THE EFFECTS OF SMALL-SCALE KELP HARVESTING ON GIANT KELP SURFACE CANOPY DYNAMICS IN THE ED RICKETTS UNDERWATER PARK REGION

Final Report to the Monterey Bay National Marine Sanctuary
and the Cities of Monterey and Pacific Grove

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SUMMARY

The effects of hand-harvesting giant kelp (*Macrocystis pyrifera*) on the surface canopy of kelp forests offshore of Monterey and Pacific Grove were investigated. This study was stimulated by concerns over the possible negative biological effects of recent intensive kelp harvesting by local aquaculture firms on giant kelp, rockfish, and sea otter populations, particularly when harvesting activities are concentrated within a small local area during the winter. We used aerial photographs dating to 1976 and kelp harvest records to address only the question of important harvest effects on giant kelp canopies, not the general effects of kelp harvesting. Three different periods of kelp harvesting relative intensity in this area have occurred since the early 1970s: a period of "moderate harvest" from 1972 - 1985, a period of "low harvest" from 1986 - 1995, and a period of "high harvest" from 1996 to present. Eight surveys were available from each of the periods of 1972 - 1985 and 1986 - 1995, and two surveys were available from the period of 1996 - 1998.

For the years in which aerial kelp surveys were available, hardcopy maps of kelp forest canopies were derived from aerial survey slides taken during the fall period of maximum canopy extent. The resultant maps were scanned into a computer, and image analysis software was used to measure kelp canopy surface area (the actual surface area of kelp canopy fronds floating on the surface), kelp forest spatial extent (the total surface area of a kelp forest canopy contained within its outer perimeter), and kelp canopy density (an index of canopy abundance within a given kelp forest ranging from "dense" to "sparse"). Using a modified Before - After - Control - Impact (BACI) study design and analysis of variance (ANOVA) statistical testing, these variables were compared between three harvested areas and one unharvested control area (Hopkins Marine Life Refuge) during each of the three periods of relative harvesting intensity. Since the period of interest (from 1996-1998) had a sample size of only two, we could not make rigorous, meaningful comparisons between this period and the other two periods. However, we were able to use a BACI approach (with two-sample t-tests) to test for a harvesting effect between the period of "moderate harvest" and the period of "low harvest." These comparisons were not directly applicable to the "high harvest" period of interest, but the results may suggest patterns to expect if the current level of kelp harvesting intensity continues. Regression analyses of the amount of kelp harvested during the winter versus the maximum amount of giant kelp surface canopy present during the following year were also performed.

No statistically significant differences in kelp canopies among periods were found using ANOVA analyses, and results of regression analyses were also statistically non-significant. No effects of current kelp harvesting practices on giant kelp canopies were *detectable*, but statistical power to detect an effect was low given the small sample size ($n = 2$) of the "high harvest" period and the inherent natural variability of kelp canopies. Therefore, these results do not necessarily indicate that there was not a harvesting effect, only that such an effect was undetectable given the available data. Separate comparisons of kelp canopies between "moderate harvest" and "low harvest" periods (NOT the period in question) showed significant differences between the two periods at one of the three harvested study sites, but these results may have been confounded by kelp harvesting immediately prior to the aerial surveys. If these results were not confounded, they suggest that harvesting concentrated within a relatively small area may negatively affect giant kelp canopies. Continued yearly aerial surveys during the period of fall maximum kelp canopy are needed in order to resolve this issue.

INTRODUCTION

Recent public debates concerning potential regulations for the newly-created Ed Ricketts Underwater Park have addressed the appropriateness of certain "uses" occurring in the region, particularly the harvesting of giant kelp. Various ocean-related user groups have asserted that kelp harvesting operations off the Monterey Peninsula may be causing a decline in the amount of surface canopy in the area extending from the Monterey Coast Guard Breakwater to Lovers Point. Indeed, one aerial photograph (which was displayed in a public forum) of Hopkins Marine Life Refuge and the adjacent area taken during winter/spring 1998 showed a relatively abundant kelp canopy within the reserve (where kelp harvesting is prohibited) and little canopy in the adjacent areas where harvesting occurs. In the spirit of science-based resource management, the Monterey Bay National Marine Sanctuary and the cities of Monterey and Pacific Grove commissioned this report to more thoroughly examine the effects of kelp harvesting on harvested canopies. Using a time series of aerial kelp canopy surveys dating to 1976 and available kelp harvest records, we addressed the following question: Are current kelp harvesting practices causing a detectable effect on the abundance of giant kelp (*Macrocystis pyrifera*) surface canopy, as measured during the period of fall maximum surface canopy, in the Ed Ricketts Underwater Park region?

BACKGROUND

Kelp has been harvested in the state of California to varying degrees since early this century, and as early as 1914 in Monterey (Scofield, 1959). Ironically, a sample of 2 wet tons of kelp taken from in front of the Del Monte Bathhouse (Monterey) led to the first-ever objection to kelp harvesting, with the claimant stating that it would ruin sardine fishing in Monterey Bay (Scofield, 1959). Kelp harvesting in the Monterey area began in earnest in the early 1930s; 200 tons were taken in 1930 and 500 tons were taken in 1931 (see reviews in Phillips, 1932; Scofield, 1959).

Two different species of kelp (a generic term for large brown algae) have been harvested historically, *Nereocystis luetkana* (also called bull or bladder kelp) and *Macrocystis pyrifera* (commonly called giant kelp). Interestingly, the Monterey-area kelp harvest in the early 1930s was exclusively composed of bull kelp, the dominant canopy-forming algal species north of Point Sur during that period (Phillips, 1932; Andrews, 1945; Scofield 1959). Phillips (1932) reported that bull kelp was harvested in the Monterey area only along the coast between Point Sur and Point Pinos, implying that this kelp was not abundant enough within southern Monterey Bay to warrant harvesting. Until at least 1962, large stands of giant kelp on the central California coast were apparently limited to protected sites within southern Monterey Bay, northern Carmel Bay, and south of Point Sur (Philips, 1932; Andrews, 1945; Scofield, 1959; McLean, 1962; reviewed in Larson and McPeak, 1995 [p. 3-74 - 3-77]). This distribution is in striking contrast to the present-day; giant kelp is now the dominant kelp as far north as Año Nuevo Island, except on shallow, exposed rocky reefs. This dramatic shift in relative abundance of bull kelp and giant kelp coincided with, and may have been facilitated indirectly by the reestablishment of the southern sea otter (*Enhydra lutris*) in its former range (Van Blaricom, 1984).

Kelp has primarily been harvested on a large scale for its chemical byproducts. This harvesting occurs mostly in southern California where giant kelp is more abundant than in central California. Approximately 95 % of the current state-wide harvest of around 100,000 wet tons per year (Leet et al., 1992) is done by Kelco Co., a subsidiary of Monsanto based in San Diego (Spratt, personal communication). Kelco harvests kelp with large ships equipped with mechanical blades that can harvest up to 600 tons per day (Larson and McPeak, 1995 [hereafter cited as CDFG E.I.R.]). Occasionally, Kelco harvests as far north as Spanish Bay off the Monterey peninsula when kelp growth is poor in southern California (Spratt, personal communication). Most of the remaining 5% of kelp harvested is taken by small-scale hand-harvesters for aquaculture purposes (Spratt, personal communication).

Due to catastrophic declines in wild abalone populations and sustained market demand, numerous abalone aquaculture facilities that require kelp for abalone feed have begun operation since the early 1970s. Four such facilities have operated in the Monterey Bay area since the late 1980s (Monterey Abalone Company, Pacific Abalone Farm, Pacific Mariculture, and U.S. Abalone Inc.). Two of the larger abalone farms, Pacific Mariculture and U.S. Abalone, are based in or near Santa Cruz, and they fulfill most of their kelp requirements from the northern Monterey Bay (D. Ebert, personal communication). Pacific Mariculture contracts an independent kelp harvester, the California Kelp Company, to supply their kelp. Occasionally, the Santa Cruz -based harvesters harvest kelp on the Monterey side of the bay when the Santa Cruz harbor mouth becomes dangerous for boat passage during winter storms or is obstructed by a sand bar during the winter months.

Monterey Abalone Company and Pacific Abalone Farm are based in Monterey harbor and harvest year-round from the Monterey peninsula area (Seavey, personal communication). Grillo Enterprises, a local firm engaged in kelp harvesting for use in the herring-roe-on-kelp fishery in San Francisco Bay, also takes a small amount of kelp from the Monterey area (Larson and McPeak, 1995). During winter, seas become increasingly treacherous as one travels west from Lovers Point to Point Pinos, and southwest of Point Pinos the coastline is exposed to the open ocean and too dangerous to harvest using small boats. Since current kelp hand-harvesting operations are conducted using skiffs equipped with small outboard motors, winter harvesting is concentrated along the 4 kilometers of relatively wave-protected coastline between the Monterey Coast Guard Breakwater and Otter Point. Since the controversy over kelp harvesting in the Monterey / Pacific Grove area began around 1996, harvesters have largely avoided harvesting the highly-visible kelp canopies from the Monterey Breakwater to Hopkins Marine Station (Seavey and Williamson, personal communication), thereby concentrating kelp harvesting between Hopkins Marine Station and Otter Point during the winter months. During the winters (defined here as November through March) of 1996/1997 and 1997/1998, 414 tons of kelp were harvested each winter, primarily from this local area. It is this volume of harvesting from a relatively small area, and the related concerns over the potential effects of harvesting from the same kelp plant multiple times, that has led to questions concerning the possible harvesting impacts on kelp forest ecology in this local region.

Numerous studies dating to 1915 have investigated the potential effects of harvesting giant kelp. The 1995 edition of the California Department of Fish & Game's Final Environmental Document, Giant and Bull Kelp Commercial and Sport Fishing Regulations (Section 30 and 165, Title 14, California Code of Regulations, edited by Larson and McPeak) provides an excellent review of these studies, including the effects of harvesting on frond growth and regeneration, holdfast development, individual plant survivorship, survivorship of populations of plants, and effects on plants associated with giant kelp (Cameron, 1915; Crandall, 1915; Brandt, 1923; Limbaugh, 1955; Clendenning, 1968; North, 1968; Miller and Geibel, 1973; Kimura and Foster, 1984; Barilotti et al., 1985; McCleneghan and Houk, 1985; Barilotti and Zertuche, 1990; reviewed in CDFG E.I.R., 1995 [p.4-14 - 4-18]). Most of this research addressed the effects of large-scale mechanical kelp harvesting, but is also applicable to hand-harvesting practices. The editors of the California Department of Fish and Game Final Environmental Document (CDFG E.I.R., 1995) concluded from these studies that no significant effects are apparent from routine mechanical and hand-harvesting practices as long as individual plants are harvested no more than three times per year. Research in southern and central California has suggested that overharvesting (i.e. cutting the fronds of the same plant four or more times within 12 months) results in decreased yield and reduced plant survivorship, and increases in associated understory plants (Brandt, 1923; North, 1957; Miller and Geibel, 1973).

Kelp harvesting clearly has short-term effects: the abundance of kelp canopy and associated invertebrates decreases when kelp is cut and removed from the nearshore environment by harvesting. Kelp fronds grow very little after being severed, and uncut fronds growing up from four feet below the surface (the maximum harvested depth by law) or lower must replace the surface canopy (Crandall, 1915; Brandt, 1923). North (1968) reported that the initial growth rate of kelp plants was retarded after being harvested, but no significant difference was detectable between harvested plants and uncut control plants within a month after harvesting. The rate of surface canopy regeneration following harvesting is variable, however, depending on conditions such as the proximity of the growing subsurface kelp fronds to the surface and plant growth rate (which is primarily dependent on nutrient availability and irradiance levels; see review in CDFG E.I.R., 1995). Based on models and empirical evidence, North (1968) concluded that harvesting of the kelp canopy stimulates growth [by increasing irradiance to subsurface fronds] or retards it, depending on conditions before and after harvesting.

The effects of kelp harvesting on populations of fishes, birds, and mammals are also reviewed in the CDFG E.I.R. (1995, p.4-1 - 4-10). Fish-oriented research has addressed potential harvesting effects on fish eggs, juveniles and adults of various species, sportfishing, and young-of-the-year rockfish in central California (Limbaugh, 1955; Davies, 1968; North and Hubbs, 1968; Quast, 1968; Miller and Geibel, 1973; and Houk and McCleneghan, 1993). The CDFG E.I.R. (1995) concluded from these studies that no significant ecological effects on fish populations occur due to kelp harvesting. Similarly, the CDFG reviewed research on invertebrates and concluded from these studies that no significant effects are apparent on the populations of either motile (e.g., the isopod *Idotea* and the snails *Tegula* and *Calliostoma* [6 species]) or non-motile (e.g., bryozoans and hydroids) species (Quast, 1968 and Miller and Geibel, 1973). All non-motile canopy invertebrates on a given kelp frond are removed by harvesting, but these animals occur in the naturally-ephemeral kelp canopy environment and no doubt settle, grow, and reproduce rapidly relative to kelp harvest frequency (CDFG E.I.R., 1995).

Based on scant available data, the CDFG E.I.R. (1995) concluded that there is no significant effect of kelp harvesting activities on bird or mammal populations. The sea otter (a species protected by state and federal laws) has the closest association with kelp canopies among all marine mammals (CDFG E.I.R., 1995), and is of particular concern in the Monterey area. It has been suggested that kelp harvesting operations occurring in southern Monterey Bay during the winter may further reduce the already sparse kelp canopy available to sea otters for rafting and resting, thereby potentially having a negative impact on the otter population. The question of whether or not kelp canopy is a limiting resource for sea otters has not been rigorously investigated.

Exhaustive reviews of kelp biology and kelp forest communities are available (reviewed in Foster and Schiel, 1985, and CDFG E.I.R., 1995 [p. 3-5 - 3-10, 3-28 - 3-30, 3-44 - 3-51]), and thus will not be summarized here. However, we do emphasize that kelp forests (and therefore their canopies) are well documented to be highly variable in space and time, extremely sensitive to environmental conditions (e.g. storm waves, nutrient availability, etc.), and highly productive. Giant kelp also plays a central role in supporting a species-rich, biologically productive community of other organisms in the nearshore environment.

For the purposes of this study, we defined an "important" effect of kelp harvesting to be a statistically significant decrease in the amount of giant kelp surface canopy in harvested kelp canopies (relative to an unharvested control canopy) after intensive kelp harvesting began. A decrease in the amount of kelp canopy within the harvested areas may be indicative of reductions in plant growth or recruitment, and/or increased plant mortality, thereby constituting a possible important biological or ecological effect. We chose to compare kelp canopies during the period of maximum kelp canopy development (or "fall maximum") primarily because most data are available for this time of year. As a result, we could not test whether or not canopy regeneration rates differed between harvested and unharvested areas. However, to test for the potential impact we defined, canopy data available during the fall maximum are ideal; confounding short-term harvesting effects (i.e. canopy loss) are minimized during this time because seas are relatively calm and harvesting within the study area is reduced. Given the opportunities and constraints of these available data, we asked a very specific question: are current kelp harvesting practices causing a detectable effect on the abundance of giant kelp surface canopy, as measured during the period of the fall maximum, in the Ed Ricketts Underwater Park region? We did not investigate related issues of possible effects of harvesting on sea otters, juvenile rockfish recruitment, kelp canopy invertebrates, or other aspects of kelp communities.

MATERIALS AND METHODS

Two primary raw data sets, kelp harvest records and kelp canopy aerial photos, were used to address the question of the effects of local kelp harvesting on giant kelp surface canopy. Kelp harvest records for bed 220 (Monterey Breakwater to Cypress Point; see Figure 1) were compiled from monthly harvest records in the California Department of Fish & Game (CDFG) archives dating to 1987 (Table 1 and Figure 2). CDFG harvest data were cross-checked for accuracy when possible with officially submitted monthly harvest reports prepared by the individual harvesters. Some discrepancies were found. In these cases, data were modified based on the harvest reports. Bed 220 is much larger than the study area (Monterey Coast Guard Breakwater to Lovers Point in Pacific Grove), so harvest amounts reported could have come from the study area (and some, if not most, surely did during the winter), but not necessarily. As shown in Table 1, Kelco has harvested from bed 220 at least five times since 1987, but they have only harvested that portion of bed 220 between Cypress Point and Point Pinos (Spratt, personal communication). Thus, Kelco harvesting records were irrelevant to the question of effects in the study area and were not used in the analyses.

CDFG harvest records for bed 220 prior to 1987 are unavailable (Spratt, personal communication), so amounts of kelp taken before 1987 had to be estimated based on anecdotal information provided by George Lockwood (personal communication), former proprietor of the Monterey Abalone Farm that operated on Cannery Row from 1972 - circa 1989. Lockwood suggested that kelp harvesting during this period ranged from 200 pounds per day or every other day during the early years, and up to 2000 pounds per day or every other day when the business peaked in 1985. Our estimates for this period are probably slight underestimates since we did not include kelp harvested by the CDFG abalone culture facility at Granite Canyon which operated during this same period (E. Ebert, personal communication). The scale of this operation was small (10,000 - 20,000 young abalone), and thus its kelp needs were negligible. Most of the kelp feed for their abalone came from the Granite Canyon area, and kelp was only occasionally harvested (i.e. 8-10 times per year) from the Monterey Breakwater area (Ebert, personal communication).

The kelp canopy aerial photographs were composed of four subsets of aerial surveys. Each of these subsets used low-altitude aerial photography with infrared-sensitive film. Years marked with asterisks in Figure 2 denote years in which surveys were available during the period of kelp canopy maximum and of sufficient quality to incorporate in the analyses. The CDFG surveyed kelp canopies regularly from 1974 to 1979, and again in 1989. The surveys done by CDFG in early 1970s were more-or-less exploratory in nature; methods were standardized and refined in the mid-1970s. The quality of the data from the early 1970s was thus questionable and not used in this study. Kelp canopy maps for the area from Seaside to Point Sur were photographed on a near-monthly basis from November 1985 to December 1991 (Harrold and Watanabe, unpublished data). These surveys were available already rendered (see definition below) from infrared slides, and one map series per year from the fall maximum was used in the analyses. Van Wagenen filled in the data gaps in the aerial survey time series (when possible) by generously providing access to his personal photographic archives (i.e. 1980, 1981, 1982, 1983, 1984, 1992, 1994, and 1997). All aerial surveys since 1980 were done by the same person using identical techniques, thereby minimizing sampling variation due to photographic technique.

Kelp maps for the area between Lovers Point and the Monterey Breakwater were rendered from the original imagery according to methods used by Van Wagenen (personal communication). In brief, individual photos (slides) were projected by a Minolta color enlarger (MOD-1) onto two contiguous 1:12000 scale baseline maps of the coastline study area. The shoreline of the baseline map was aligned with the projected image, and magnifying eyeglasses (+4.0) were used to aid "transfer" of kelp surface canopy from image to map. To transfer data from image to map, the portion of the projected image interpreted as kelp canopy was shaded in on the baseline map with a Sanford Vis a Vis wet-erase fine point overhead transparency marker (series 16000). Areas within the greater perimeter of the kelp forest canopy that were devoid of surface canopy were left unshaded. Only the center 75% of the projected image was rendered in order to minimize bias due to distortion. This could be done without loss of information because the aerial photographs were overlapping. The rendered baseline maps that were used in the analyses are shown in Figure 3 (in miniaturized form).

The rendered baseline maps were scanned into a PC with a Hewlett-Packard scanner (model C6260a) as a bitmap file at 350% resolution and imported into Jandel Sigma Scan Pro (v.4.0) image analysis software. Once the baseline maps were imported and the map scale was calibrated, the variables Canopy Area and Planimeter Area were calculated. Canopy Area represented the spatial extent (in hectares) of kelp fronds floating on the sea surface within a defined geographic area (i.e. "gaps" in the kelp canopy were not included in the area measurement). Planimeter Area represented the spatial extent of a kelp forest within the boundaries of its outer canopy perimeter (i.e. "gaps" in the kelp canopy were "filled" and included in the area measurement), and was derived from Canopy Area using pre-determined conventions that filled in the gaps. A third variable, Relative Density Index (R.D.I.) was calculated by dividing Canopy Area by Planimeter Area. This derivation approximates the probability of encountering kelp on the surface at a random point within the perimeter of the kelp forest; R.D.I. values approaching 1 indicate a "dense" surface canopy and values approaching 0 indicate a "sparse" surface canopy (VanWagenen, personal communication).

Study Design:

The question addressed in this study was evaluated with a modified Before - After - Control - Impact (BACI) approach. The BACI design is currently the most statistically rigorous way to test for "impact" effects (Stewart-Oaten et al., 1986; Schmitt and Osenberg, 1996). In brief, this approach permits testing of an impact hypothesis by comparing the abundance of a variable at a Control site to a potential Impact site both Before the impact begins and After the impact has begun. If the *differences* between the abundance of the measured variable at the Control and Impact site Before the impact has begun are not statistically different from the *differences* between the Control and Impact site After the impact has begun, then it would be concluded that there is no impact. The difference values are determined multiple times in both the Before and After periods, and thereby constitute Before and After replicates.

Designation of discrete Before and After periods was not possible with the available data. Instead, Figure 2 suggests three general "periods" of kelp harvesting relative intensity in the Monterey area: a "moderate harvest" period from 1972 - 1985, a "low harvest" period from 1986 - 1995, and a "high harvest" period from 1996 - present. For the purposes of this study, "low harvest" was arbitrarily defined as < 50 tons/year, "moderate harvest" as 50 - 250 tons/year, and "high harvest" as > 250 tons/year. According to this convention, the 1989 harvest of 84 tons and the 1990 harvest of approximately 200 tons both fall into the category of "moderate harvest," even though these two years occurred within the period of "low harvest." Therefore, data from these years were not included in the analyses. Ideally, the data from the Before period should be collected *before* any potential impact begins. For comparison purposes in this study, the period of "low harvest" was used as a "best approximation" of a Before period in which kelp was not harvested, even though this period occurred *after* a period of "moderate harvest." Conceptually, it is not a serious problem that the Before period occurred after a period of moderate harvesting because giant kelp plants on the central California coast exhibit a relatively fast "turnover" rate (on the order of 1-2 years). Therefore, it is improbable that prolonged effects on kelp canopies would have occurred due to the relatively small amount of harvest from 1972-1985.

The study area was divided into one unharvested Control site (Hopkins Marine Life Refuge [HMLR]) and three potential Impact sites (San Carlos, Cannery Row, and Lovers Point) which are open to kelp harvesting (Figure 4). Sites were designated when possible by persistent natural features such as sand channels, and were similar in spatial area for comparability. The HMLR control site was delineated by the reserve boundaries; however, only the main kelp forest directly offshore and surrounding Cabrillo Point was used to calculate Canopy and Planimeter Area. HMLR was chosen as a control site for two important reasons. First, the reserve was established in 1892 and therefore was not harvested during the study period. Second, it is conveniently nestled within the study area and thus influenced by essentially the same range of natural conditions (e.g. storm waves, nutrient availability) as the harvested sites. An important assumption was also made that the HMLR kelp forest was similar in other respects (e.g. depth of bed, substrate, topography, etc.) to the other kelp forests studied. Another control site would have been desirable to help assess canopy variation unrelated to harvesting, but no such site was available.

Testing for a harvesting effect on kelp bed surface canopy was done by analyzing the *differences* between the variables of Canopy Area, Planimeter Area, and R.D.I. at HMLR and each harvested site among the periods of moderate, low, and high harvest (see Stewart-Oaten et. al., 1986 for detailed account of experimental design). This was achieved by subtracting the raw abundance for a given variable at a Control site from the raw abundance of the same variable at a harvested Impact site. This "difference" value was calculated for the three variables at each impact site for each year within each of the three different periods. Control and Impact sites were sampled (i.e. photographed) simultaneously, and each sampling time was represented in the analysis by only one value for each of the three variables measured, the difference between the Control and each Impact for that time. Thus, the sampling times (17 different years) were used as replicates. For example, the Canopy Area at HMLR in 1976 (3.27 hectares) was subtracted from the Canopy Area at the Cannery Row site in 1976 (5.52 hectares), resulting in a "difference" value of 2.25 hectares; this same calculation was performed for each year in which aerial kelp surveys were available for a total of 17 values.

The mean differences between Control and Impact sites within each of the three periods ("moderate harvest", "low harvest", and "high harvest") were tested against each other using a one-way, 3-level Model I analysis of variance (ANOVA) for each measured variable (Canopy Area, Planimeter Area, and R.D.I.). A kelp harvesting effect would be indicated by statistically significant differences among the three harvest periods. Since the "high harvest" period of interest (from 1996-1998) had a sample size of only two, comparisons involving this period will not be informative until more data is collected. Therefore, a more powerful BACI approach (with one-tailed, two-sample t-tests) was also used to test for a harvesting effect between the period of "moderate harvest" and the period of "low harvest." These comparisons were not directly applicable to the "high harvest" period of interest, but the results may suggest patterns to expect if the current level of kelp harvesting intensity continues.

BACI testing does not distinguish a harvesting effect from any other environmental effects that might have occurred coincident with harvesting. Therefore, regression analyses of each measured variable versus the amount of kelp harvested the previous winter for each site were also done. Again, this test does not assess causation, but can be used as circumstantial evidence of harvesting effects. The independent variable chosen to regress against each kelp forest variable was the amount of kelp harvested from bed 220 during the previous winter (defined as November - March). This choice was logical because most of the kelp harvested during the winter would have likely come from within the study area, and therefore should correlate more closely to effects observed within the study area than would total yearly harvest from bed 220.

All statistical analyses were done using Systat v. 7.0.1.

RESULTS

Annual variability of the fall maximum kelp canopy was quite high from 1976 – 1998. Nevertheless, Canopy Area, Planimeter Area, and R.D.I. measurements exhibited close correlation among all study sites (Table 2 and Figure 5). Note that the lines connecting data points in Figure 5 are for illustrative purposes only and do not include seasonal variation between sampling periods. Missing datapoints in the trend-line of Figure 5 represent years in which aerial surveys were not available (i.e. 1978, 1979, 1993, 1995, and 1996). Canopy Area, Planimeter Area, and R.D.I apparently declined between 1991 and 1997, although this can't be confirmed due to lack of data (Figure 5). This possible decline could not have been due to kelp harvesting since large harvests were not made until 1996, and Canopy Area, Planimeter Area, and R.D.I. at unharvested HMLR also declined during these years. Environmental factors, possibly conditions associated with frequent and persistent El Niño events, may have caused consistently low surface canopies during this time.

As with the canopy abundance data, some of the "difference" values calculated from the raw abundance data also displayed high variability (Table 3 and Figure 6). In particular, the Lovers Point and San Carlos sites exhibited substantial within-period variation of Canopy Area and Planimeter Area during the periods of "moderate harvest" (1976 – 1985) and "low harvest" (1986 – 1995). This variation was not problematic in the analyses, however, since all "difference" values within a given harvesting period were averaged, but this variation did result in high standard errors for some of these averages (especially for the "high harvest" period due to small sample size). ANOVA comparisons of the average "difference" values among the three periods at each Impact site (for each variable) were not statistically significant ($P > 0.05$; Table 4 and Figure 7), indicating that no effect of kelp harvesting on the three measured variables was detectable. However, statistical power to detect such an effect was low (Power ≤ 25; desired Power = 80), resulting, in part, from the small sample size of period 3 (1996 - 1998; $n = 2$). Given the natural variability of the kelp canopy, this small sample size would allow the detection of only extremely large harvesting effects.

BACI analyses of the "moderate harvest" and "low harvest" periods with one-tailed, two-sample t-tests allowed more powerful hypothesis testing of harvesting effects. Most comparisons yielded non-significant results, but Canopy Area at the San Carlos study site exhibited a significant difference between periods ($P = 0.036$; Table 5). This indicates that the average abundance of kelp canopy was depressed during the "moderate harvest" period of 1976 – 1985, and then increased (on average) during the "low harvest" period from 1986 – 1995. However, the result for Canopy Area at San Carlos was probably confounded by short-term harvesting effects if kelp harvesting was localized in this area year-round during the 1970s and early 1980s.

None of the slope coefficients obtained from regression analyses of canopy with the previous winter's harvest were statistically significant (P>0.05; see Table 6 and Figure 8), indicating an undetectable harvesting effect. Two clusters of data points are evident in Figure 8, based on two primary levels of winter harvest (harvest greater than 400 tons and harvest less than 100 tons). No relationship between winter harvest and any of the three variables measured at each site was apparent when winter harvest was less than 100 tons. Note that the slope coefficient at HMLR displayed essentially the same downward trend as the other sites even though HMLR was not harvested; this result, though statistically non-significant, would not be expected if harvesting had an effect. Also, note the extremely wide 95% confidence intervals in Figure 8 due to data from the "high harvest" period. As with the ANOVA results, however, statistical power to detect a significant trend was low due to only 2 samples taken during the "high harvest" period. Some comparisons failed a test of regression assumptions and the results were not reported.

DISCUSSION & RECCOMENDATIONS

There was no *detectable* effect of kelp harvesting, as currently practiced off Monterey and Pacific Grove, on the density or spatial extent of the fall maximum kelp canopy. However, it must be emphasized that statistical power to detect such an effect was very low given the small sample size (n = 2) and high natural variability of kelp canopies. Therefore, these results do not necessarily indicate that there wasn't a harvesting effect, only that such an effect was undetectable given the available data. Because of the small sample size and high natural variability, we could have only detected a very large harvesting effect, so there could indeed have been an impact ranging from the limit of what we could detect to no impact at all. Increasing sample size (i.e. more yearly aerial kelp canopy surveys in the future) is the only way to further refine these results. Assuming future winter harvesting is maintained at present (or greater) levels within the study area and no persistent environmental factors are confounding, four or more annual aerial kelp surveys are necessary to meaningfully assess harvesting effects. The inherent limitation to greater resolution of our question is a fixed sample size (n = 6 for the period of "low harvesting" from 1986 - 1995). Statistically, it would be ideal to compare periods with equal sample sizes, in which case a one-tailed, two-sample t-test could be used to compare the "low harvest" period with the "high harvest" period.

Since we could not make rigorous, meaningful comparisons with data from the "high harvest" period because of insufficient sample size, comparisons between the periods of "moderate harvest" and "low harvest" might suggest patterns to expect within the Ed Ricketts Park region in the future. BACI testing yielded statistically non-significant differences between the "moderate harvest" and "low harvest" periods at the Cannery Row and Lovers Point sites, but a significant difference in Canopy Area at the San Carlos site. However, this result may have been confounded by short-term harvesting effects (and we suspect it was) if kelp harvesting was localized in this area year-round during the 1970s and early 1980s. One of the assumptions we made in the analyses was that short-term canopy effects (i.e. missing canopy due to recent harvesting) were negligible during the fall period of maximum canopy. This assumption was probably violated during the "moderate harvest" period of 1976 - 1985, however, because Monterey Abalone Farm most likely concentrated their kelp harvesting activities in the San Carlos area (since San Carlos was the closest kelp forest to the harbor mouth, it was thereby the easiest and most economical canopy to harvest). If these results were not confounded, they suggest that a harvesting effect on the abundance of kelp canopy may occur if extant kelp harvesting activities are focused in a localized area, particularly in the vicinity of Lovers Point and Otter Point during the winter.

As discussed in the Background section above, previous research has suggested that routine kelp harvesting operations have unimportant effects on canopy yield and plant mortality, with the caveat that individual plants were not harvested more than three times per year. The concentration of kelp harvesting effort at Lovers Point and Otter Point during the winter (i.e. 414 tons taken from bed 220 during the winters of 96/97 and 97/98) increase the likelihood that an individual kelp plant may be repeatedly harvested and thus result in negative effects. The recent designation of a no-harvest area between Lovers Point and the Monterey Breakwater will provide a useful second Control area, but also may exacerbate the possibility of multiple pruning since harvesting would be further concentrated in other areas.

To put the amount of kelp currently harvested into perspective, Harrold et al. (1998) estimated that the kelp forests occurring from the Monterey Breakwater to Cypress Point (Bed 220) generate more than 200,000 tons of drift kelp per year (wet weight production estimate from Gerard, 1976). The study area is approximately 1/6 of the size of Bed 220, and therefore a rough estimate of drift kelp production from this area is 33,000 tons per year. The current annual kelp harvest in the study area by local aquaculture firms is approximately 600 tons per year, or 2% of the estimated amount of drift kelp from this same area. Therefore, further reasoned debate over the effects of kelp harvesting and its management might be sharpened by a consideration of scale.

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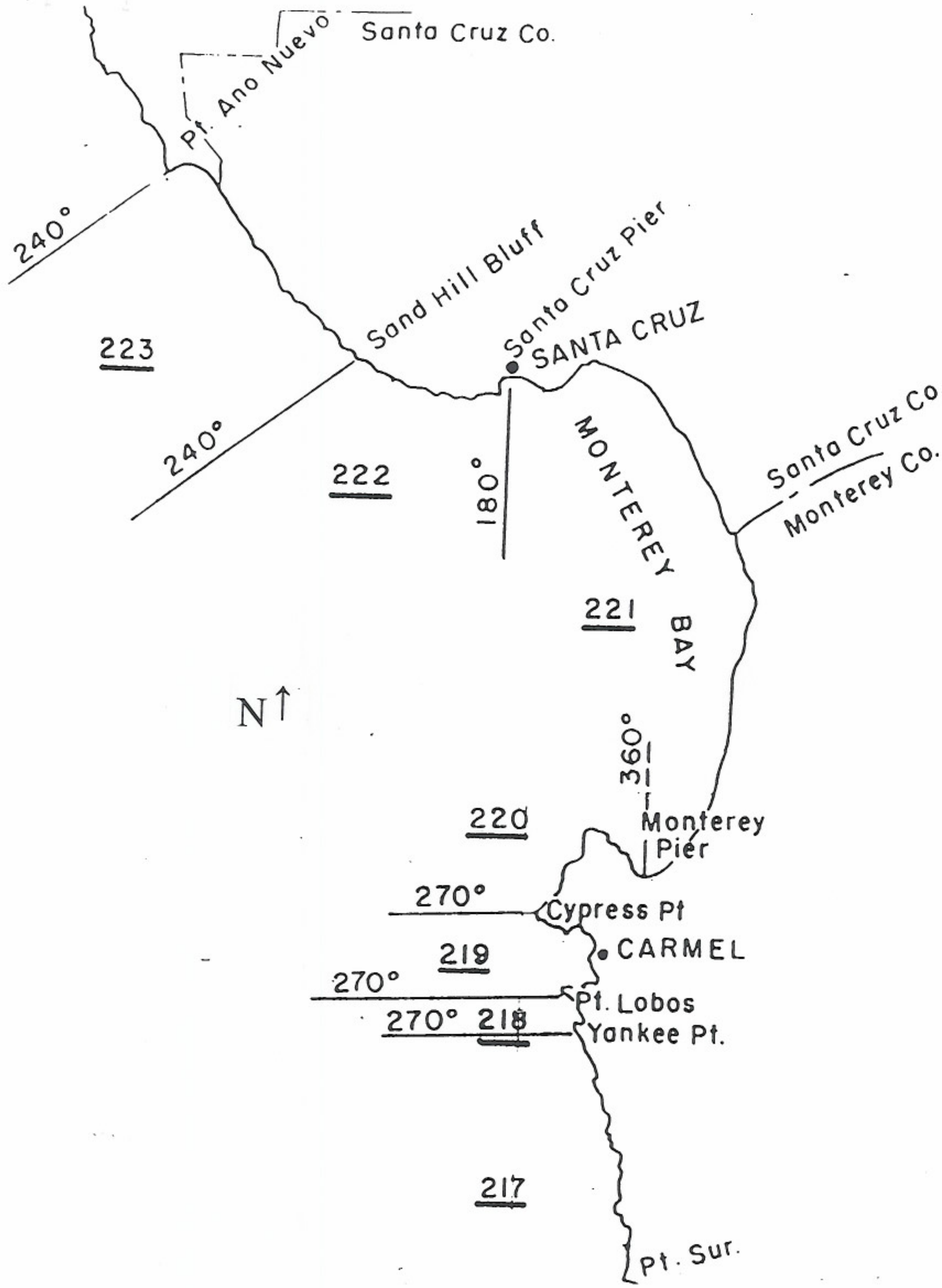


Figure 1. California Department of Fish and Game-designated kelp bed 220 (center), extending from the Monterey Coast Guard Breakwater to Cypress Point. Beds 217, 218, 219, 221, 222, and 223 also shown. Note location of study site on the northeast side of the Monterey Peninsula.

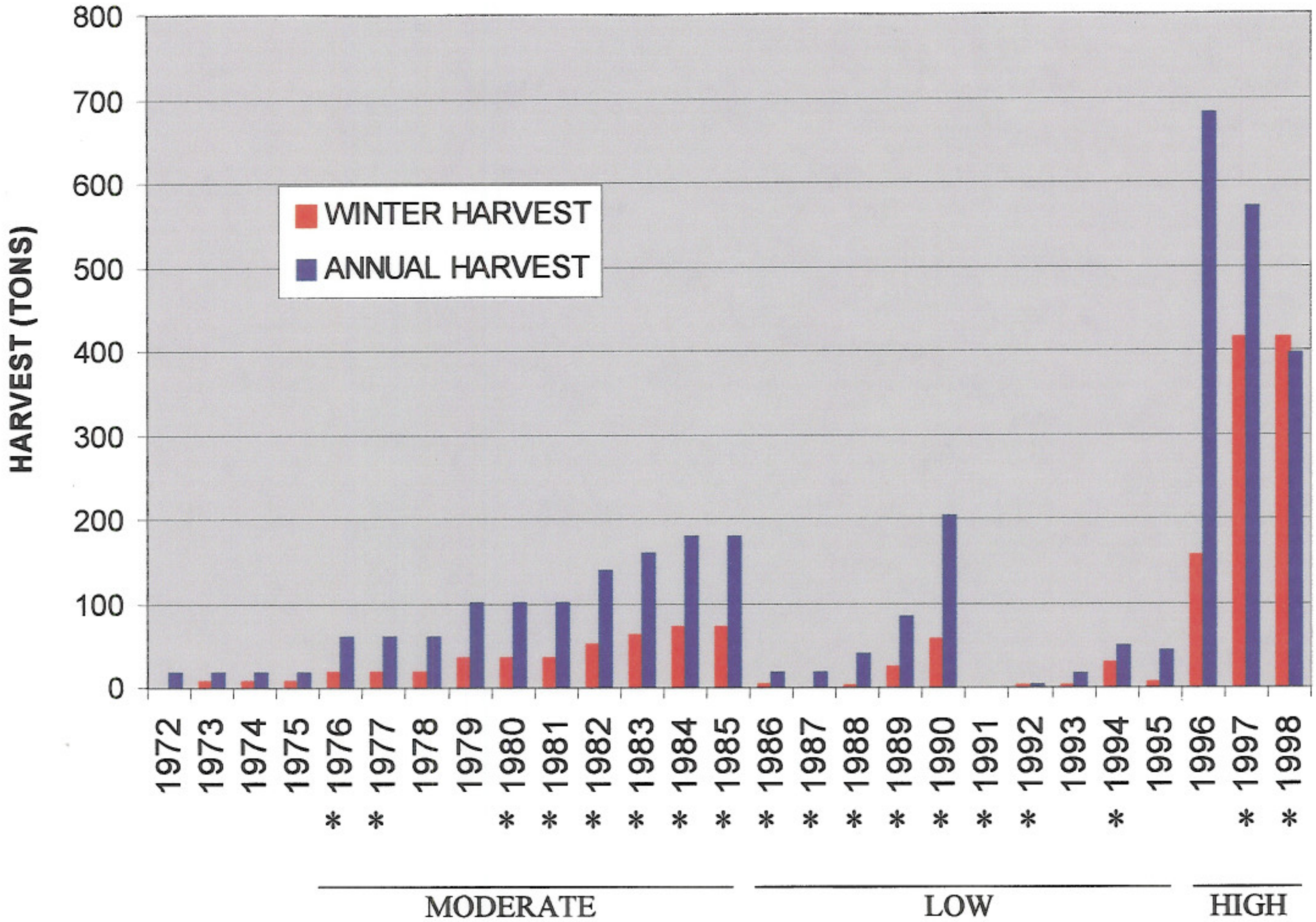


Figure 2. Annual and winter (November – March) kelp harvest from bed 220, excluding harvest by Kelco. Due to lack of detailed records, amounts of harvest prior to 1987 were estimated from anecdotal information provided by George Lockwood, the primary local kelp harvester during that period. Asterisks represent years in which aerial kelp surveys were available during the period of fall maximum canopy and of sufficient quality to incorporate into the analyses. Note the three general "periods" of kelp harvesting relative intensity in bed 220 (denoted below the x-axis).

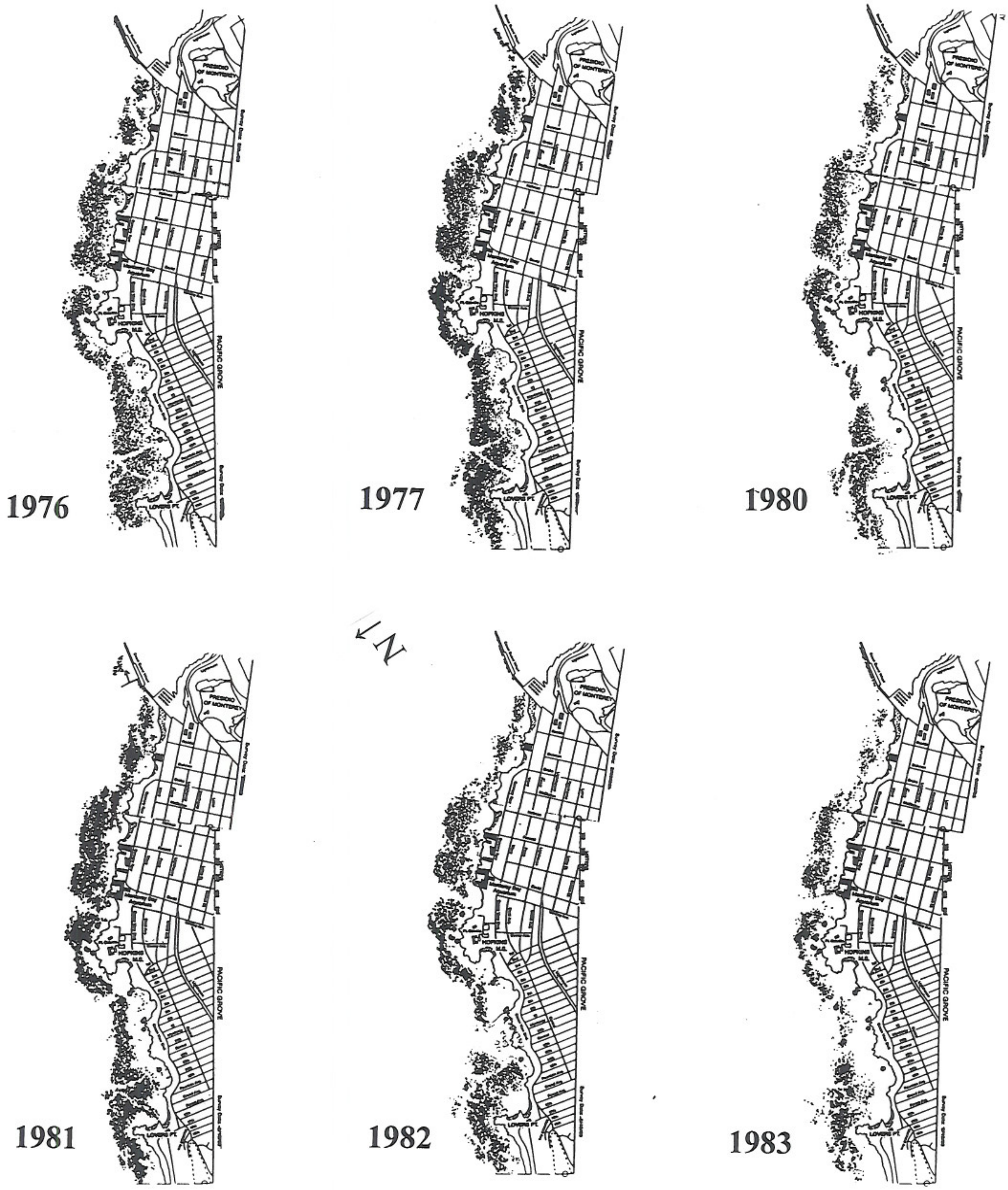


Figure 3. Baseline maps of study area with "rendered" kelp canopies for years in which aerial surveys were available. The rendering process involved manual transfer of data from the aerial survey slides to hardcopy maps. This was done by projecting slides from a photo enlarger onto 2 contiguous 1:12,000 scale baseline maps of the study area and shading in areas interpreted to be kelp.

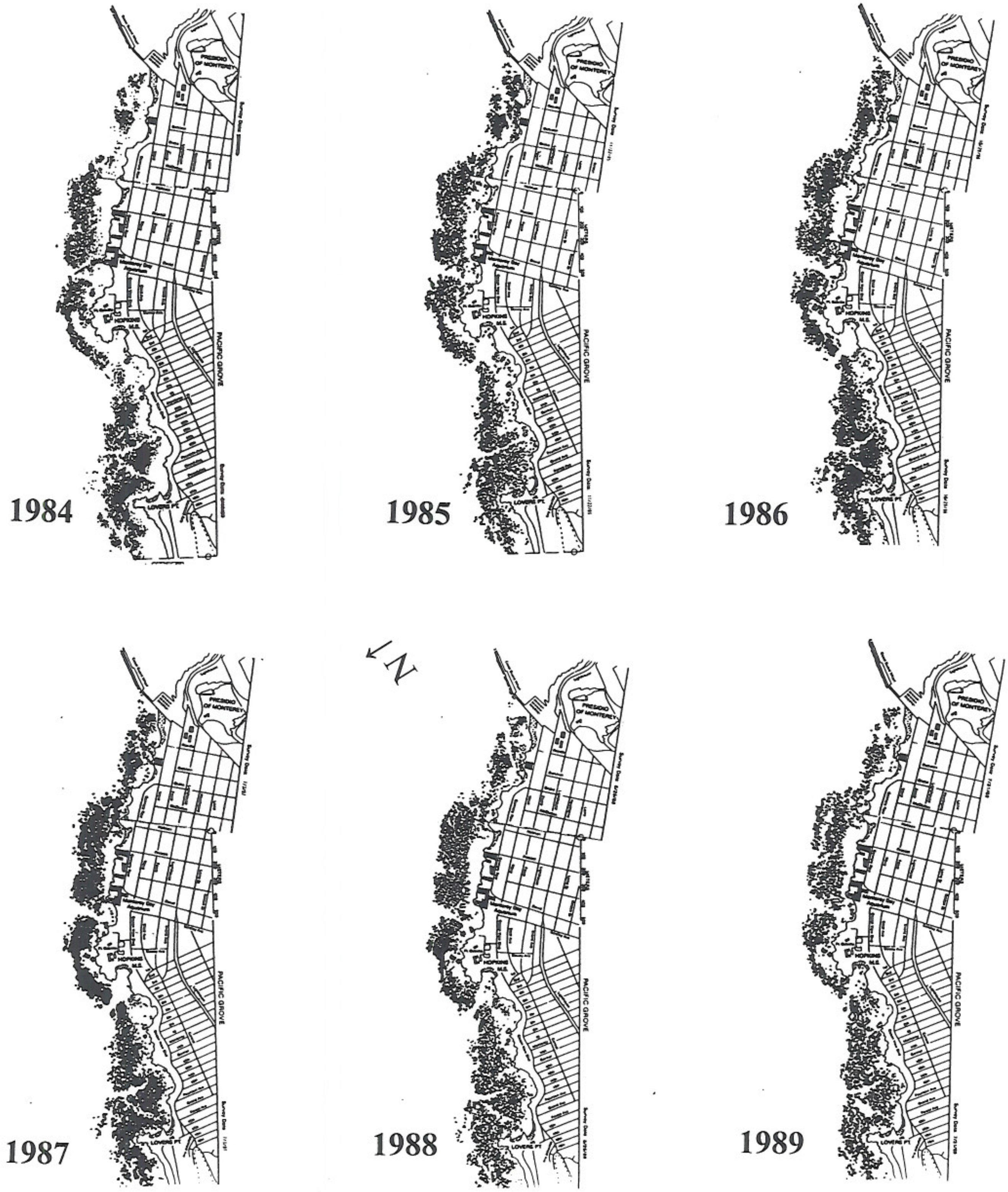


Figure 3. Continued

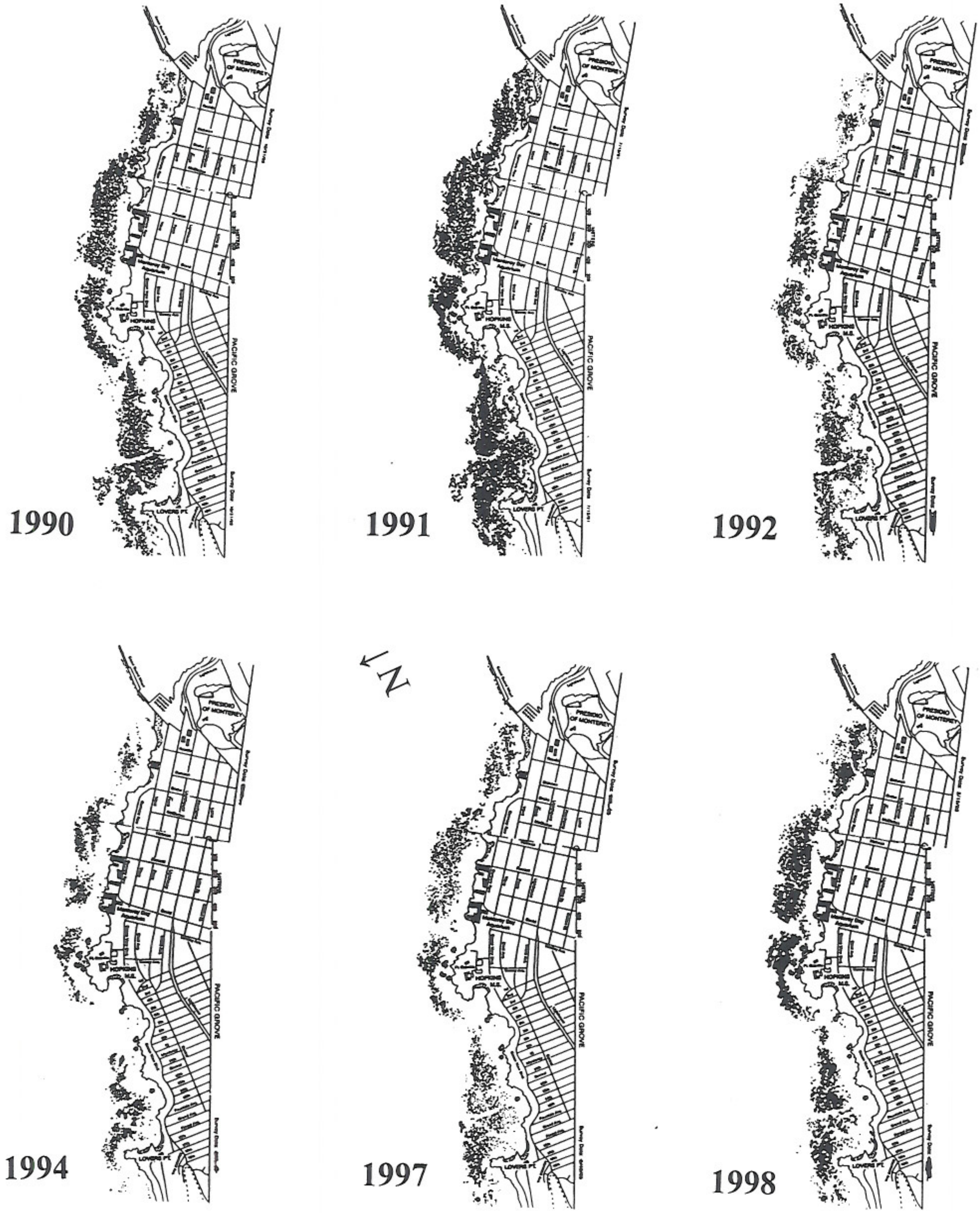


Figure 3. Continued

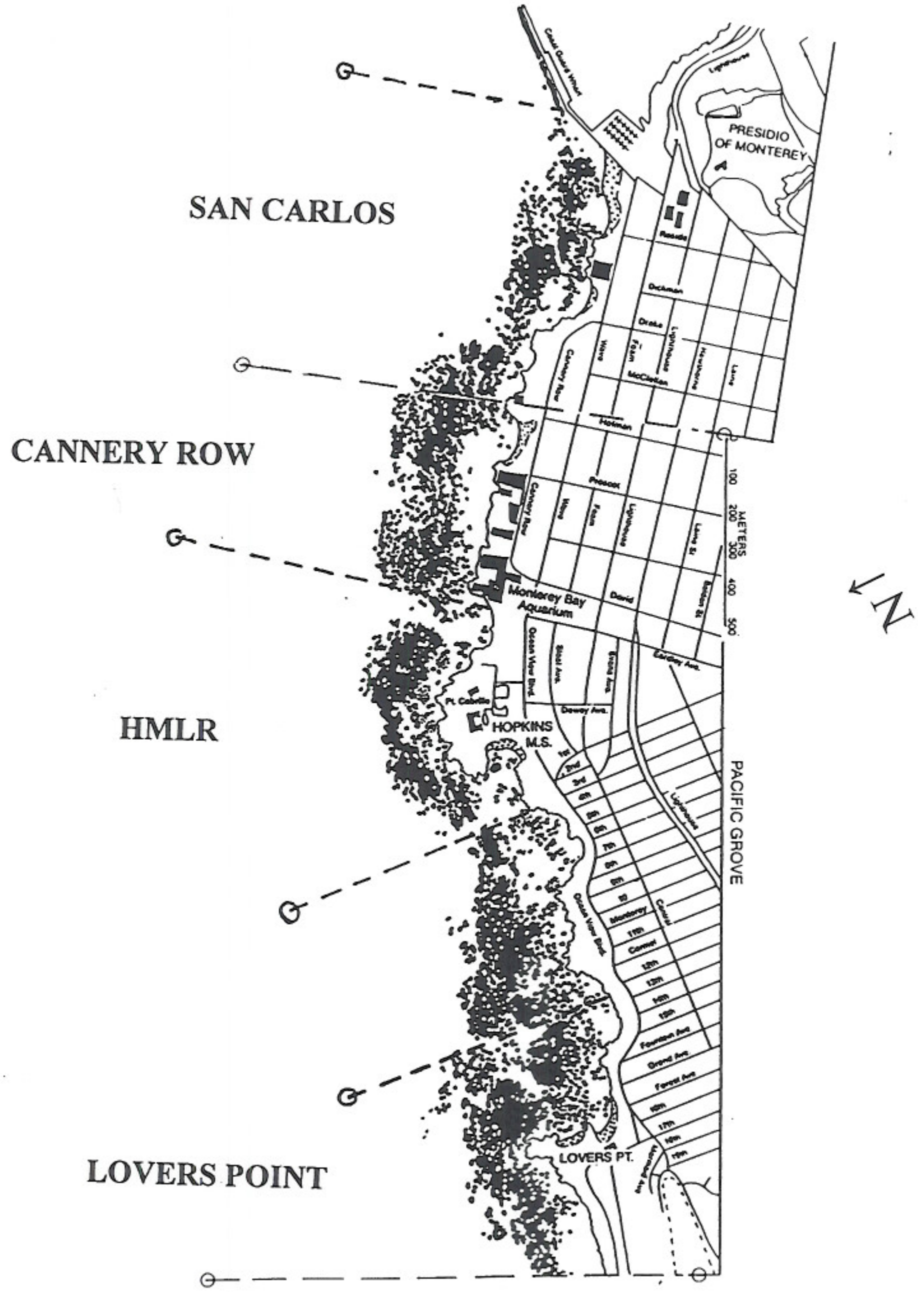


Figure 4. Designation of the four study sites, including one control site (HMLR) and three potential "impact" sites which are open to kelp harvesting. The region between HMLR and Lovers Point was not studied due to lack of appropriate data.

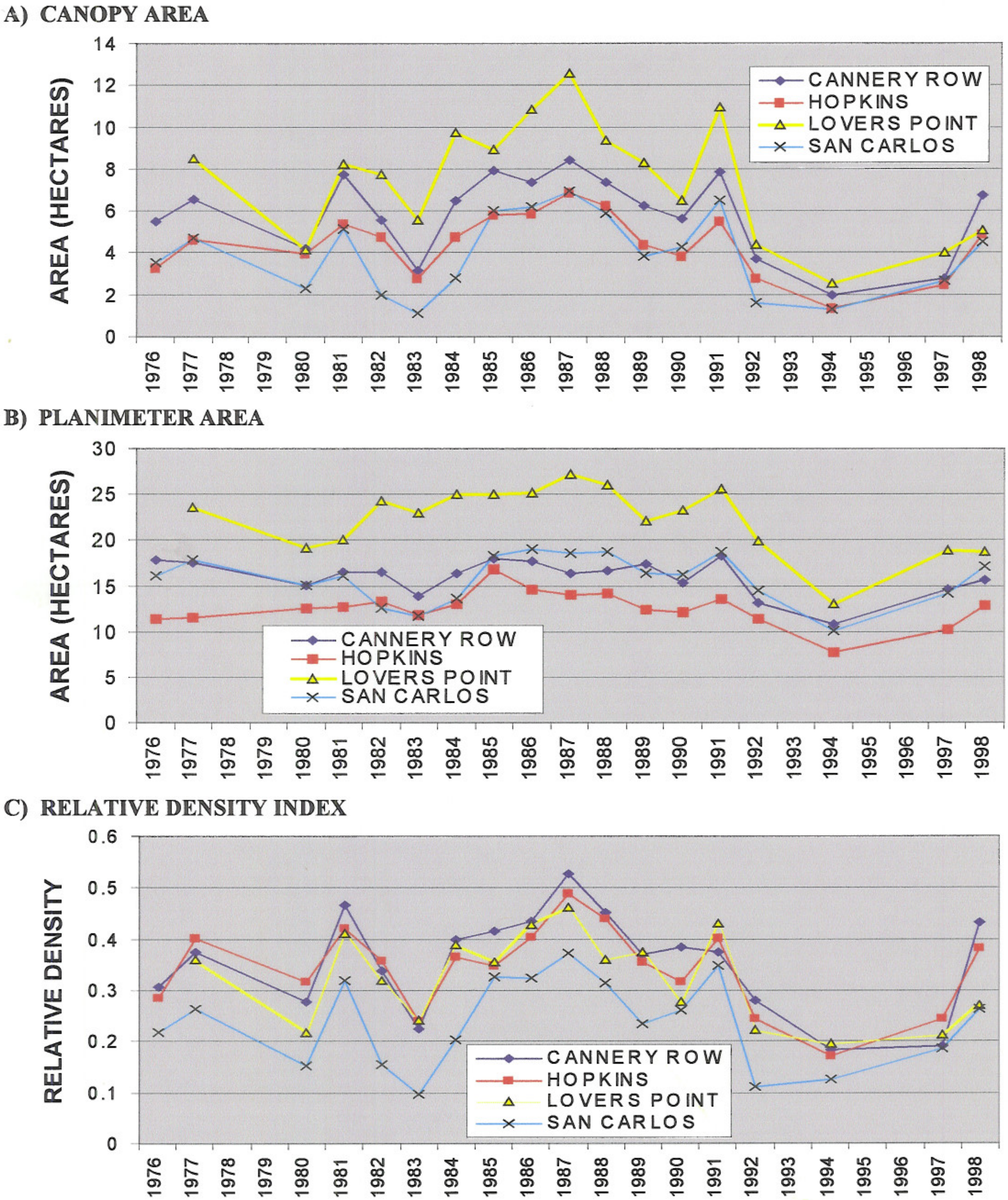
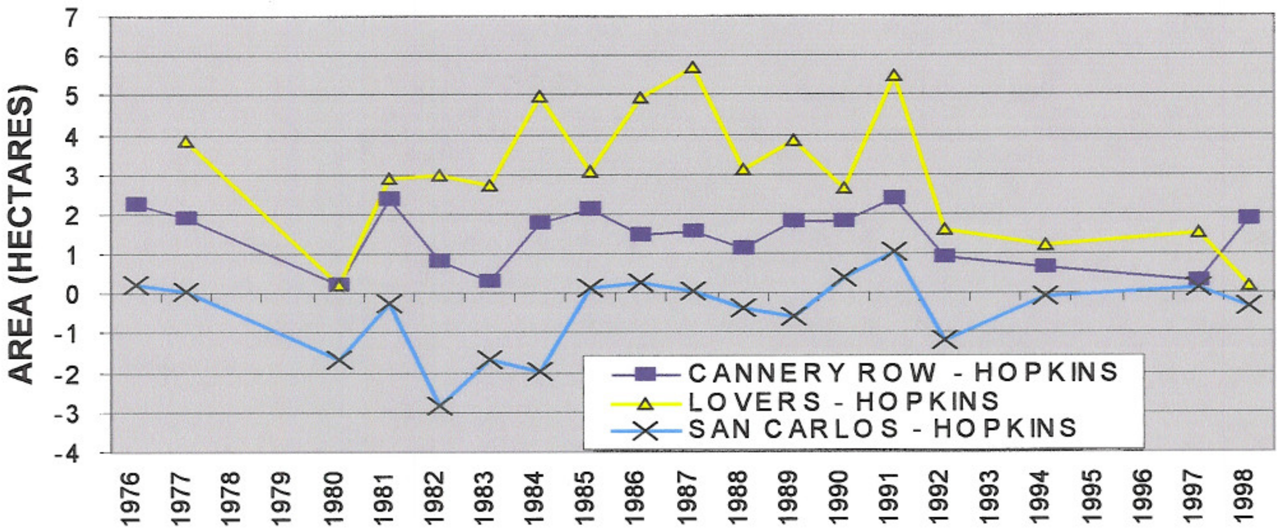
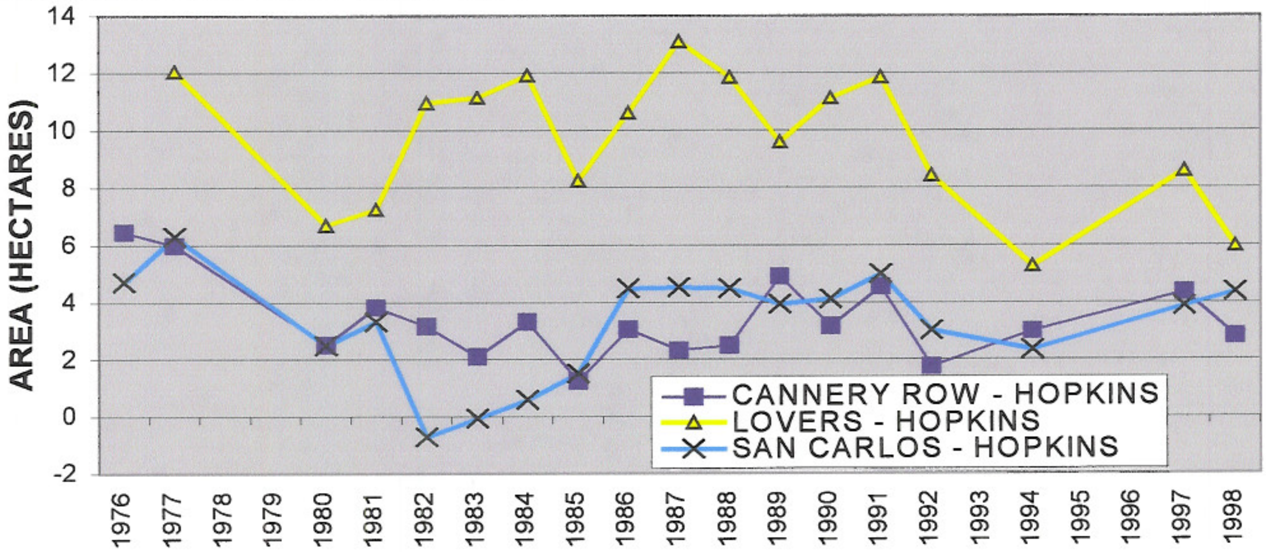


Figure 5. Time series of three measurement variables (Kelp Canopy Area, Planimeter Area, and Relative Density Index) derived from kelp canopy aerial photos. Note that lines connecting data points are for illustration only – seasonal variation between samples are not incorporated and data gaps are present (i.e. 1978, 1979, 1993, 1995, and 1996). Also note high correlation between study sites (including Hopkins control site) for each variable.

A) CANOPY AREA DIFFERENCE



B) PLANIMETER AREA DIFFERENCE



C) RELATIVE DENSITY INDEX

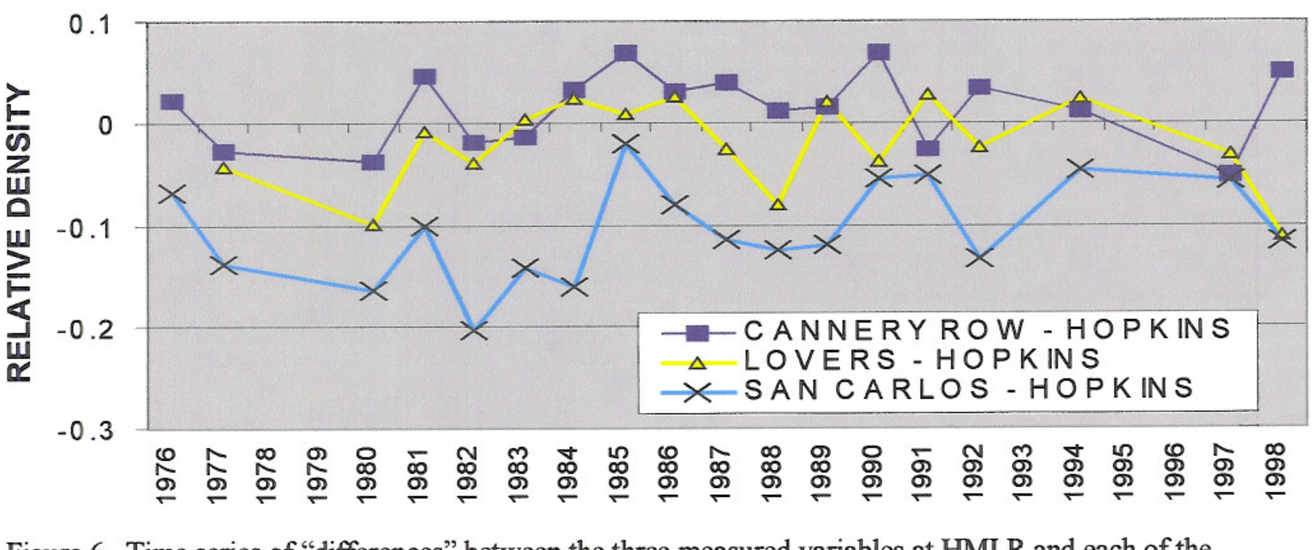


Figure 6. Time series of "differences" between the three measured variables at HMLR and each of the harvested sites. Note that lines are for illustration only – data gaps are present in 1978, 1979, 1993, 1995, and 1996, and no interpolations should be made given the year-to-year data variability.

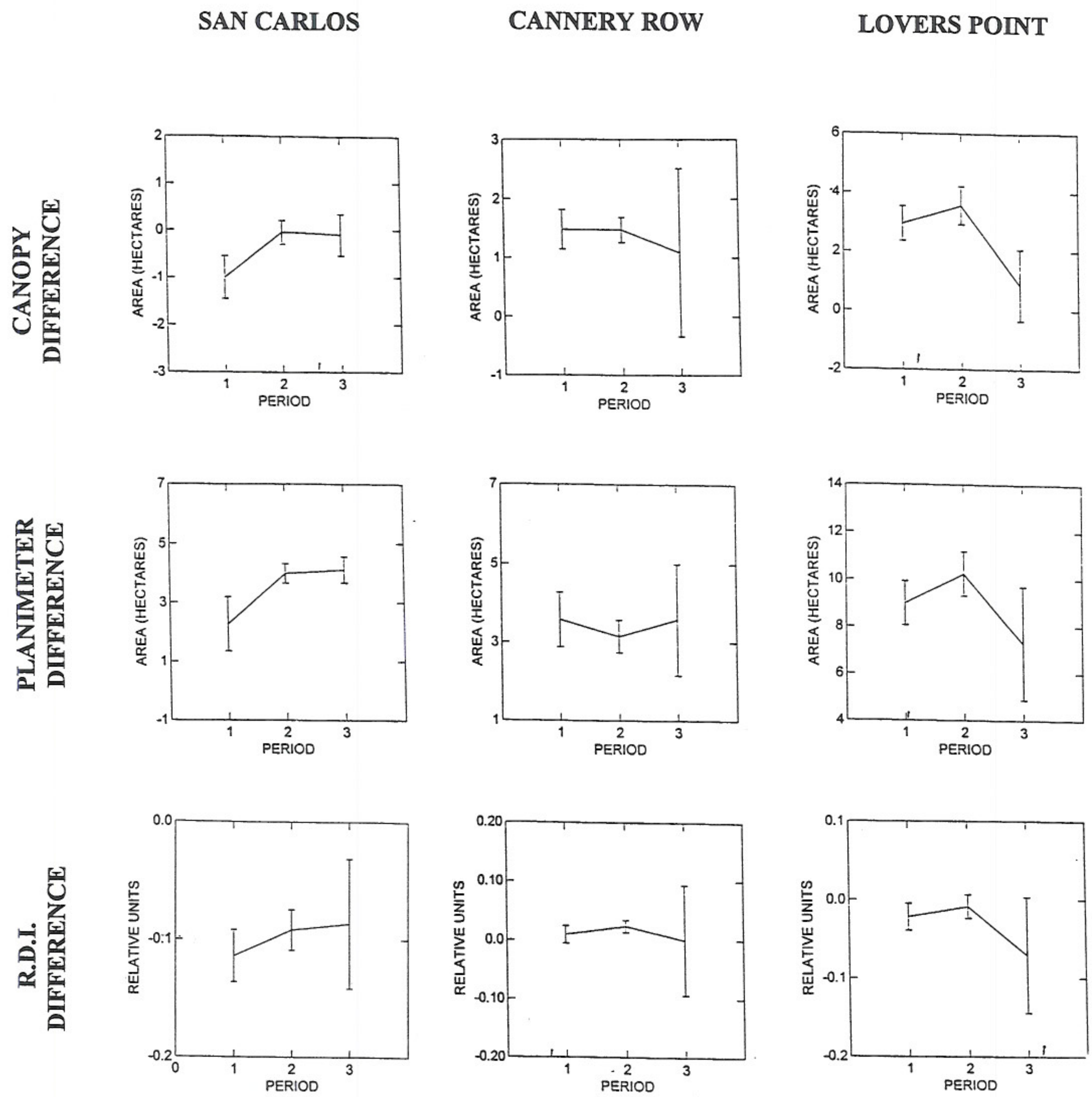


Figure 7. Results of ANOVA analyses, showing means and standard error bars for Canopy Area, Planimeter Area, and R.D.I. at each impact site within each of the three periods (Period 1: "low harvest" from 1976-1985, n=8; Period 2: "low harvest" from 1986-1995, n=6; and Period 3: "high harvest" from 1996 to present, n=2). All comparisons between periods for a given variable were statistically non-significant (P>0.05).

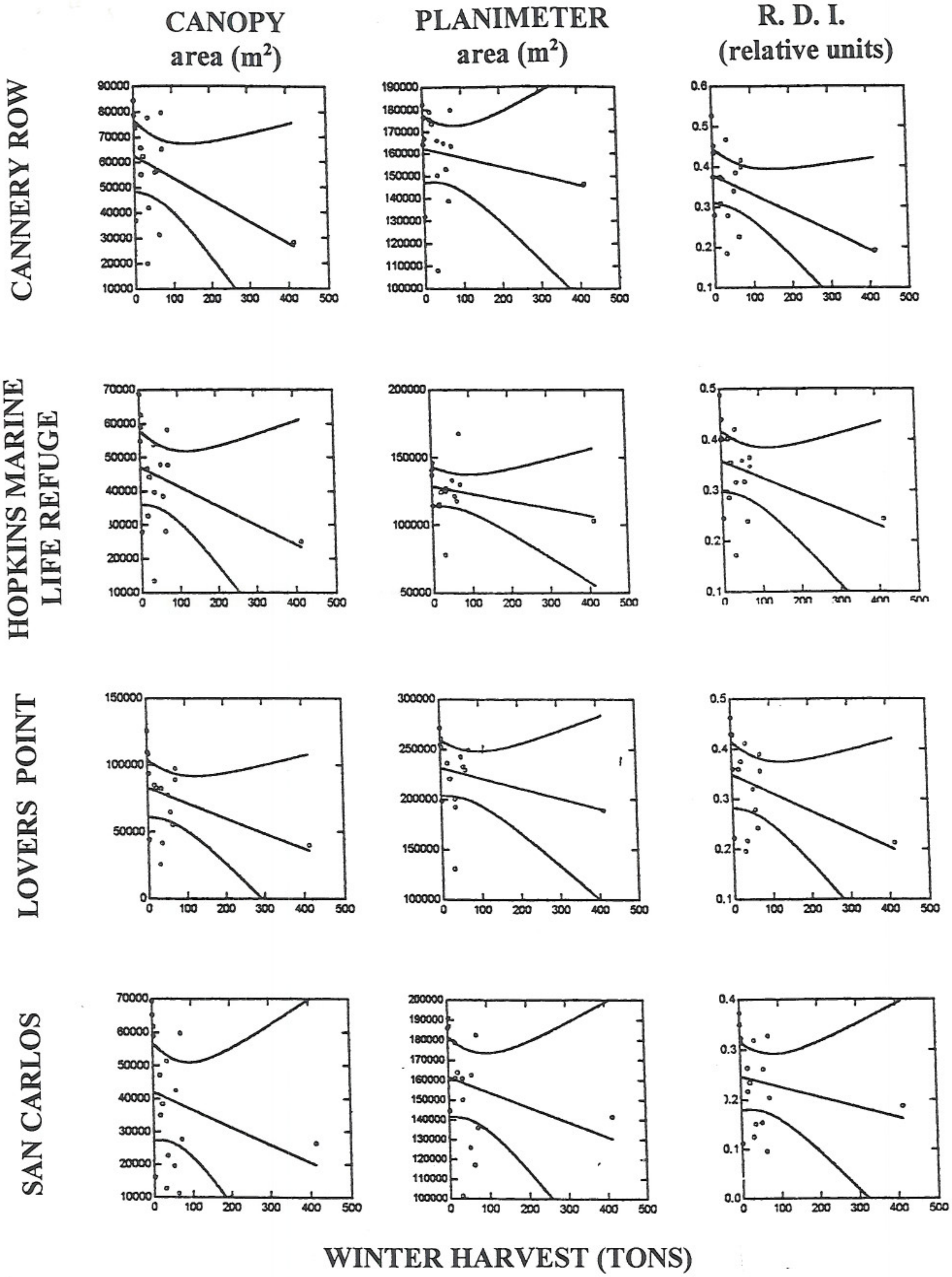


Figure 8. Regression analyses of giant kelp fall maxima canopy variables versus the amount of kelp harvested during the previous winter. All regressions were statistically non-significant (P>0.05). Note high leverage of outlier data points and extremely broad 95% confidence interval of regression slope during years of high harvest. Also, note similar trend of negative slope (though not statistically significant) at HMLR, which would be expected to have a slope of zero (i.e. no relationship to kelp harvesting since the bed is not harvested).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1987	0	0	0	0	0	4	4	3	4	3	1	1	20
1988	0	0	0	1	1	1024 (4)	22	2	4	2	1219 (2)	1219 (3)	3494 (41)
1989	2	6	8	11	2	2	0	1114 (10)	12	11	13	7	1188 (84)
1990	15	7	14	12	20	20	20	14	0	80	0	0	202
1991	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0.25	1	0	0	0	0	0.2	1	0.2	0.2	0	0	2.85
1993	0.1	1	0.8	1	0.7	1	1.2	3	2.2	1195 (1.9)	1.9	1.8	1209.7 (16.6)
1994	19.6	1.9	4.3	2	2.2	3	2.5	2.7	3.2	2.5	2.5	3.3	49.7
1995	0	0	0	0	0	5.6	5.6	7.2	5.6	6	7.5	6	43.5
1996	16	71.5	54.3	79.8	67.4	70.9	114	13.4	11	14.4	53.4	117	683.1
1997	117.2	111.2	14.6	18.6	16.7	14.9	19	19.8	21.8	22.2	92.7*	102*	571
1998	87*	76.9*	55.7*	23.2	22.6	25.3	24.6	23	22.6	N/A	N/A	N/A	360.9

Table 1. California Dept. of Fish and Game harvest records, in tons, for giant kelp *Macrocystis pyrifera* taken from bed 220. Unusually high harvest amounts within a given month (> 1000 tons) are due to Kelco, the largest-scale harvester in California. Numbers below these large values represent estimates for amount of kelp harvested by local harvesters (which could occur within the study area, whereas Kelco would not). Asterisks represent months in which approximately 50% of the kelp harvest consisted of drift kelp dislodged by winter storms. Harvest amounts for 1998 were summarized from available harvest reports and may be incomplete.

PERIOD		AERIAL SURVEY DATE	CANNERY ROW			HOPKINS MARINE LIFE REFUGE		
			CANOPY (HECTARES)	PLANIMETER (HECTARES)	R.D.I.	CANOPY (HECTARES)	PLANIMETER (HECTARES)	R.D.I.
	1	9/76	5.52	17.89	0.31	3.27	11.43	0.29
		9/77	6.58	17.55	0.37	4.65	11.57	0.40
		11/80	4.19	15.04	0.28	3.96	12.53	0.32
		9/19/81	7.76	16.60	0.47	5.37	12.78	0.42
		8/29/82	5.59	16.47	0.34	4.77	13.31	0.36
		9/21/83	3.13	13.89	0.23	2.81	11.80	0.24
		8/25/84	6.53	16.35	0.40	4.76	13.03	0.37
		11/22/85	7.95	18.00	0.42	5.82	16.76	0.35
	2	10/29/86	7.36	17.66	0.43	5.89	14.61	0.40
		7/3/87	8.44	16.40	0.53	6.87	14.09	0.49
		8/25/88	7.39	16.69	0.45	6.25	14.21	0.44
		7/31/89	6.25	17.36	0.37	4.42	12.45	0.35
		10/31/90	5.66	15.30	0.39	3.85	12.15	0.32
		7/12/91	7.87	18.23	0.38	5.49	13.68	0.40
		9/92	3.70	13.19	0.28	2.80	11.44	0.24
		9/94	2.00	10.80	0.18	1.34	7.80	0.17
	3	9/97	2.82	14.66	0.19	2.51	10.31	0.24
		10/5/98	6.75	15.63	0.43	4.89	12.82	0.38

PERIOD		AERIAL SURVEY DATE	LOVERS POINT			SAN CARLOS		
			CANOPY (HECTARES)	PLANIMETER (HECTARES)	R.D.I.	CANOPY (HECTARES)	PLANIMETER (HECTARES)	R.D.I.
	1	9/76	NA	NA	NA	3.50	16.13	0.22
		9/77	8.50	23.63	0.36	4.71	17.86	0.26
		11/80	4.17	19.23	0.22	2.28	15.03	0.15
		9/19/81	8.26	20.04	0.41	5.14	16.11	0.32
		8/29/82	7.76	24.27	0.32	1.95	12.60	0.16
		9/21/83	5.55	22.95	0.24	1.12	11.73	0.10
		8/25/84	9.73	24.96	0.39	2.77	13.62	0.20
		11/22/85	8.91	25.02	0.36	5.98	18.27	0.33
	2	10/29/86	10.82	25.24	0.43	6.17	19.08	0.32
		7/3/87	12.58	27.19	0.46	6.93	18.61	0.37
		8/25/88	9.37	26.07	0.36	5.89	18.68	0.32
		7/31/89	8.28	22.05	0.38	3.85	16.39	0.23
		10/31/90	6.49	23.29	0.28	4.26	16.27	0.26
		7/12/91	10.98	25.55	0.43	6.52	18.67	0.35
		9/92	4.41	19.86	0.22	1.62	14.45	0.11
		9/94	2.56	13.07	0.20	1.27	10.15	0.13
	3	9/97	4.02	18.90	0.21	2.65	14.18	0.19
		10/5/98	5.09	18.79	0.27	4.55	17.17	0.26

Table 2. Canopy Area, Planimeter Area, and Relative Density Index (R.D.I.) for each of the study sites for dates when adequate aerial surveys were available.

PERIOD		DATE	CANNERY ROW CANOPY (hectares)	CANNERY ROW PLANIMETER (hectares)	CANNERY ROW R.D.I.	LOVERS POINT CANOPY (hectares)	LOVERS POINT PLANIMETER (hectares)	LOVERS POINT R.D.I.	SAN CARLOS CANOPY (hectares)	SAN CARLOS PLANIMETER (hectares)	SAN CARLOS R.D.I.
	1	9/76	2.25	6.46	0.02	NA	NA	NA	0.23	4.70	-0.07
		9/77	1.92	5.99	-0.03	3.85	12.06	-0.04	0.06	6.29	-0.14
		11/80	0.23	2.51	-0.04	0.21	6.70	-0.10	-1.68	2.49	-0.16
		9/19/81	2.39	3.82	0.05	2.88	7.26	-0.01	-0.24	3.33	-0.10
		8/29/82	0.82	3.16	-0.02	2.99	10.96	-0.04	-2.82	-0.72	-0.20
		9/21/83	0.32	2.09	-0.01	2.73	11.15	0.00	-1.69	-0.07	-0.14
		8/25/84	1.77	3.32	0.03	4.97	11.93	0.02	-1.99	0.59	-0.16
		11/22/85	2.13	1.24	0.07	3.09	8.26	0.01	0.16	1.51	-0.02
	2	10/29/86	1.47	3.05	0.03	4.93	10.63	0.03	0.28	4.47	-0.08
		7/3/87	1.57	2.32	0.04	5.71	13.10	-0.02	0.06	4.52	-0.12
		8/25/88	1.14	2.48	0.01	3.13	11.87	-0.08	-0.36	4.48	-0.12
		7/31/89	1.83	4.91	0.02	3.86	9.61	0.02	-0.57	3.94	-0.12
		10/31/90	1.81	3.15	0.07	2.64	11.14	-0.04	0.41	4.12	-0.05
		7/12/91	2.38	4.55	-0.03	5.49	11.87	0.03	1.04	4.98	-0.05
		9/92	0.90	1.76	0.04	1.60	8.43	-0.02	-1.18	3.01	-0.13
		9/94	0.65	3.00	0.01	1.22	5.27	0.02	-0.07	2.35	-0.05
	3	9/97	0.31	4.35	-0.05	1.52	8.60	-0.03	0.14	3.87	-0.06
		10/5/98	1.86	2.81	0.05	0.20	5.97	-0.11	-0.34	4.35	-0.12

Table 3. "Difference" values calculated by subtracting the raw abundance of each of the three variables (Canopy Area, Planimeter Area, and R.D.I.) at HMLR from each of the Impact sites for each year.

Table 4. Results of multi-sample analyses of "difference" data for each Impact site. No statistically significant differences among periods were detected at any of the impact sites ($P > 0.05$). ANOVA analyses were done when assumptions were met; non-parametric Kruskal-Wallis tests were performed when the assumptions of equal variances were severely violated (i.e. Cochran's test values > 0.60). ANOVA analyses were unbalanced, Model 1, one-way, 3-level tests.

A. SAN CARLOS

i. **Canopy** Cochran's test C = 0.68

Kruskal Wallis test statistic = 1.9099 DF = 2 P = 0.385 Not Significant

	Least Squares Mean	Standard Error	N
Periods =1	-0.9950	0.3481	8
Periods =2	-0.0380	0.4019	6
Periods =3	-0.1000	0.6962	2

ii. **Planimeter** Cochran's test C = 0.83

Kruskal Wallis test statistic = 2.228 DF = 2 P = 0.328 Not Significant

	Least Squares Mean	Standard Error	N
Periods =1	2.266	0.6688	8
Periods =2	3.969	0.7723	6
Periods =3	4.110	1.3377	2

iii. **R.D.I.** ANOVA Summary Cochran's test C = 0.52

Source of Variation	Sum-of-Squares	DF	Mean-Square	F-ratio	P	Result
Periods	0.0049	2	0.0024	0.950	0.412	NS
Error	0.0332	13	0.0026			

	Least Squares Mean	Standard Error	N
Periods =1	-0.125	0.018	8
Periods =2	-0.092	0.021	6
Periods =3	-0.087	0.036	2

B. CANNERY ROW

i. **Canopy** ANOVA Summary Cochran's test C = 0.51

Source of Variation	Sum-of-Squares	DF	Mean-Square	F-ratio	P	Result
Periods	0.2538	2	0.1269	0.194	0.82	NS
Error	8.5218	13	0.6555			

	Least Squares Mean	Standard Error	N
Periods =1	1.478	0.2863	8
Periods =2	1.353	0.3305	6
Periods =3	1.087	0.5725	2

ii. **Planimeter** Cochran's test C = 0.61

Kruskal Wallis test statistic = 0.9926 DF = 2 P = 0.609 Not Significant

	Least Squares Mean	Standard Error	N
Periods =1	3.573	0.5283	8
Periods =2	2.859	0.6100	6
Periods =3	3.581	1.0566	2

Table 4. continued

iii. **R.D.I** Cochran's test C = 0.70

Kruskal Wallis test statistic = 0.110 DF = 2 P = 0.946 Not Significant

	Least Squares Mean	Standard Error	N
Periods =1	0.0094	0.0134	8
Periods =2	0.0175	0.0155	6
Periods =3	-0.0002	0.0268	2

C. LOVERS POINT

i. **Canopy** ANOVA Summary Cochran's test C = 0.57

Source of Variation	Sum-of-Squares	DF	Mean-Square	F-ratio	P	Result
Periods	11.93	2	5.969	2.17	0.157	NS
Error	32.96	12	2.747			

	Least Squares Mean	Standard Error	N
Periods =1	2.961	0.6264	7
Periods =2	3.680	0.6766	6
Periods =3	0.8585	1.1719	2

ii. **Planimeter** ANOVA Summary Cochran's test C = 0.41

Source of Variation	Sum-of-Squares	DF	Mean-Square	F-ratio	P	Result
Periods	13.543	2	6.7713	1.07	0.375	NS
Error	76.241	12	6.3534			

	Least Squares Mean	Standard Error	N
Periods =1	8.994	0.9527	7
Periods =2	10.194	1.029	6
Periods =3	7.2836	1.7823	2

iii. **R.D.I.** ANOVA Summary Cochran's test C = 0.47

Source of Variation	Sum-of-Squares	DF	Mean-Square	F-ratio	P	Result
Periods	0.0058	2	0.0029	1.508	0.261	NS
Error	0.0230	12	0.0019			

	Least Squares Mean	Standard Error	N
Periods =1	-0.0218	0.0166	7
Periods =2	-0.0084	0.0179	6
Periods =3	-0.0704	0.0310	2

		t	df	P	RESULT
SAN CARLOS	CANOPY	-1.97	12	0.04	*
	PLANIMETER	-1.55	12	0.07	NS
	R.D.I.	-1.64	12	0.06	NS
CANNERY ROW	CANOPY	0.035	12	0.49	NS
	PLANIMETER	0.74	12	0.24	NS
	R.D.I.	-0.90	12	0.19	NS
LOVERS POINT	CANOPY	-0.66	11	0.26	NS
	PLANIMETER	-0.76	11	0.23	NS
	R.D.I.	-0.98	11	0.18	NS

Table 5. Results of one-tailed, two-sample t-test comparisons of the "difference" values between Period 1 "moderate harvest" ($n = 8$, except $n = 7$ for Lovers Point) and Period 2 "low harvest" ($n = 6$) at each of the impact sites. t = t statistic value; df = degrees of freedom; P = Probability of rejecting the null hypothesis when it is in fact true; NS = result was not statistically significant ($P > 0.05$); * = statistically significant result ($P \leq 0.05$). Note that the amount of kelp canopy surface area at San Carlos was significantly greater during the period of "low harvest" than the period of "moderate harvest."

		Effect	N	R^2	Coeff.	Std.Error	t	P	Result
SAN CARLOS	CANOPY	Winter harvest	17	0.008	-53.6	50.4	-1.06	0.30	NS
	PLANIMETER	Winter harvest	17	0.011	-74.9	69.0	-1.09	0.29	NS
	R.D.I.	Winter harvest	17	0.000	0.0	0.0	-0.89	0.39	NS
CANNERY ROW	CANOPY	Winter harvest	17	0.122	-86.9	48.4	-1.80	0.09	NS
	PLANIMETER	Winter harvest	17	0.000	-40.8	52.2	-0.78	0.45	NS
	R.D.I.	Winter harvest	ASSUMPTIONS NOT MET						
HOPKINS	CANOPY	Winter harvest	17	0.077	-57.0	37.3	-1.53	0.15	NS
	PLANIMETER	Winter harvest	ASSUMPTIONS NOT MET						
	R.D.I.	Winter harvest	17	0.078	0.00	0.00	-1.54	0.15	NS
LOVERS POINT	CANOPY	Winter harvest	16	0.092	-113	71.0	-1.59	0.14	NS
	PLANIMETER	Winter harvest	16	0.012	-101	93.1	-1.09	0.30	NS
	R.D.I.	Winter harvest	16	0.104	0.00	0.00	-1.65	0.12	NS

Table 6. Results of regression analyses between the previous year's winter harvest amount (independent variable) and Canopy Area, Planimeter Area, and R.D.I. (dependent variables) at each study site. None of the slope coefficients were statistically significant (P>0.05).