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RELATIONSHIP BETWEEN KELP BEDS AND BEACH WIDTH IN SOUTHERN CALIFORNIA

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ABSTRACT: The relationship between the width of kelp beds and the width of the beaches inshore was examined in the San Diego region of Southern California. Two statistical approaches were used. The first simply determined the correlation between kelp-bed width and adjacent-beach width. A small (0.3), but statistically significant, positive correlation was found in the 20% of shoreline that had both a nonzero beach width and an offshore kelp bed; however, no correlation was found when the entire shoreline was considered. The second method examined differences in width between beaches inshore of the kelp beds and those immediately to the north and south. No statistically significant differences were found. The overall conclusion is that there is no clear correlation or consistent pattern indicating that offshore kelp beds have any direct influence on adjacent-beach width.

INTRODUCTION

The objective of the present paper is to examine the relationship between offshore kelp beds and the width of nearby beaches in the San Diego region of Southern California (Fig. 1). The study area is between Dana Point and Imperial Beach, which at present has 14 major kelp beds fronting about 35% of the shoreline (North and Jones 1991). Most of the remaining 65% of the shoreline has beaches but no kelp. The widest beach exists in Coronado where there is no kelp, and the largest kelp beds, nearly 200 m wide, exist off La Jolla and Point Loma, which have essentially no sand beaches. The area's beaches vary greatly in width, both in space and time, depending upon the wave climate, sand supply, and the presence of barriers (Flick 1993).

A public perception exists that kelp can somehow detrimentally or beneficially affect beach widths. Interest in this potential relationship has been renewed with concern that creating kelp beds may imply liability if any adjoining or down-drift beaches are adversely affected as part of environmental mitigation efforts. In addition, an unconventional effort at beach-erosion control in Long Beach, Calif. has used plastic fronds purported to act like natural "seaweed" and lead to beach accretion; however, laboratory and field tests suggest that this approach fails to halt the erosion of medium- and high-energy beaches such as those in Southern California (Jenkins and Skelly 1987; Rogers 1987).

It is reasonable to assume that a kelp bed must alter the incoming waves to have any effect on adjacent beaches, since waves are the principal cause of coastal sand transport in Southern California. Elwany et al. (1994) indicated that kelp beds of moderate size (700 m long, 350 m wide) and average density (>10 plants per 100 m^2) have no measurable effect on surface gravity waves. However, beach dynamics are so complex that it is worthwhile to determine directly if a statistically significant relationship exists between kelp-bed width and beach width.

KELP BEDS IN SOUTHERN CALIFORNIA

There are about 10 kelp species in Southern California, the most abundant being *Macrocystis pyrifera* or giant kelp. *Macrocystis* kelp is commonly found along the Southern California coastline where bottom substrate and other conditions are suitable. Mature giant kelp plants are typically several years old, may have 100 or more fronds, and attain lengths of 15 to 50 m while attached to the seafloor by holdfasts.

Kelp plants grow together, forming an underwater kelp-bed forest. The average density of typical kelp beds in this area varies from 6 to 12 plants per 100 m^2. Physical factors that affect kelp growth and recruitment include water temperature, underwater light, nutrient levels, and the concen-

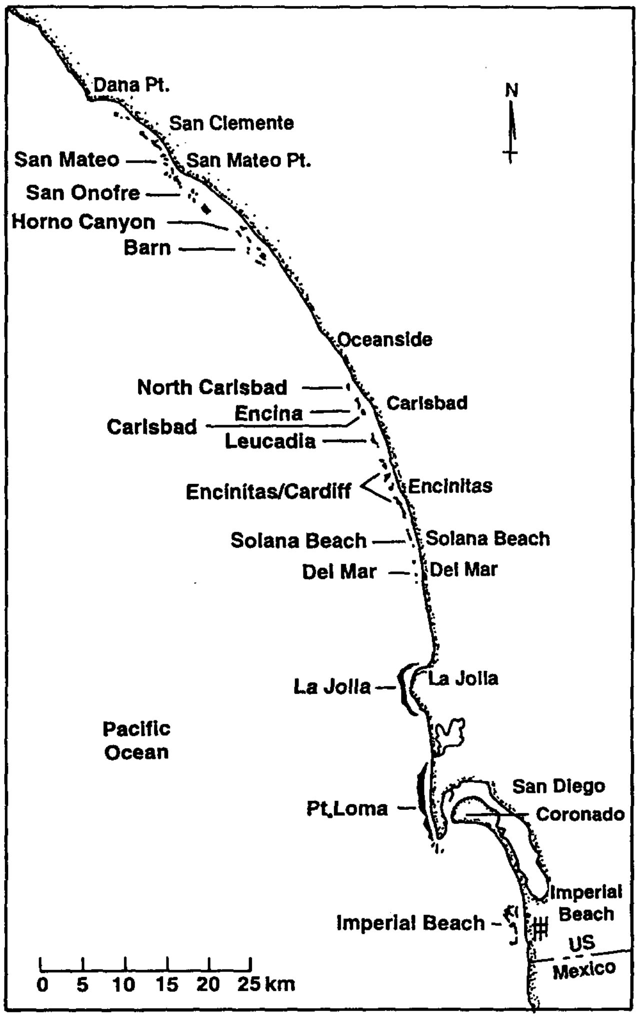

FIG. 1. Major Kelp Beds in San Diego Region

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tration of suspended particles near the bottom (Deysher and Dean 1986; Jackson and Winant 1983; North and Jones 1991).

The deep-water limit of kelp growth, approximately 20 m or less, is generally determined by the level of available light. The inshore limit is believed to be determined by the physical stresses imposed by the largest breaking waves. Storm waves, which cause the holdfasts of giant kelp to break loose from the bottom, are probably the most important source of mortality among adult *Macrocystis* (Dayton et al. 1984; Seymour et al. 1989).

The rocky, moderate relief bottom substrate required for anchoring holdfasts is fairly common along the Southern California coast, and kelp beds are widespread. However, some areas seem particularly favorable to kelp growth and have sustained large beds for long periods of time. The 1,000-acre Point Loma kelp bed is the largest in the region, followed in acreage by the La Jolla kelp bed (Fig. 1).

It may be significant that La Jolla and Point Loma are both areas of uplift. Compared with adjacent coastline, relatively old rocks are exposed at sea level [Greene and Kennedy (1978)]. Other persistent but smaller beds occur off north San Diego County. These areas have very different beach configurations, ranging from essentially no beaches at La Jolla and Point Loma, to relatively wide sand beaches at San Mateo Point.

North and Jones (1991) describe 16 major kelp beds in San Diego and Orange Counties, including those at San Clemente and north of Dana Point. The San Clemente kelp bed disappeared in 1959 and there is no beach-width data available north of Dana Point, so these areas are not considered in the present study.

BEACHES IN SOUTHERN CALIFORNIA

Most Southern California beaches consist of a sand veneer covering a wave-cut bedrock terrace [U.S. Army Corps of Engineers (USACE) 1991] backed by a sea cliff. Normal wave action pushes the sand landward over the terrace and piles it up in a berm against the base of the cliff. The sand layer thickness varies from zero to several meters. Thicker beaches form on the barrier spit fronting San Diego Bay, and across river and lagoon mouths in numerous other locations.

Southern California beaches fluctuate in width primarily in response to changes in wave amplitude and direction and the rate of sand supply. While individual storm events can cause beaches to retreat in a matter of hours or days, the largest changes occur on seasonal and longer time scales. Seasonal beach-width changes on this stretch of coast range from 10 to 50 m. Seasonal fluctuations or long-term erosion cannot exceed the original natural beach width and are therefore limited to less than 100 m in most parts of San Diego. On the other hand, beach width increases are potentially unlimited, and have reached several hundred meters in Coronado and Mission Beach as a result of nourishment and structural stabilization.

Most beaches widen during summer and autumn as mildly sloping waves transport sand inshore, and narrow in winter and spring as seasonally higher and steeper storm waves move sand offshore (Inman et al. 1993). Also, waves breaking at an angle to the beach generate longshore currents that transport sand along the shore. Natural barriers or human-made structures impede this transport and can cause accumulations of sand. If kelp beds reduce the energy of waves, however slightly, or if they alter the speed of coastal currents, then sedimentation rates on nearby beaches could be changed, resulting in erosion or accretion.

Qualitatively, the factors that cause beach-width changes are well known. However, even if all the physical variables on a particular beach were perfectly specified, the detailed evolution of the beach still could not be accurately quantified. This is because the dynamics of the fluid-sediment interactions are too complicated to solve in detail yet. Furthermore, the amount of sand reaching the coast from rivers, cliffs, and other sources can never be quantified or forecast accurately enough to be useful for detailed predictions of beach configuration over time.

These constraints imply that any effects of an offshore kelp bed on local beach width cannot be successfully modeled. Kelp-bed effects on waves have long been postulated and quantitative models have been developed (Dalrymple et al. 1984; Kobayashi et al. 1993), although the effects seem negligible for typical Southern California conditions (Elwany et al. 1994). However, in view of the inability to model kelp effects on beaches, it seems of interest to determine directly if any statistically significiant relationship exists.

CORRELATION BETWEEN KELP-BED WIDTH AND ADJACENT-BEACH WIDTH

Kelp-bed and beach widths from Dana Point in Orange County to the Mexican border for 1983–88 were respectively estimated using data from North and Jones (1991) and the U.S. Army Corps of Engineers (1991). North and Jones used aerial photographs to derive the dimensions and percentage of coverage of kelp-bed canopies, with errors ±20%. The average beach-width data presented by USACE is based on repeated beach-profile surveys and aerial photographs over the period 1983–88. The average cross-shore kelp-bed width was used to characterize the potential for kelp beds to influence beaches because the dampening of waves approaching a beach depends primarily on the cross-shore extent of the kelp bed (Dalrymple et al. 1984). For each of the 14 presently existing kelp beds in the study area tabulated by North and Jones (1991), a mean cross-shore bed width was estimated as the ratio of the mean canopy area to the mean longshore bed length over the study period.

The areas used in this calculation are those actually covered by canopy in the photographs, so the calculated width is an "effective width" equal to the width of the bed if the sea surface were completely covered by kelp. Because the kelp canopy coverage is usually incomplete within the kelp bed, the effective width is generally narrower than the actual cross-shore extent of the kelp bed. Using the effective width approximately accounts for variations in kelp plant density between beds.

USACE (1991) defined beach widths as the distance from

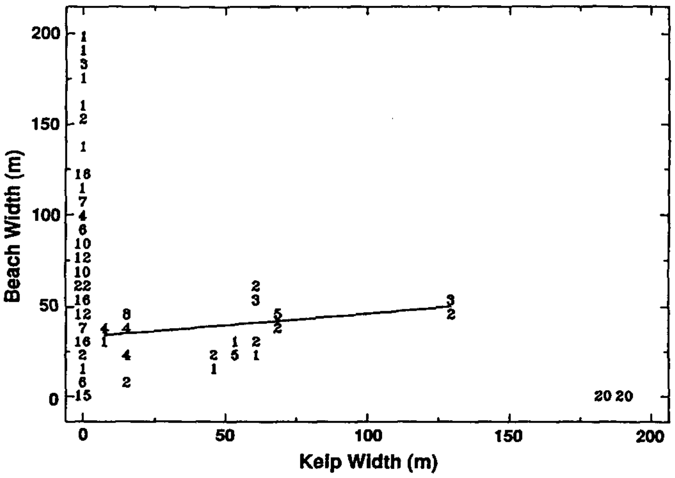

FIG. 2. Beach Width as Function of Kelp-Bed Width for Each 500-m-Long Coastal Segment (Numbers Indicate How Many Coastal Segments Fall within Each Beach-Kelp Bed Width Combination)

the intersection of the beach face with the elevation of mean sea level, to the most appropriate of three points: the toe of the sea cliff, the vegetation line, or the development line. An average beach width was estimated for each 500-m segment throughout the 132.5-km-long study area, yielding beach widths for 265 segments. The number of 500-m-long segments of coastline occurring for a particular combination of beach and kelp-bed widths are indicated in Fig. 2 (blank spaces indicating no occurrences).

The largest class consists of 173 segments, 65% of the total, that have no kelp but cover the entire range of beach widths. The primary reason for the absence of kelp in these many segments may be the lack of a hard substrate necessary to anchor adult kelp plants. In some locations, the lack of a hard substrate may be a corollary to a plentiful sand supply, which also favors wide beaches. The large range of width in beaches without an offshore kelp bed illustrates that other factors dominantly determine local beach width. A second class of 40 segments (15%) represents La Jolla and Point Loma. These contain San Diego's widest kelp beds, with average widths of nearly 200 m, but have effectively no beach. These sites are sand-starved, being geographically isolated (Fig. 1), or located down coast from sand sinks. Lack of sand produces narrow or absent beaches, and probably favors kelp, together with the local bedrock configuration. If this is the case, increased sand supply would have negative effects on kelp-bed width, without involving any causal relation between kelp-bed width and beach width. The third class, of 52 segments (20%), has both kelp beds and beaches. Given the proper balance between a hard substrate and the sand supply to support both a kelp bed and a beach, the local wave climate is probably the most important factor regulating the width of both.

Medium-sized waves are energetic enough to keep the substrate clear of fine sediment without physically damaging the plants. However, highly energetic waves dislodge holdfasts and tear and tangle adult plants (Seymour et al. 1989). Storm conditions also stir the substrate, increasing turbidity and reducing near-bottom illumination and kelp recruitment. Because external factors such as sand supply and wave energy affect the widths of both kelp beds and beaches, a correlation between these widths must be cautiously interpreted. A correlation analysis was nevertheless performed between the beach width and kelp width data. When all the data points (all three classes) shown in Fig. 2 are included, there is no statistically significant correlation. Plausible arguments can be made to exclude the first two classes of data from the correlation analysis, since there is clear evidence that the lack of beaches or the lack of kelp can be assigned respectively to other causes. As noted, the absence of beaches inshore of the wide La Jolla and Point Loma kelp beds is certainly related to their isolation from sources of sand. Similarly, the widest beaches in Coronado have no exposed hard substrate, and therefore have no kelp.

Regression analysis of sites with nonzero kelp-bed and beach width (the third class), shows a weak but statistically significant (95% confidence level) positive correlation of 0.3 between them. The solid line in Fig. 2 is the best-fit linear regression for this case. This suggests that beach width is weakly associated with offshore kelp-bed width. The result, however, is ambiguous, given that it depends on neglecting 80% of the shoreline segments comprising the first and second classes mentioned previously. Furthermore, the mean width of all beaches without offshore kelp beds (the first class) is 72 m, which is much wider than the 24 m mean width of all beaches with offshore kelp beds (classes 2 and 3), and considerably wider than the 40 m mean width of the class 3 beaches alone (neglecting La Jolla and Point Loma). All of this is consistent with a negative correlation between beach width and kelp-bed width.

As a second approach to the problem, the differences in width were examined between the beaches inshore of each kelp bed and "control" beaches with no kelp immediately to the north or south. Eleven sites between Dana Point and Imperial Beach were suitable for analysis. The differences between the width of each subject beach inshore of its respective kelp bed and the beach width at some variable distance (equal to the length of the kelp bed) to the north and south was calculated. Table 1 lists the beach widths to the north, directly inshore, and to the south of each named kelp bed. A missing value (represented by a dash) for the north or south beach indicates that it had an offshore kelp bed also, and therefore was not useful as a control.

We have computed differences by subtracting the width of each subject beach from the widths of its control beaches in four different ways: 1) Subject minus northern control; 2) subject minus southern control; 3) subject minus average of north and south controls; and 4) use of north and south control beaches as replicates, where the set of width differences consists of both cases 1 and 2. A one-sample *t*-test was used to test the null hypothesis that the width differences are equal to zero. The resulting *p*-value represents the probability of rejecting the null hypothesis when it is true. The results of the statistical tests are presented in Table 2, which lists the mean and the standard deviation of the beach-width differences and the *p*-values of each of the four tests. All reported *p*-values are greater than 0.05, which means that we cannot reject the null hypothesis. That is, the respective differences between the width of beaches with kelp and the adjacent control beaches without kelp are statistically insignificant.

TABLE 1. Beach Widths North, Inshore, and South of Named Kelp Beds

	Beach Width (m)		
Kelp bed location (1)	North (2)	Inshore (3)	South (4)
San Mateo	60	53	—
San Onofre	67	66	60
Barn	58	59	67
North Carlsbad	12	10	17
Encina	32	24	—
Carlsbad	—	39	35
Leucadia	50	49	—
Encinitas/Cardiff	35	46	50
Solana Beach	28	26	35
Del Mar	31	29	28
Imperial Beach	45	48	65

TABLE 2. Results of *t*-Test on Beach-Width Differences between Beaches with Offshore Kelp Beds and Adjacent Control Beaches with No Kelp

	Beach Width Difference		
Test case (1)	Mean (m) (2)	Standard deviation (m) (3)	*p*-value (4)
North − inshore	0.85	5.30	0.62
South − inshore	4.26	7.60	0.16
Average north and south − inshore	2.49	4.35	0.08
North and south as replicates − inshore	2.34	6.45	0.14

SUMMARY AND CONCLUSIONS

Correlations between the widths of existing natural kelp beds and the widths of the beaches immediately inshore of these beds were examined. Differences in width between beaches with kelp beds and adjacent beaches without kelp were also studied.

The widths of beaches, with and without offshore kelp beds, span a wide range owing to variations in wave conditions and sand supply, as well as other factors. Most of the shoreline (65%) has no kelp beds, but does have beaches with the full range of observed widths. The widest kelp beds in the region cover 15% of the shoreline, and these have essentially no sand beaches. Only 20% of the shoreline has both kelp beds and beaches.

No statistically significant correlation exists between beach width and kelp-bed width when all coastal segments are used in the calculation. In the class of segments that have both kelp beds and beaches, a small positive correlation exists between kelp-bed width and beach width. However, the mean width of all beaches without kelp beds is much wider than the mean width of all beaches with kelp beds, consistent with a negative correlation. Also, there is no statistically significant difference between the width of beaches with offshore kelp beds and adjacent beaches with no kelp.

The overall conclusion is that in Southern California, there is no strong correlation or consistent pattern indicating that beaches directly inshore of kelp beds are either wider or narrower than beaches not fronted by kelp beds because of any influence of the kelp.

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