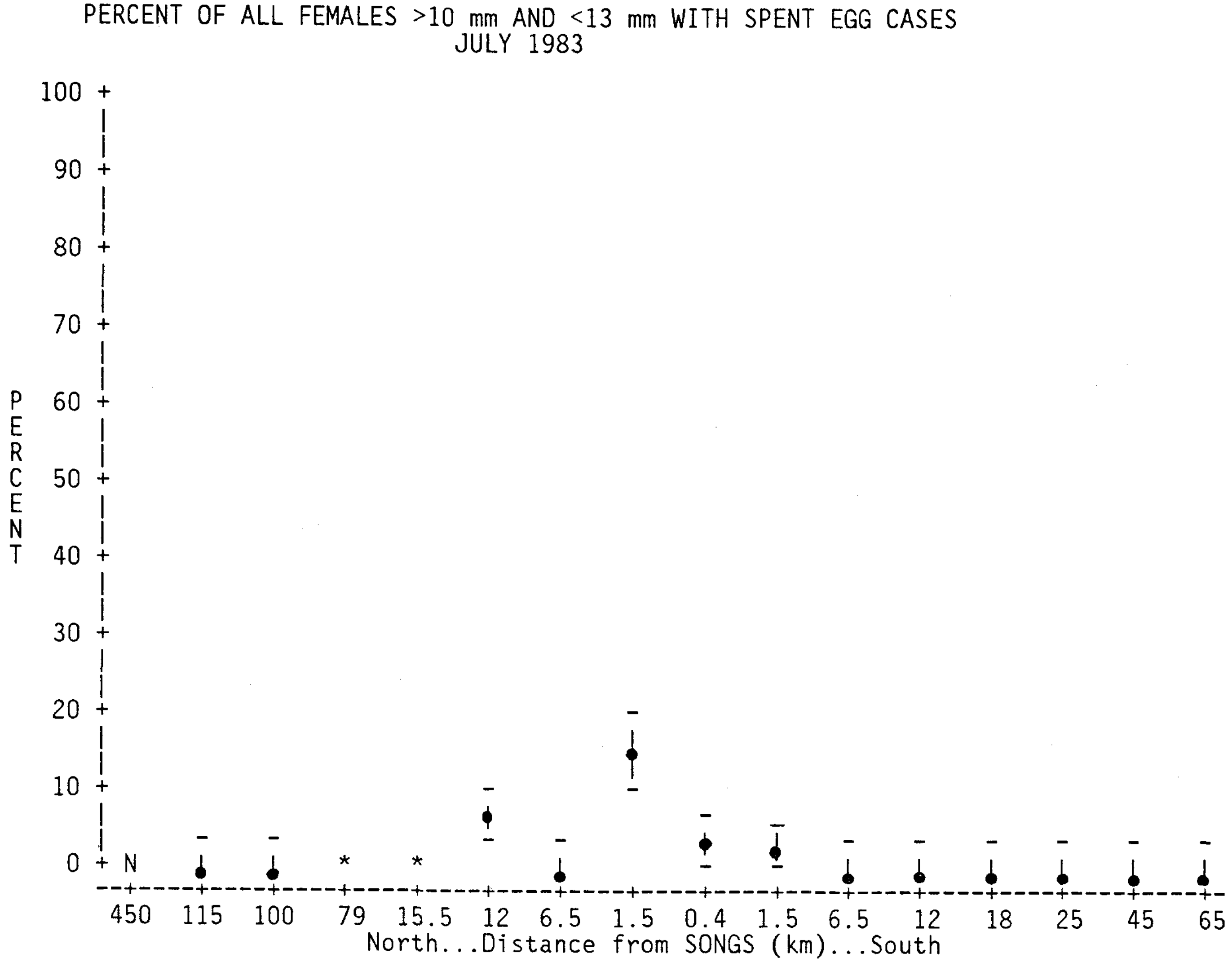


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	12.107	6	115 km N
A	9.166	6	100 km N
B	1.389	4	45 km S
B	0.644	6	25 km S
B	0.609	3	65 km S
B	0.542	3	18 km S
B	0.000	1	79 km N

Figure 3-30a. Mean percentages, by beach, of females larger than 13 mm carapace length with spent egg cases in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

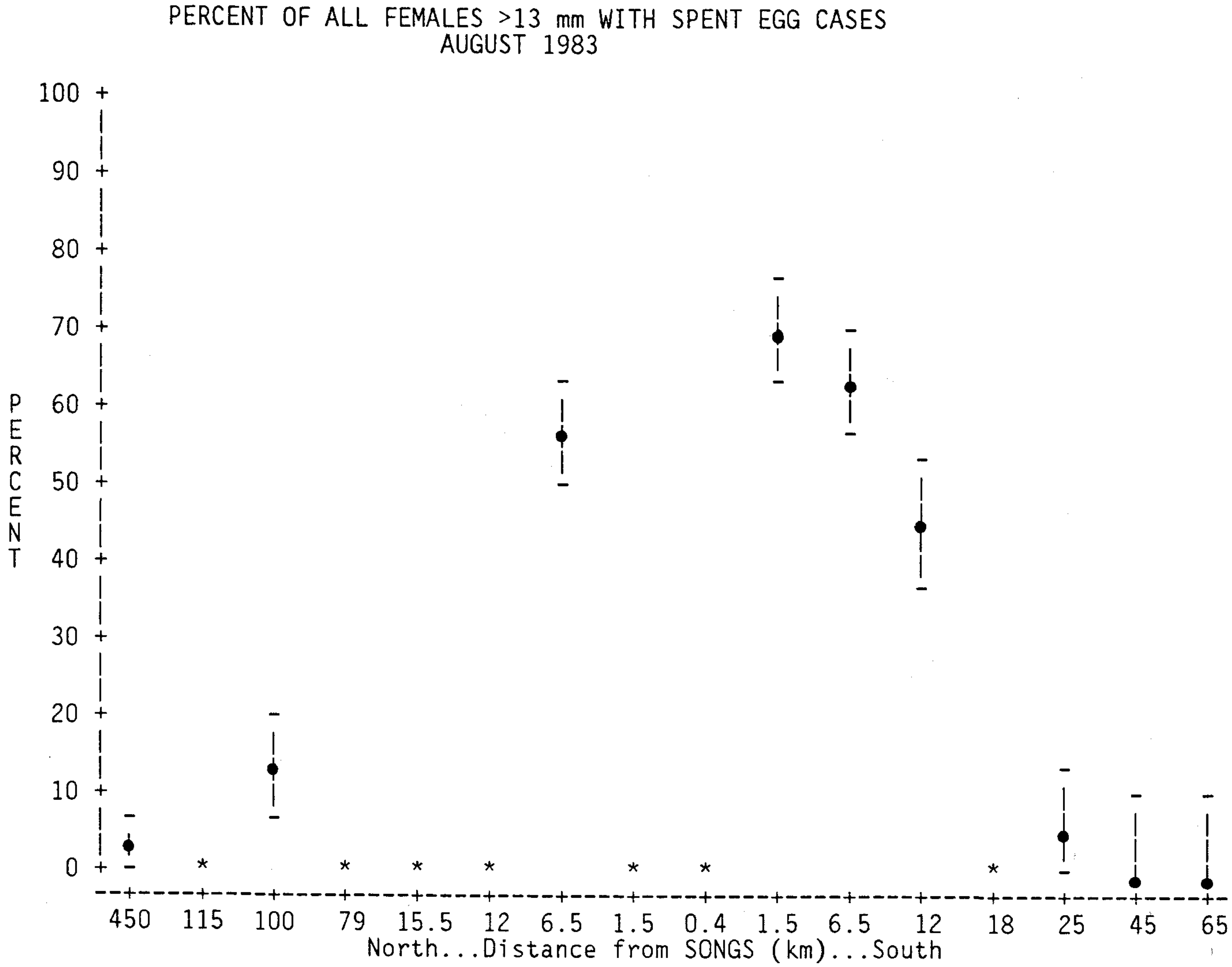


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	15.385	1	1.5 km N
B	7.052	4	12 km N
C	3.125	2	0.4 km N
C	1.812	4	1.5 km S
C	0.667	5	6.5 km S
C	0.450	6	100 km N
C	0.268	6	25 km S
C	0.161	4	6.5 km N
C	0.122	6	115 km N
C	0.103	4	45 km S
C	0.000	4	12 km S
C	0.000	3	18 km S
C	0.000	4	65 km S

Figure 3-30b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with spent egg cases in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



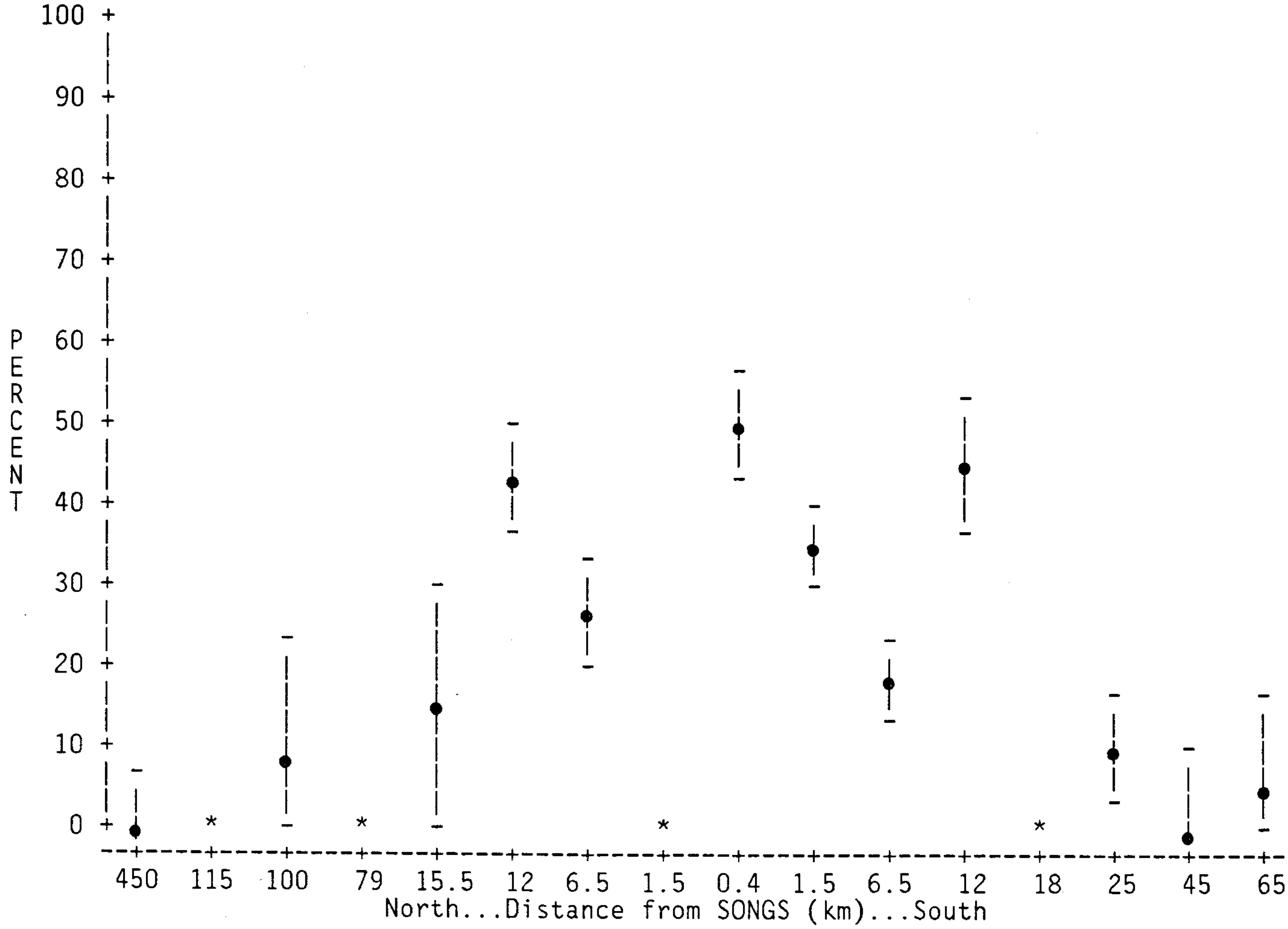
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	70.394	4	1.5 km S
B	A	63.002	6	6.5 km S
B		56.822	4	6.5 km N
	C	44.172	3	12 km S
	D	13.539	4	100 km N
	D	4.964	4	25 km S
	D	2.026	6	450 km N
	D	1.503	3	45 km S
	D	1.311	4	65 km S

Figure 3-31a. Mean percentages, by beach, of females larger than 13 mm carapace length with spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >10 mm AND <13 mm WITH SPENT EGG CASES
AUGUST 1983



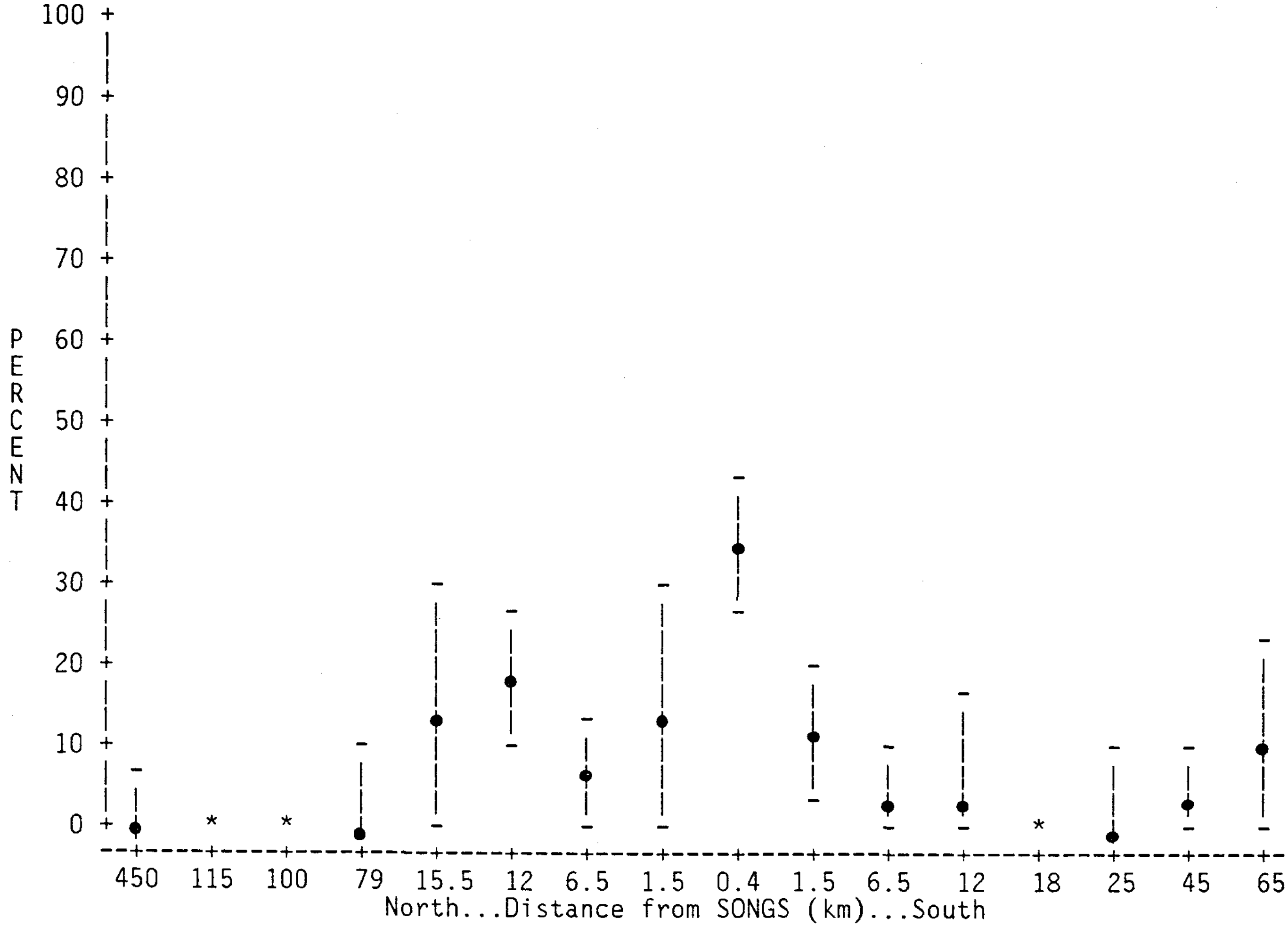
* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING		MEAN	REPS	BEACH
	A	50.714	4	0.4 km N
	A	45.000	4	12 km S
	A	43.436	4	12 km N
B	A	35.618	6	1.5 km S
B	C	25.712	6	6.5 km N
D	C	18.569	6	6.5 km S
D	C	15.385	1	15.5 km N
D	C	9.964	4	25 km S
D	C	7.692	1	100 km N
D		4.811	2	65 km S
D		0.993	4	45 km S
D		0.000	6	450 km N

Figure 3-31b. Mean percentages, by beach, of females larger than 10 mm and smaller than 13 mm carapace length with spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF ALL FEMALES >7 mm AND <10 mm WITH SPENT EGG CASES
AUGUST 1983

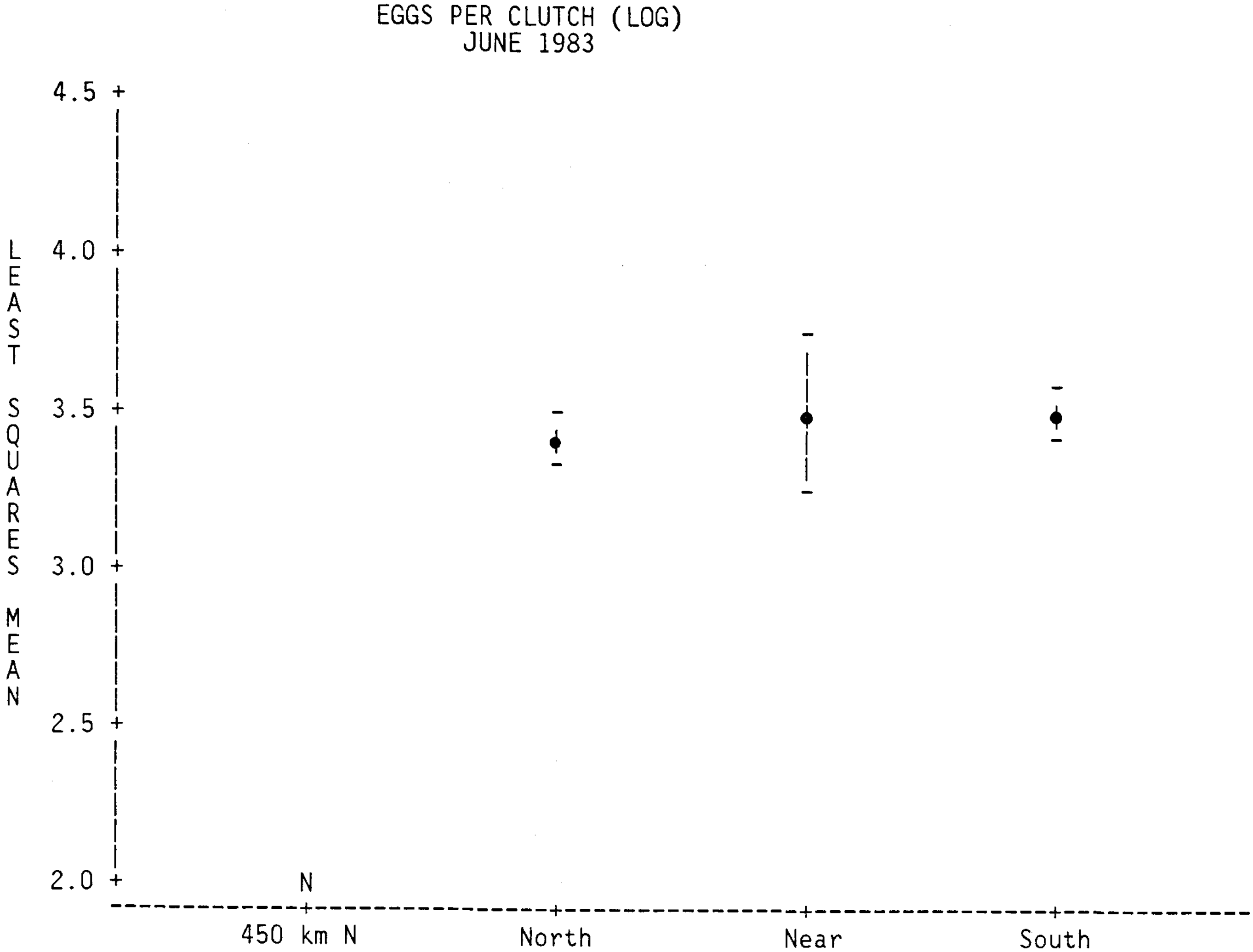


* = less than 10 animals per replicate
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

GROUPING	MEAN	REPS	BEACH
A	34.065	4	0.4 km N
B	18.419	4	12 km N
B	12.000	1	15.5 km N
B	11.779	3	1.5 km S
B	11.765	1	1.5 km N
B	10.000	2	65 km S
B	6.741	6	6.5 km N
B	3.571	2	12 km S
B	3.540	6	6.5 km S
B	2.664	4	45 km S
B	0.565	3	25 km S
B	0.000	6	450 km N
B	0.000	4	79 km N

Figure 3-31c. Mean percentages, by beach, of females larger than 7 mm and smaller than 10 mm carapace length with spent egg cases in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

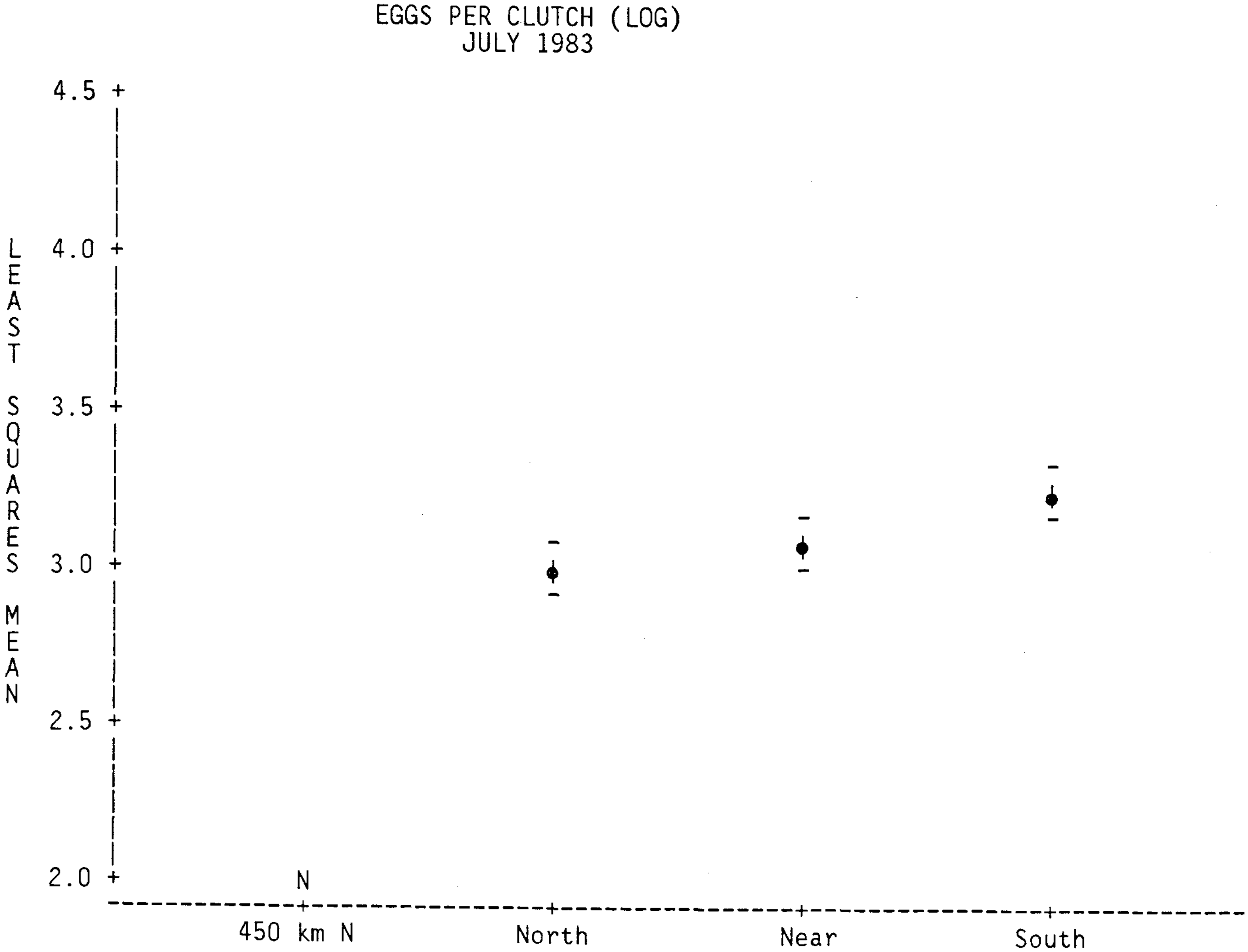


N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING	MEAN	REPS	BEACH
A	3.511	31	South
A	3.486	1	Near
A	3.450	11	North

Figure 3-32. Least square means of log (x + 1) transformed number of eggs per egg mass for beach sites near, north and south of SONGS that were sampled in June 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.



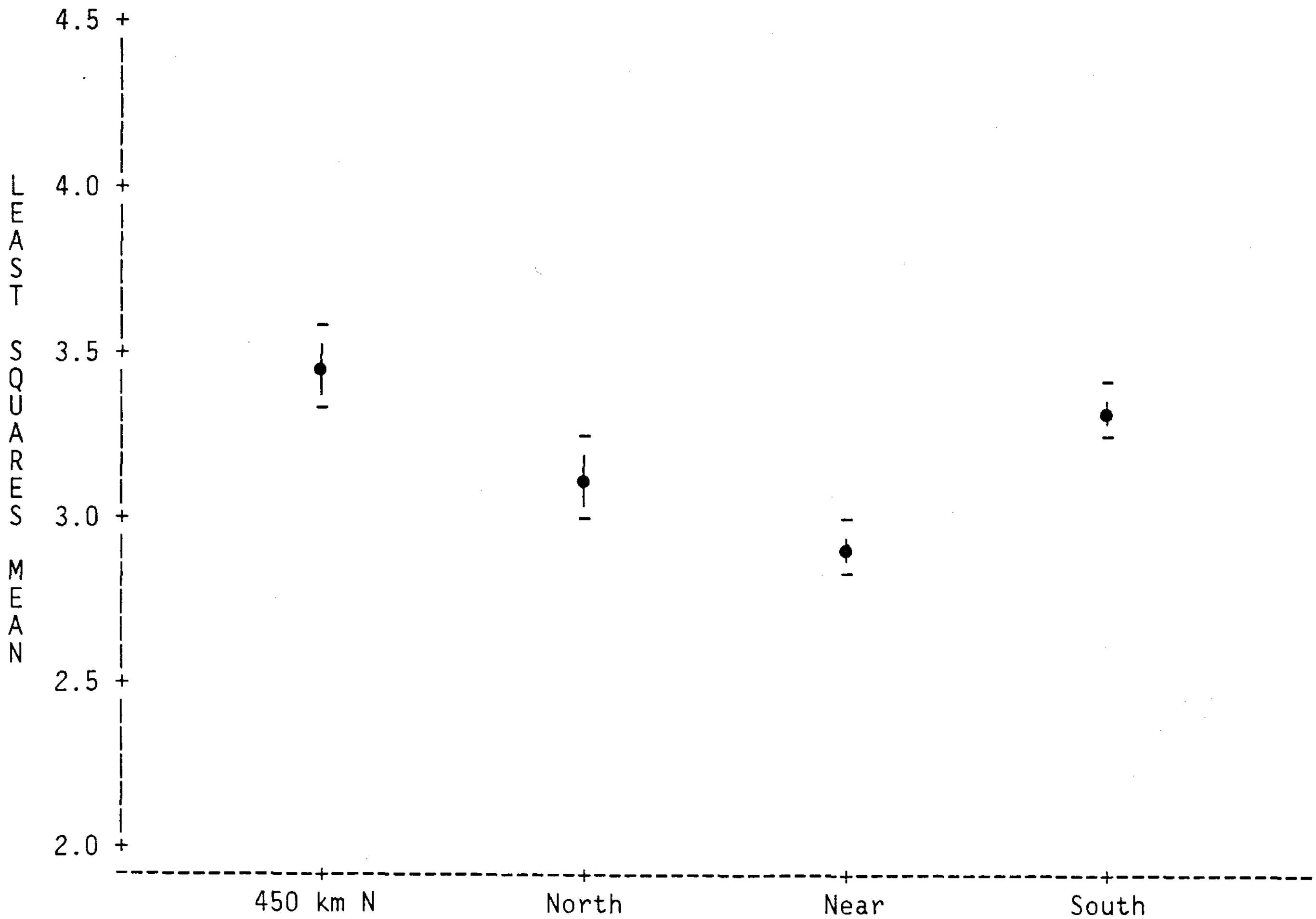
N = not sampled

STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING	MEAN	REPS	BEACH
A	3.253	32	South
B	3.107	24	Near
B	3.008	13	North

Figure 3-33. Least square means of log (x + 1) transformed number of eggs per egg mass for beach sites near, north and south of SONGS that were sampled in July 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

EGGS PER CLUTCH (LOG)
AUGUST 1983



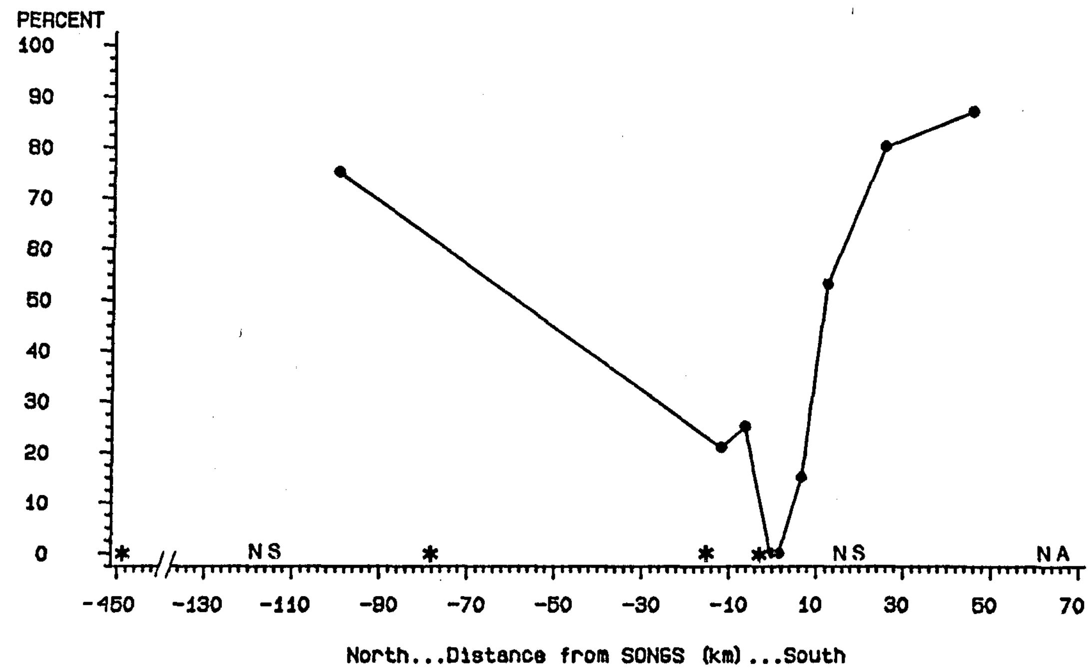
STUDENT-NEWMAN-KEULS TEST
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

GROUPING	MEAN	REPS	BEACH
A	3.446	7	450 km N
A	3.358	55	South
B	3.100	7	North
C	2.942	30	Near

Figure 3-34. Least square means of log (x + 1) transformed number of eggs per egg mass for beach sites near, north and south of SONGS that were sampled in August 1983 and the results of the SNK test on these values. Site means (dots) ± 2 S. E. are shown. Note that the "Distance" axis is not to scale.

PERCENT OF SPENT FEMALES 8–13 mm THAT WERE PRODUCING ANOTHER BATCH OF INTERNAL EGGS

Sampling period–August 1983



* – Less than 10 spent females per beach

NA – not analyzed

NS – not fully sampled because of weather or disturbance (see section 2.1.3.1)

Figure 3-35. The percentage of spent females (8-13 mm C.L.) that were producing another batch of internal eggs in August. Few small spent females were collected in August at Hermosa Beach (100 km N), therefore, females with burnt or grey eggs were also included in the percentage for that beach site.

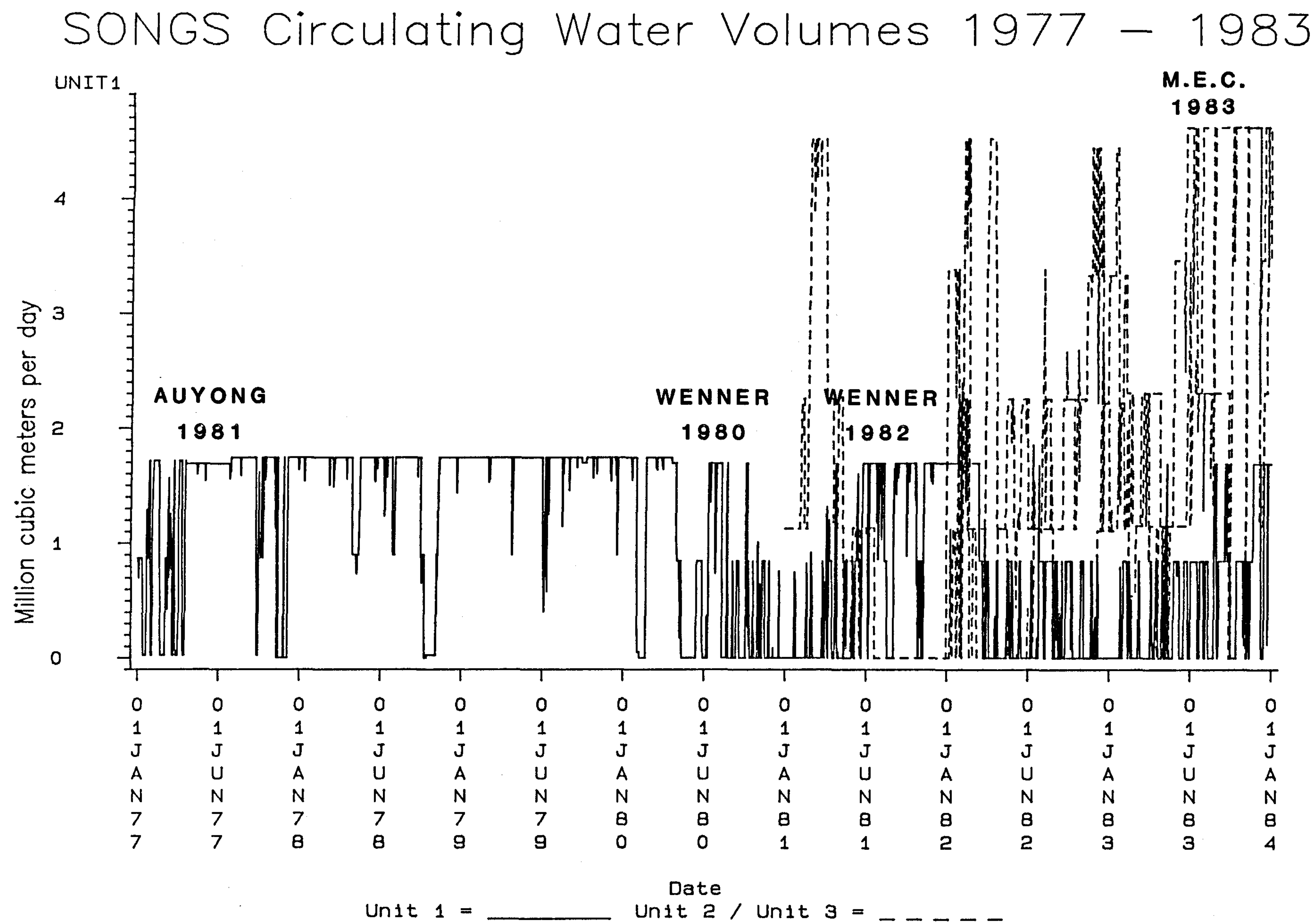


Figure 3-36. Water volumes (million cubic meters per day) that were circulated through SONGS Units 1, 2, and 3 during the period January 1977 to January 1984. The periods of 1983 and previous MRC studies of sand crabs are shown.

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