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CHANGES IN KELP FORESTS AT PALOS VERDES

Giant kelp, *Macrocystis pyrifera*, is the largest and most important seaweed in California. In rocky subtidal areas, such as off the Palos Verdes Peninsula, it forms underwater forests (or beds) that serve as refuge and a source of food for nearshore fin fish and invertebrates. It also is one of California's most important commercially harvested living marine resources: for example, nearly 156,000 metric tons of kelp--or about 26 percent of California fishery landings--were landed in 1975 (Pinkas 1977).

Southern California kelp forests have undergone large variations in size during the past century. Although limited, historical data indicate that, in the 1940's, kelp forests near urban areas of Los Angeles and San Diego began a decrease in size that continued into the 1960's. All kelp beds off southern California decreased in size during the "warm water" years of 1957-59, but most, including those off San Diego, began to increase again in the 1960's. However, kelp forests off the Palos Verdes Peninsula continued to decrease, in 1967, the last known adult *Macrocystis* plants died.

Restoration efforts, initated in 1967 by the California Institute of Technology and in 1971 by the California Department of Fish and Game, met with little success until 1973-74, when offspring of transplanted kelp were found at a restoration site in Abalone Cove. A small stand of kelp soon formed. Encouraged by the results, the two groups initiated restoration work at other Palos Verdes sites in 1974 and 1975. A naturally established stand of kelp appeared off Bluff Cove in 1975. By July 1977, there were over 34 ha (84 acres) of kelp along Palos Verdes Peninsula. Photographic surveys of kelp beds on Palos Verdes Peninsula have been conducted on a quarterly basis since 1974. Detailed aspects of the actual kelp restoration work is reviewed by Wilson (1978).

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The main objective of this paper is to report on the present condition of Palos Verdes kelp beds and describe the extent to which recent changes in kelp are related to changing ocean conditions, sewage discharges, restoration efforts, and local commercial and recreational fisheries. As indicated in more detail below, we found that the Palos Verdes kelp beds have continued to grow at a remarkable rate, returning from no kelp in 1967 to 240 ha (593 acres) in January 1980, i.e., nearly the area they occupied 33 years ago. The recovery seems to be related to several factors including direct control of grazing sea urchins, removal of competing vegetation, increased transparency, and reduced emissions of suspended solids from the adjacent outfalls. The ultimate size that the beds will attain is uncertain, but it is probable that turbidity, sedimentation, and continued fishing pressure on predators and competitors of sea urchins will prevent the beds from reaching sizes found in the early 1900's.

METHODS

As a part of its kelp restoration operations, the California Department of Fish and Game has been monitoring changes in kelp beds along Palos Verdes Peninsula since 1974. Monitoring operations include aerial, boat, and diving observations. Aerial surveys have been used to document location, condition, and size of *Macrocystis pyrifera* beds, while boat and diving operations provide information on density, growth rate, grazing of herbivores, and *M. pyrifera* recruitment.

Aerial infrared photography is used for documentation of kelp canopies. Photographs were taken using a hand-held 35-mm reflex camera with color infrared slide film (Kodak IE-135-20) and a No. 25A filter to enhance images of surface canopies. Photographs were taken through an aircraft bottom viewing port at altitudes ranging from approximatedly 1.5 to 2.6 km. To minimize reflected glare, surveys were conducted whenever possible from 2 to 4 hours before or after apparent noon, and a circular polarizing filter was employed when necessary. A 10 to 20 percent overlap was included between adjacent photographs to assure full coverage and minimize barrel distortion at film edges. Slides of the kelp beds were projected and drawn onto charts of the coast. The surface areas of canopies were calculated from these charts using a polar planimeter or a measured grid-network.

To determine what factors may have contributed to the decline and resurgence of these kelp beds, we acquired and analyzed additional oceanographic, wastewater, and biological data from other sources. Sea surface temperatures and transparency have been measured weekly in southern Santa

Monica Bay since July 1956 by personnel of the Hyperion Treatment Plant. We selected a station (5C) offshore of Bluff Cove to represent changing ocean conditions and computed annual variations in temperature and transparency. Data and estimates of emissions of suspended solids from 1937 to the present were provided by Dr. Irwin Haydock of the Sanitation Districts of Los Angeles County. An analysis of urchin fishery landings from Palos Verdes were provided by David Parker, California Department of Fish and Game. Finally, we reviewed publications of several studies dealing with predator-prey interaction in kelp bed communities. Data on variations in kelp canopy size, ocean temperature and transparency and wastewater emissions were subjected to regression analysis and the results examined for significant relationships.

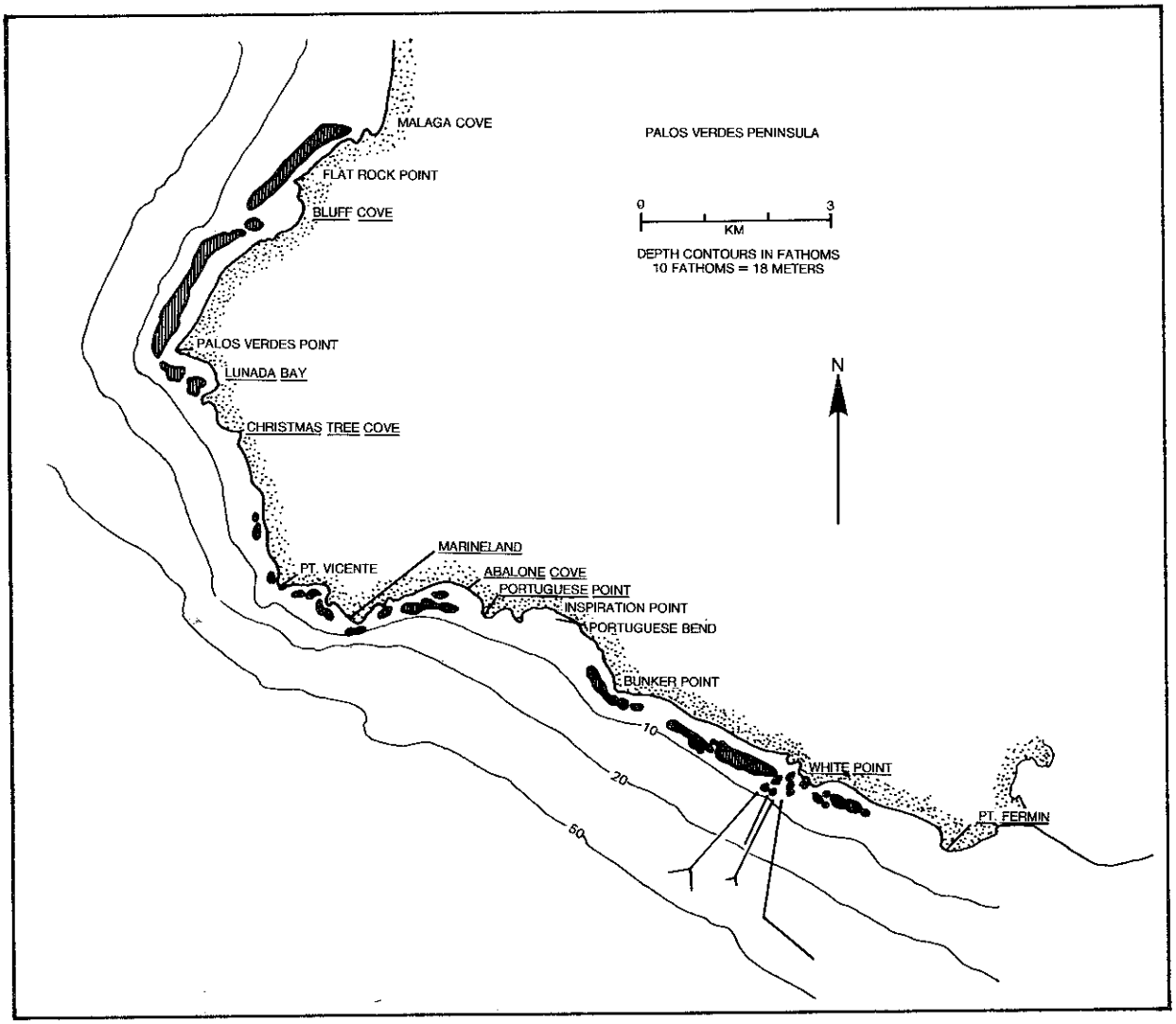

Figure 1. The Palos Verdes Peninsula showing approximate locations and sizes of surface canopies of giant kelp (Macrocystis pyrifera) observed during January 1980 aerial survey by the California Department of Fish and Game. Kelp restoration sites are underlined.

RESULTS

In January 1980, there were 240 ha (593 acres) of giant kelp surface canopy along the Palos Verdes coastline. This represents and increase of about 560 percent over the 36 ha reported in our 1977 Annual Report (Mearns 1977). About 13 km of the 21.6 km of Palos Verdes coastline contained observable kelp canopies in January 1980.

Kelp beds were concentrated in three major areas along the Peninsula (Figure 1). The largest beds, totaling approximately 107 ha, were found along the northern coast between Palos Verdes Point and Malaga Cove generally ranging in depths from 5.5 to 14m. The next largest beds, 73 ha, occurrred from about 0.8 km east of White Point to Inspiration Point and ranged in depths from 3 to 12 m. Los Angeles County's outfalls at White Point, located in the center of this area, discharge their effluent into 59 m of water at a distance of approximtely 2.8 km offshore. There

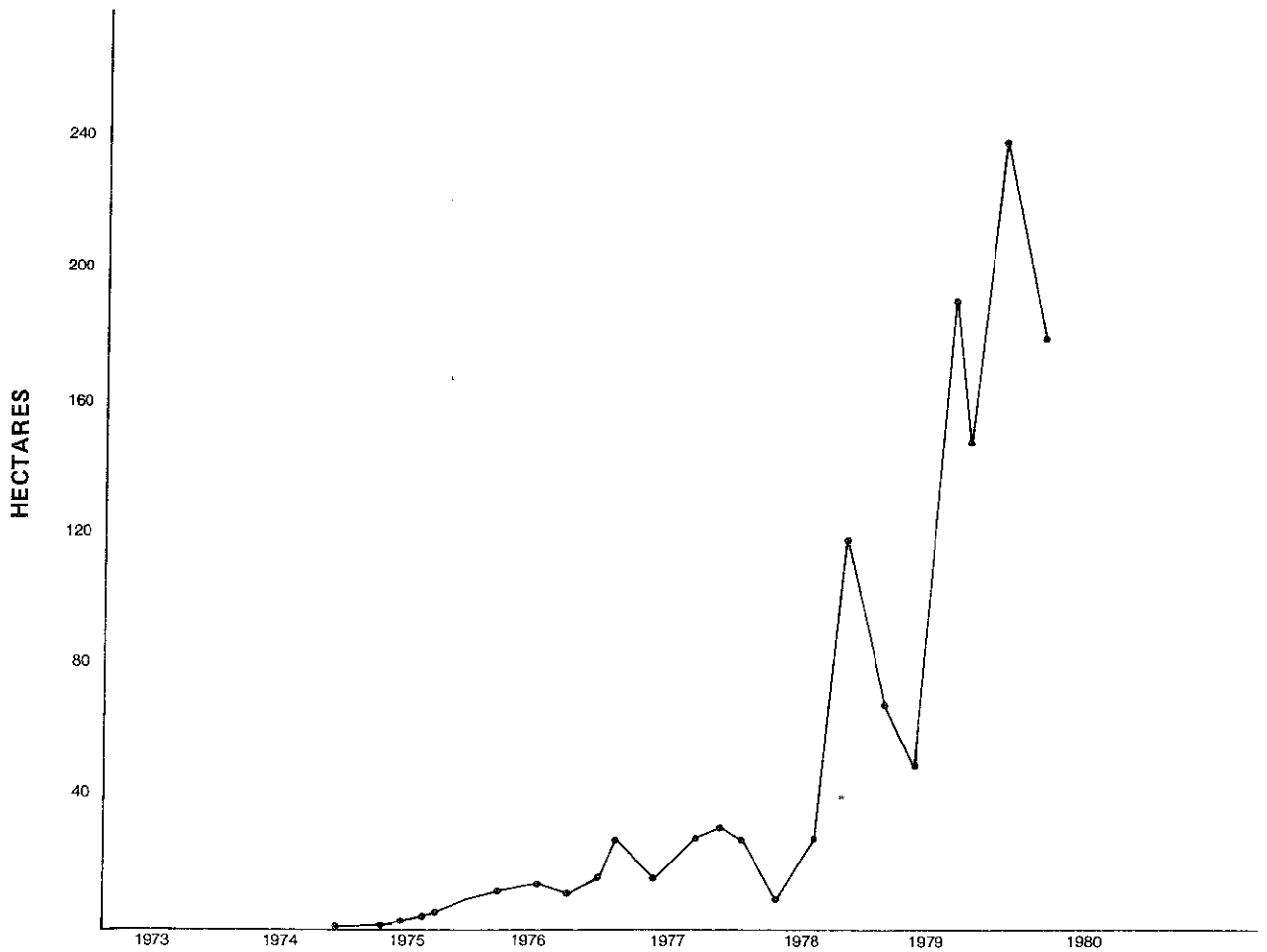

Figure 2. Hectares of surface canopy of giant kelp (Macrocystis pyrifera) Palos Verdes Peninsula 1973-80.

were approximately 36 ha of kelp canopy between Inspiration Point and Point Vicente ranging in depths from 3 to 12 m. The smallest kelp canopy was located between Point Vicente and Palos Verdes Point, where 24 ha of kelp were found in Lunada Bay in depths ranging from 3 to 14 m.

The total kelp bed area in January 1980, 240 ha, was similar to that reported by the State Water Resources Control Board (1964) for the year 1947, 272 ha. However, the total canopy size was only 40 percent of that reported in 1911, 607 ha, and 33 percent of that reported in 1928, 728 ha (Figure 3; State Water Resources Control Board 1964).

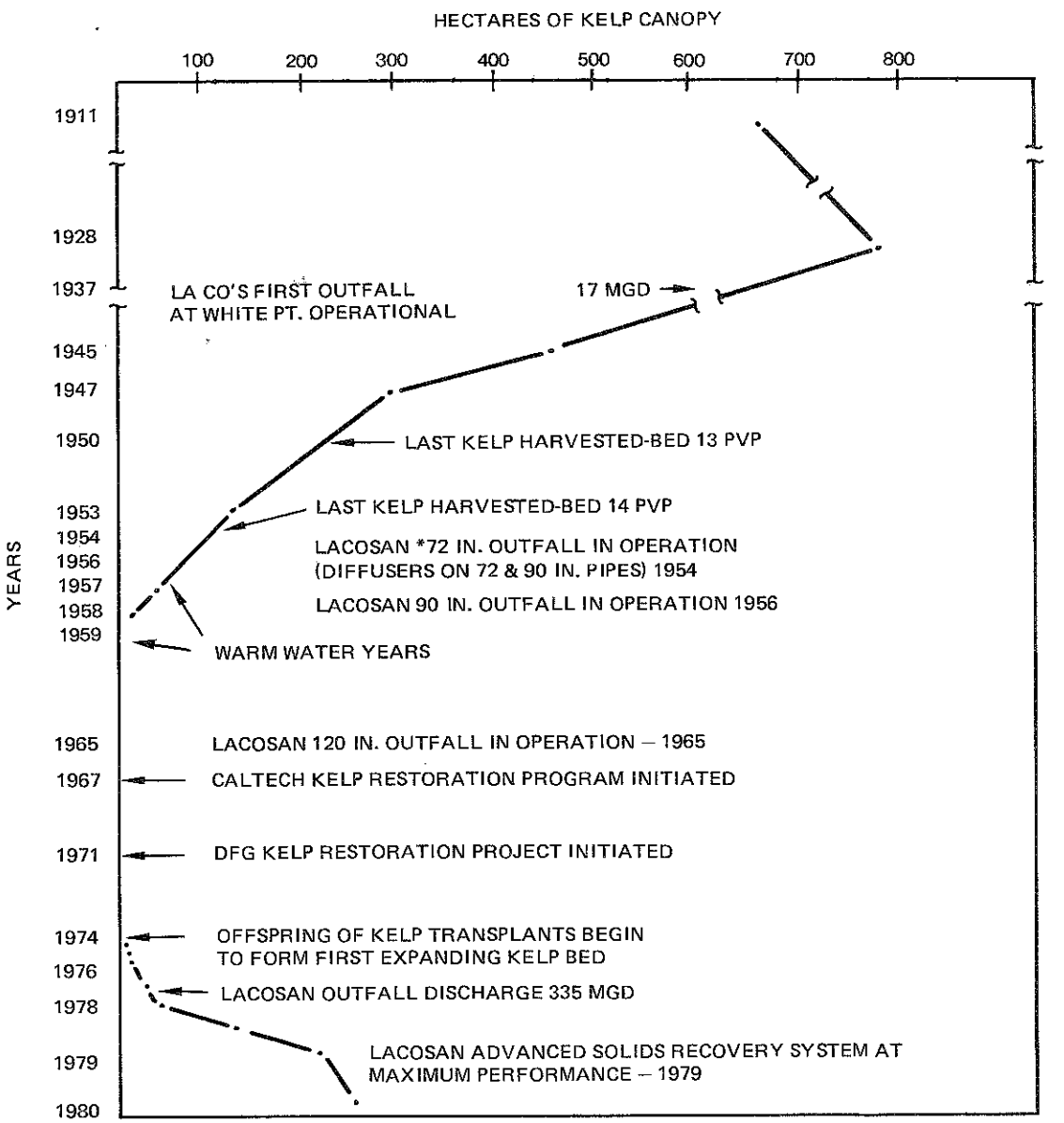

Figure 3. Maximal canopy of giant kelp beds on Palos Verdes Peninsula with Historical Notes. *LACOSAN - L.A. County Sanitation Districts.;

Overall growth of kelp beds along Palos Verdes Peninsula has been remarkable, canopy size has approximately doubled each year since 1973-74 (Figure 2).

With the exception of the area immediately around White Point, it appears that kelp beds are returning to many areas in approximately the reverse order in which they disappeared; that is, the last beds to disappear and the first to reappear were those in the vicinity of Abalone Cove and the northwest coast (Figure 4 a-f).

Review of oceanographic and wastewater emissions data reveals some interesting trends. As shown in Figure 4, sea surface temperatures and transparency were higher in the late 1970's than during the mid-1960's through mid-1970's; both were also unusually high during the period 1957-59. A decade (1944-56) of cool water preceded this (Secchi depth data were not available for this area prior to 1956).

Wastewater emissions of suspended solids increased steadily from the time discharge was initiated off Palos Verdes Peninsula in 1937, until a peak was reached in 1971 when nearly 170,000 metric tons (dry weight) were discharged. However, by 1979, emissions had dropped to about 95,000 metric tons per year or about the level discharged in 1956.

There are correlations between these and other variables. For example, variations in total Palos Verdes kelp canopy size were significantly correlated with suspended solids emissions from Joint Water Pollution Control Plant for the period 1947 through 1959 but not for the period 1957 through 1959 (Table 1). Kelp canopy size was also significantly correlated with transparency in southern Santa Monica Bay (Station 5C) for the period 1974 through 1979, but not for the period 1957-79. Transparency in southern Santa Monica Bay during 1957-79 was, in turn, significantly related to sea surface temperature and to suspended solids mass emissions rates.

These correlations suggest that variation in kelp canopy size at Palos Verdes was related to both changing ocean conditions and wastewater emissions from the nearby outfalls, and also that transparency in southern Santa Monica Bay was related to variation in the solids emissions.

Another set of calculations (bottom, Table 1) suggests that variations in Palos Verdes kelp canopy size were not related to temperature variations over the period 1945-79; however, variations in kelp harvest at La Jolla (a nondischarge site) were significantly inversely related to annual variations in temperature during the period 1946-58. Thus annual temperature variations may have some effect on kelp bed size, but this has not been apparent at Palos Verdes.

DISCUSSION

There is no question that giant kelp forests are once again returning to the Palos Verdes Peninsula coastline. Pertinent questions are: (1) What caused the decline, (2) what changes caused recent regrowth, and (3) what factors, present and projected, might limit full regrowth of kelp canopies along Palos Verdes Peninsula?

Factors related to decline of the kelp beds

A number of factors have been implicated in the decline of kelp forests along Palos Verdes Peninsula. Pollution, in the form of sewage discharge from White Point, caused environmental changes that included: siltation and smothering of rocky surfaces by floc originating from both sewage and plankton (Grigg and Kiwala 1970; Grigg 1978; Meistrell and Montagne 1979, unpublished report), reduction in depth of the euphotic zone by suspended materials (Peterson 1974), and, historically, high concentrations of potentially toxic compounds (Mearns 1977). Declines in kelp forests have also been attributed to extended periods of abnormally warm ocean temperatures (State Water Resources Control Board 1964), and overgrazing by sea urchins and other herbivorous animals (State Water Resources Control Board 1964; North 1976; Leighton 1966).

Our analysis of variations in oceanographic conditions and wastewater discharges suggests that solids emissions and variations in offshore transparency might well have been contributing factors in both the decline and recovery of the Palos Verdes kelp beds. At this site, these factors seem to

Table 1. Correlation coefficients (r) and their significance for Palos Verdes Kelp canopy size, sea surface temperature and transparency in southern Santa Monica Bay (Station 5C), suspended solids mass emissions at Palso Verdes and for Scripps Pier temperatures[1] and kelp harvest at La Jolla[2]. Based on annual averages.

Independent Variable (x)	Dependent Variable (y)	df	r	Significance
Sus. solids, MER	Kelp Canopy, 1947-79	9	-0.925	$p < 0.01$
Sus. solids, MER	Kelp Canopy, 1957-59 (avg.)	6	-0.593	n.s.
Transparency, 5C	Kelp Canopy, 1974-79 only	4	0.851	$p < 0.1 > 0.01$
Transparency, 5C	Kelp Canopy, 1957-79	5	0.472	n.s.
Temperature, 5C	Transparency, 5C, 1957-79	21	0.726	$p < 0.01$
Sus. solids, MER	Transparency, 5C, 1957-79	21	-0.535	$p \leq 0.01$
Temperature Anomaly	Kelp Canopy, 1945-79	9	-0.333	n.s.
Temp. Scripps Pier	La Jolla Kelp, % harvest, 1946-58	N	-0.662	$p < 0.1 > 0.01$

[1] From Radovich 1961.

[2] From State Water Resources Control Board

n.s. = not significant

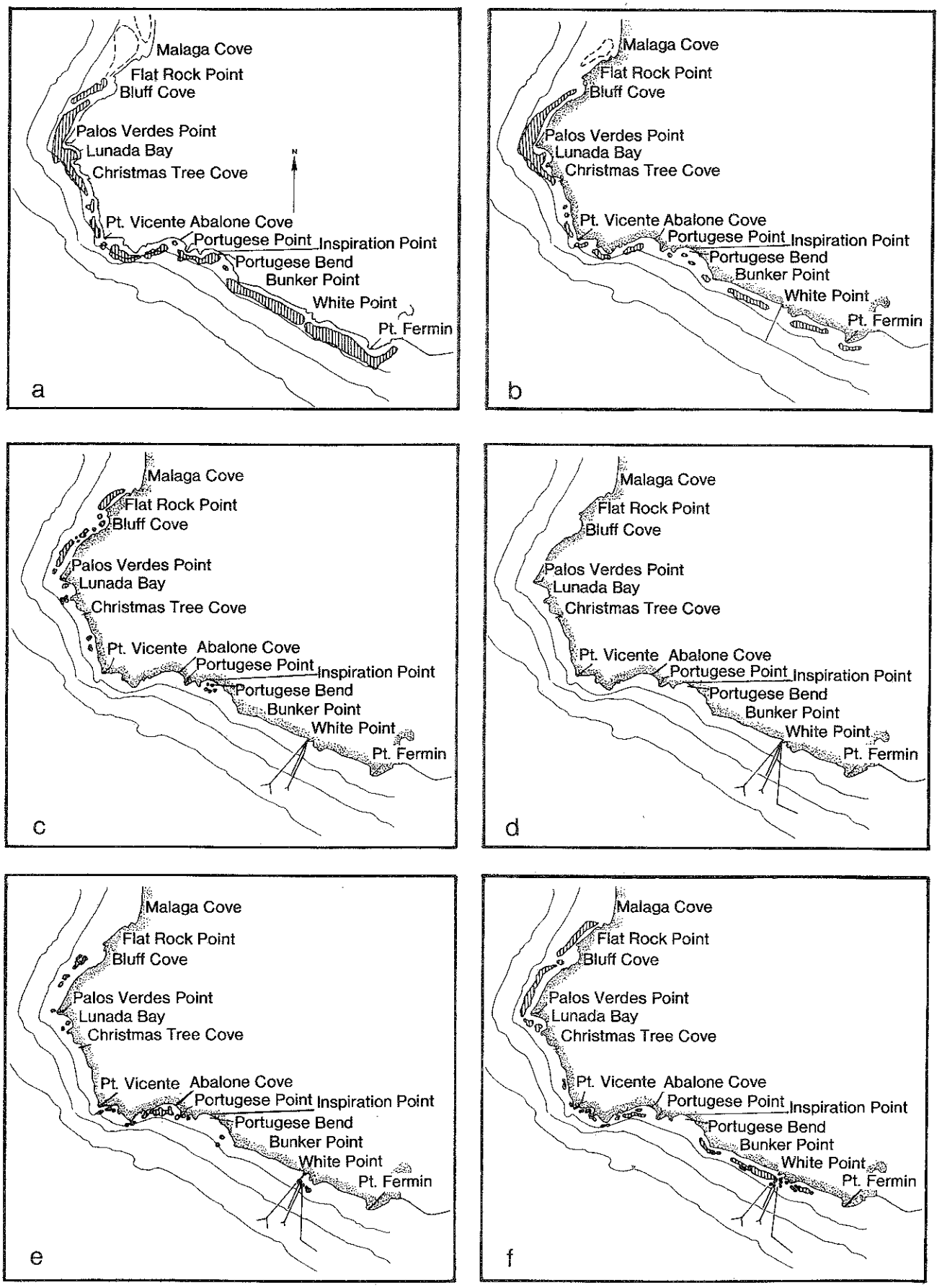

FIGURE 4 a-f. Changes in the distribution of kelp beds along the Palos Verdes Peninsula, 1928 to 1980. (Maps a-c from State Water Resources Control Board, 1964; Map d from W.J. North.)

overide variations in temperature as a contributing factor. Moreover, as noted above, kelp forests near the White Point outfalls disappeared later than some of those further away; this suggests the effects of sewage began after these beds started to decline.

Selective fishing of competitors and predators of sea urchins over the past two centuries udoubtedly contributed to the instability and loss of kelp forests along Palos Verdes. The major predator on sea urchins, the sea otter, *Enhydra lutris*, was removed from southern California's nearshore marine environment approximately 140 years ago. During its absence, nearshore populations of sea urchins and other large invertebrates expanded greatly all along the coast. During the last 40 to 50 years, there has been heavy fishing on kelp bed fishes and invertebrates. Some of these oraganisms, such as sheepshead and lobster, are known predators on sea urchins, while red, green, and pink abalone compete with sea urchins for food and habitat (Tegner 1979). Elsewhere (Australia and Nova Scotia), it has been demonstrated that selective fishing on sea urchin predators (lobsters) leads to increases in sea urchin populations and subsequent overgrazing of seaweeds by sea urchins (Mann and Breen 1972, Breen and Mann 1976, Mann 1977). We believe this has been part of the problem at Palos Verdes; in fact, some of the first areas to show decline of kelp beds (the western side of the peninsula) were those subject to heavy fishing on lobsters and abalone. Sedimentation resulting from land development and road construction runoff may also be involved in the decline of kelp forests. Such sediments have caused the burial of otherwise suitable rocky substrate in scattered areas along Palos Verdes Peninsula (such as Portuguese Bend).

It is probable that either pollution or increased grazing pressure could have eventually destroyed large portions of Palos Vedes kelp forests. We believe that both acted together to devastate kelp around the entire peninsula.

Factors related to recovery of the kelp beds

A review of historical data on the disappearance and regrowth of *Macrocystis* shows that kelp restoration efforts from 1973 onward contributed considerably to the rapid return of kelp along Palos Verdes Peninsula. Restoration efforts began at Abalone Cove in 1973, at Point Vicente and White Point in 1974, at Lunada Bay and Portuguese Point in 1976, and at Long Point in 1976, and included transplantation of kelp, sea urchin controls. and removal of competing vegetation. These efforts succeeded in establishing stands of kelp, stable nuclei from which larger

beds could grow. Urchin control and removal of competing vegetation also encouraged the return and stability of a naturally seeded stand of kelp in Bluff Cove along the north coast of Palos Verdes Peninsula. However, it is also evident from 6 years of unsuccessful restoration work prior to 1973 that restoration efforts alone did not bring back *Macrocystis pyrifera*; presumably, environmental conditions were not favorable for its growth prior to 1973 but were favorable afterwards.

As indicated above, it is possible that long-term changes in water temperatures and transparency and recent reductions in emission of waste solids from White Point outfalls may have contributed to the renewed growth of kelp that began in 1973. Prolonged periods of elevated temperature (above 17°C) are considered lethal to kelp (State Water Resources Control Board 1964); it may be that the low nutrient content of warmer waters is actually responsible, (R. Eppley, Scripps Institution of Oceanography, personal communication). As shown in Figure 5a, the periods 1936-37, 1939-42, 1957-60 and most recently, 1976-79, have been abnormally warm, and kelp growth should have been reduced during these periods. Based on available data, it appears that kelp canopy size began to decrease years before the warm water episode of 1957-59 and that the recent regrowth of kelp has taken place during a moderate warm water period.

While there are no canopy data available for the warm water episodes of 1936-37 or 1939-41, kelp harvest records may reflect trends in canopy size. Harvesting success during warm water periods appeared to be lower than when normal or cooler conditions were prevalent (Figure 5d). From these observations, we conclude that warm water episodes, per se, were not the primary factors limiting kelp growth at Palos Verdes.

Offshore, increased water transparency accompanies warm water events, as evident in a comparison of Figures 5a and 5b. In fact, transparency several miles offshore was very high during 1958-59 and again during 1976-79. Thus kelp beds were continuing to deteriorate during the very warm but very clear water period of 1958-59 but were recovering during the moderately warm but very clear offshore water period of 1976 through 1979. Inspection of transparency data from both station 5C and from a county station near the Malaga Cove-Palos Verdes Point beds confirms that transparency was improving in this area from 1973 until the time sampling was discontinued in 1977. However, transparency did not improve markedly near the White Point area itself (Los Angeles County Sanitation District data). These observations suggest improved transparency might be a factor aiding recovery of the northwesternmost beds during the late 1970's.

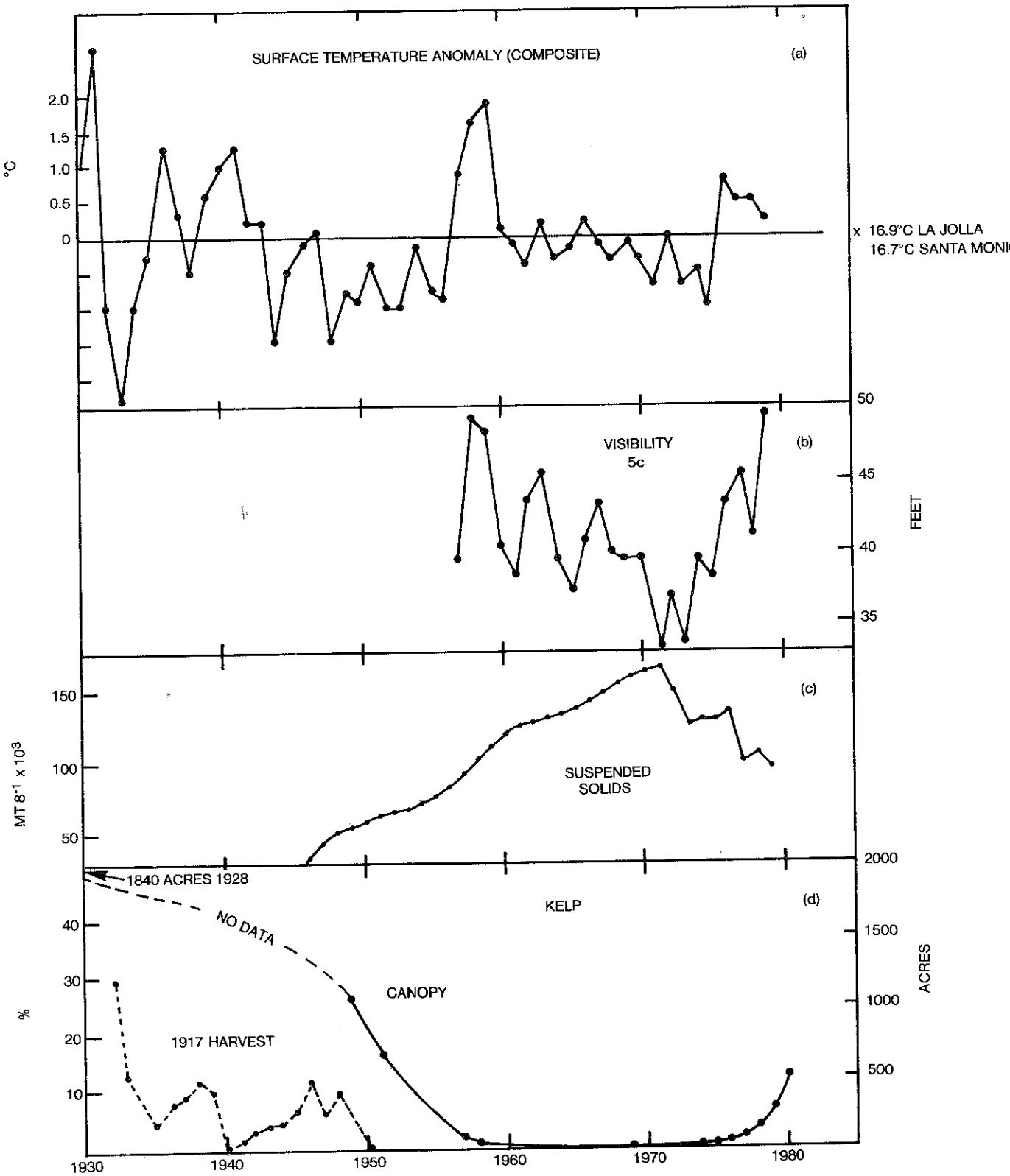

Figure 5. Long-term changes in ocean conditions, waste discharge emissions, and kelp canopy density at Palos Verdes, 1930-1980. Warm-water episodes (a) occurred in 1931, 1936-37, 1939-1941, 1957-59 and 1976-1979; Data from Radovich 1961 (for 1930-1956) and from Hyperion monitoring Station 5C in Santa Monica Bay (1957-1979). Changes in visibility (b) from Hyperion monitoring Station 5C in Santa Monica Bay (1957-1979). Suspended solids mass emission rates (c) from Dr. I. Haydock and Mr. R. Caballero, Los Angeles County Sanitation Districts. Kelp canopy size and harvesting data (d) from State Water Resources Control Board (1964) and California Department of Fish and Game.

Discharge of sewage effluent off White Point began in 1937-38, and emission of solids increased steadily through 1971, after which major reductions began to take place (Figure 5c). There is a strong possibility that the decrease in these solids since 1971 has been partly responsible for the improved transparency measured at Station 5C in southern Santa Monica Bay and for the recovery of kelp. Since both wastewater emissions and changes in oceanic conditions occurred in such a way as to lead to improved transparency, it is difficult to determine the absolute significance of each.

Other factors related to the recovery of kelp at certain sites off Palos Verdes may include recent harvesting of competitive seaweeds and of sea urchins. For example, commercial harvesting of agarweed, *Gelidium robustum*, occurred along the Santa Monica Bay side (western side) of the Palos Verdes Peninsula in the mid-1970's. This seaweed may have competed for substrate and light with *Macrocystis pyrifera*, and its removal may have encouraged giant kelp to settle and grow off Bluff Cove at a time when transparency was improving.

Commercial harvest of red sea urchins *Strongylocentrotus franciscanus*, contributed considerably to the reduction of urchin densities in several areas where kelp beds now exist along Palos Verdes Peninsula. Urchin fishing began in this area in about 1973 and reached a peak in the 1976 through 1978 seasons. An estimated 1,500,000 pounds of urchins were harvested from rocky habitat off Palos Verdes Peninsula in depths ranging from about 5 to 11 m from 1973 through 1978. The heaviest fishing effort occurred from Malaga Cove to Palos Verdes Point and from Point Fermin to Inspiration Point where some of the most extensive *Macrocystis pyrifera* beds now exist. Large-scale urchin fishing efforts preceded the wide spread rapid exapnsion of *M. pyrifera* beds into the aforementioned areas except where kelp restoration efforts had already succeeded in reducing urchin populations.

To summarize, we believe that a combination of changing factors has lead to the recovery of kelp beds off Palos Verdes during the 1970's. Kelp transplanting efforts from 1972 onward provided stock and reproductive products to "seed" new beds, even though none appeared until 1973-74; then in the mid-1970's, urchin control, commercial fishing of competitive seaweeds and sea urchins, and reductions in discharge of sewage solids combined to open up new substrate for *Macrocystis pyrifera* colonization. Improved transparency, due in part to changing ocean conditions and reductions in solids inputs and possibly to reductions in emissions of toxic chemicals such as DDT (Mearns 1977) aided rapid growth of those beds which became established.

Factors Limiting Future Growth of Kelp Beds

Historically, kelp forests rimmed nearly the entire Palos Verdes Peninsula growing to depths of at least 18 m. Today Palos Verdes kelp forests only grow to depths of 12 to 13 m around most of the Peninsula; this depth limitation is particularly evident along portions of the southern shoreline from Inspiration Point to Point Fermin, where kelp beds rarely occur in depths greater than 12 m even though substrate is available in most areas. In addition, several sections of coastline which formerly supported substantial kelp forests today do not. These include waters in the vicinity of Point Fermin and from Point Vicente to south Lunada Bay.

It is apparent from the dramatic regrowth of kelp forests along Palos Verdes Peninsula, which began in the mid-seventies, that environmental changes favoring the return of *Macrocystis pyrifera* must have occurred. However, the absence of kelp forests in some locations around Palos Verdes Peninsula and in depths greater than 12 to 13 m along the southern coastline of Palos Verdes Peninsula suggests that some negative environmental factors still occur.

Scientists at Los Angeles County Sanitation Districts believe siltation and increased light attenuation due to sewage solids emission still limit the expansion of Palos Verdes kelp beds into deeper waters; they forecast that further solids reduction could lead to additional expansion of the beds off White Point and adjacent areas. We concur with this conclusion.

We also believe sea urchins and other grazing animals will continue to limit expansion of kelp beds in some areas. For example, little urchin fishing has taken place from Point Vicente to Lunada Bay because urchins along most of this section of coast are too small and of low roe content (edible portion). The poor condition of sea urchins in this area is due to high population densities that preclude regrowth of algal cover necessary for urchin growth and high roe quality. Until these urchins are removed or otherwise brought under control, they will continue to preclude establishment of stable kelp beds on this part of the coast regardless of further improvements in water quality.

It is also possible that *Macrocystis pyrifera* beds are still precluded along portions of the Palos Verdes coastine from Point Fermin to Long Point because of competition from other perennial algae, particularly forms tolerant of low light such as *Cystoseira*, which became established when *M.pyrifera* declined. As indicated above, removal of one competitor (*Gelidium robustum*) may have contributed to the recovery of kelp on the northwestern coast of the Peninsula.

Failure of kelp forests to grow to depths of 18 m along several portions of Palos Verdes Peninsula may be due, in part, to burial of rocky substrate. Palos Verdes is a geologically active area. Land slippage occurs along several sections of the southern coastline particularly in east Abalone Cove and Portuguese Bend, near the eastern boundary of Rancho Palos Verdes, and in the vicinity of Point Fermin. Futhermore, steep cliffs composed of semiconsolidated, consolidated, and metamorphosed sedimentary rocks are deeply incised by gullies and gorges in several areas along Palos Verdes Peninsula. These geological features provide evidence of chronic erosion and are sources of heavy sediment loads in nearshore waters during periods of heavy rainfall runoff and wave activity. Diving reconnaisance surveys in Abalone Cove and Portuguese Bend revealed expanses of sand in depths greater than 12 m where large kelp beds were depicted in early kelp bed surveys (Figures 4a,b). Such evidence suggests that at least in some areas, rocky substrate formerly occupied by kelp forest may now be covered by sediments. This erosion sanding-in process may have been accelerated by coastal developments along the Peninsula.

Finally, return of sea otters to southern California could help stabilize the entire kelp bed ecosystem off Palos Verdes. Not many otters would be required. Because of thermoregulatory needs, sea otters maintain a high metabolic rate that requires food equal to 20 to 25 percent of their body mass each day. This is about 2.5 tons per animal each year. Sea urchins are among sea otters' most preferred food. As indicated above, the commercial sea urchin fishery has been responsible for the harvest of at least 1,500,000 pounds of urchins over the last 6 years. The roe content of these urchins is equivalent to the food requirements for 42 sea otters for 1 year. However, otters would also consume available abalone and lobsters, and such a management approach would be extremely unpopular with sport and commercial fishermen. Moreover, kelp forests would still exhibit fluctuations resulting from other biological influences such as competition for space and light, natural succession and maturation and grazing by herbivorous fishes, if present.

CONCLUSIONS

Giant kelp beds are now thriving and reproducing rapidly off Palos Veres. However, there are still some areas where kelp is absent, and the forests still do not extend to their former depth range. Considering all the available data, we think the future size of the forests will depend largely on

(1) adjustments of predator and prey densities resulting from restoration, new fisheries, and enforcement of new fishery regulations (2) the emissions of solids from outfalls, and (3) long-term patterns in ocean conditions. It seems obvious to us that all three factors have acted, and will continue to act, synergistically on kelp bed production and size at Palos Verdes.

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