Effects of El Niño events on natural kelp beds and artificial reefs in southern California

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Since 1978, bottom characteristics and giant kelp (Macrocystis pyrifera) population dynamics of three historically productive natural kelp beds located south of San Clemente, California, have been monitored on a semi-annual basis using diver observations, sidescan sonar, and downlooking sonar. Aerial photographs of the kelp-bed surface canopies have been recorded annually since 1968. Since 1981, studies have been intermittently performed on the Pendleton Artificial Reef. Ecological studies were also conducted pre- and post-1997–1998 El Niño and qualitatively from 1994 to 1999 at the Mission Beach Artificial Reef. El Niño events have been associated with catastrophic ecological conditions in the southern California nearshore zone that may have significant influence on both reef structure and reef community. The variation of kelp populations in the three natural kelp beds is reviewed relative to recent El Niño events, local wave climate, local sea surface temperatures, and regional precipitation. The local temperature and precipitation data show that El Niño periods have had varying and non-consistent effects with respect to kelp growth. Yet, periods of low kelp density appear to be related to extended periods of above normal sea surface temperatures and increased precipitation generally associated with El Niño events. Examination of artificial reef data from the standpoint of substrate and kelp persistence through the latest 1997–1998 El Niño event revealed effects that are consistent with natural kelp bed information. The population dynamics of natural kelp beds through various El Niño periods indicate that the range of kelp density fluctuations over time on an artificial reef designed for kelp can be expected to be quite high.

Introduction

Kelp forests are an important ecological feature along the southern California coast. These nearshore habitats are dominated by the giant kelp (Macrocystis pyrifera), a brown alga forming structurally complex, species-rich, and highly productive habitat (North, 1971; Mann, 1973; Gerard, 1976; Carter et al., 1985; Dayton, 1985). Fish and invertebrates have substantially higher standing stocks in kelp forests compared with the flat sandy bottom common to the nearshore zone (Foster and Schiel, 1985; DeMartini and Roberts, 1990). Viable kelp beds of Macrocystis form surface canopies that range in areal extent from 0.1 ha, as seen in small north San Diego County beds, to 600 ha in the largest bed at Point Loma, City of San Diego (North and Curtis, 1998). The 24 kelp beds of San Diego and Orange Counties in southern California have been monitored since the 1960s (North, 1971; North et al., 1993; North and Curtis, 1998). Most of these beds are
located on low-relief hard bottom substrate consisting of either cobble and boulder fields, outcappings of bed rock, or on smaller cobble and silt-stone substrate areas on the sandy bottom.

The construction of artificial reefs that target the enhancement of kelp communities has been suggested as a means of mitigating human-induced impacts to natural kelp forests in southern California. The first experimental reef designed to test the efficacy of improving kelp habitat and constructed in 1980 was the high-relief (3–5 m off bottom) Pendleton Artificial Reef (Grove, 1982; Grant et al., 1982). Kelp has not flourished or persisted on this reef (Carter et al., 1985). The creation of new kelp forests using low-relief (0.5–1.5 m off bottom) artificial reefs is now being tested (Deysher et al., 1998) by scattering hard substrata (a single layer of quarry rocks and/or broken concrete) in sandy bottom areas in the appropriate depth zone (10–18 m).

A complicating and possibly dominant factor in assessing the performance of artificial kelp reefs is the influence of large-scale weather patterns that are influenced strongly by El Niño/La Niña cycles. El Niño events have been identified as influencing catastrophic conditions in the southern California nearshore zone that can have significant influence on both the structure and community of reefs (Dayton and Tegner, 1984; Dean and Jacobsen, 1986; Tegner and Dayton, 1987). La Niña events result in cooler and calmer conditions that may be more favourable for kelp. Since 1978, bottom characteristics and Macrocystis population dynamics of three historically productive natural kelp beds located south of San Clemente (Figure 1) have been monitored on a semi-annual basis using diver observations, aerial photography, sidescan sonar, and down-looking sonar techniques. In addition, studies have been performed on the nearby high-relief Pendleton Artificial Reef. Additional qualitative studies were conducted from 1994 to 1999 at the Mission Beach Artificial Reef, which was built off San Diego in 1991. Ecological studies focused specifically on the influence of the 1997–1998 El Niño. The Mission Beach reef is the only artificial reef that has developed a long-term kelp population. We present data from these studies on the effects of El Niño/La Niña cycles on kelp distribution on natural reefs and on artificial reefs.

Study sites

The three natural reefs persistently supporting kelp in the San Clemente study area are the San Mateo, San Onofre, and Barn kelp beds (Figure 1). These kelp beds are located in water depths of 10–18 m and have ranged in size from 0 to 100 ha each since 1980 (North et al., 1993; North and Curtis, 1998).

Figure 1. Setting of the San Onofre Area Kelp Beds, Pendleton Artificial Reef, the San Onofre Nuclear Generating Station (SONGS) Diffuser Cooling System near the City of San Clemente, and the Mission Beach Artificial Reef adjacent to the City of San Diego, California, USA.

The Pendleton Artificial Reef was built in August–September 1980 using 9100 t of quarry rock (Grant et al., 1982). The rock averaged 0.3–1.2 m in size, typical of material used to construct breakwaters. The reef consists of 8 modules situated on a featureless sand bottom at 14 m depth (MLLW). The reef (approximately 1 ha) is located south of San Clemente (Figure 1) at 33°20’N 117°31’W. The modules are approximately 30 × 13 m with heights between 3 and 5 m. The 8 modules are spaced approximately 20 m apart.

The Mission Beach Kelp Artificial Reef, constructed in October 1991, consists of a low profile (0.3–1.5 m off bottom) field of broken concrete obtained from local demolition projects. The material is said to consist of slabs 15–21 cm thick, 1.2–1.8 m wide, and 0.6–1.9 m long. The amount of concrete is estimated to be at least 1800 t, and possibly more. The material was barged offshore and dumped on a gently sloping sand bottom in 15–18 m depth (Figure 1). The reef (about 1.7 ha) lies about midway between the Point Loma and La Jolla kelp forests, and the nearest natural hard substrate (and kelp population) is approximately 3 km to the south at Point Loma.
Methods

The three natural reefs have been routinely surveyed for kelp abundance since 1968 using an aerial photography method to document surface canopy area (North et al., 1993), and by sonar between 1978 and 1998. The sonar method consisted of two different systems: sidescan and downlooking sonar (Zabloudil et al., 1991). Seafloor substrate boundaries and relative kelp densities are defined with the sidescan sonar data. The downlooking sonar serves to collect bottom contour changes and kelp frond and plant density information. Diver surveys were used to ground-truth and calibrate the sonar records.

The Pendleton Artificial Reef was surveyed for kelp using diver transects from 1981 through 1986 (Wilson and Lewis, 1991). These surveys resulted in a quantitative description of kelp coverage on a per square metre basis. The reef has been periodically monitored by the California Department of Fish and Game Artificial Reef Program dive team between 1989 and 1998. A sonar survey was performed in 1999 using the sonar methods described above.

Sidescan sonar surveys of the Mission Beach Artificial Reef were performed in 1995, and 1997 and 1998, before and after the latest El Niño event. These surveys were used to compare the coverage of reef substrate. Diver surveys have also been conducted on this reef. Qualitative observations were performed from 1994 through 1996 by the California Department of Fish and Game. In 1997 and 1998, diver surveys were performed along a series of 30-m-long transects at a random selection of sites within the reef and provided quantitative data on substrate, kelp, and invertebrate distributions within the reef. A total of 12 transects were compared over time for coverage of concrete and densities of plants and invertebrates.

Oceanographic data were obtained from the NOAA Coastal Ocean Program. NOAA’s Climate Diagnostics Center routinely follows El Niño phenomena as they periodically develop in the eastern half of the equatorial Pacific. La Niña events, abnormally cold sea surface temperatures in the eastern half of the equatorial Pacific, are the opposite of El Niño events, and consist of an east–west tracked. This periodic series of events is termed the Southern Oscillation phenomenon (ENSO) by estimating an ENSO index based on the main six observed variables over the tropical Pacific: sea-level pressure, the east–west and north–south components of the surface wind, sea surface temperatures, and total amount of cloudiness. Positive index values represent warm El Niño phases and negative values represent cold La Niña phases. The ENSO index depictions of tropical oceanographic events are compared to local southern California oceanographic and meteorological conditions that are recorded routinely at the Scripps Institution of Oceanography, as well as at the San Clemente pier, and in San Diego (precipitation).

Results

El Niño events

Based on the multivariate ENSO index, there have been four significant El Niño events since 1980: 1982–1983, 1986–1987, 1991–1992, and 1997–1998. A time-line of temperature data (Figure 2) shows the El Niño periods as positive temperature anomalies, and the lingering thermal effects after the events have dissipated in the equatorial Eastern Pacific. Figure 2 also shows the ENSO index for the seven historic El Niño events since 1950, the 1982–1983 event being the largest one, followed by the 1997–1998 event that had two peaks just below the 1982–1983 peak. The other two El Niños since the kelp studies were initiated were smaller (1991–1992 and 1986–1987). Figure 2 also shows the ENSO index for the seven strongest La Niña events since 1949. The 1998+ event has been one of the strongest, followed by events in 1988–1989, 1975–1976, 1972–1973, and 1970–1971. Southern California oceanographic data demonstrate that the El Niño/La Niña cycles appear to have a direct influence on the regional oceanographic and climatological picture (Figure 3). Positive temperature anomalies in the San Clemente pier temperature records correspond directly to the 1997–1998 and the early 1990s El Niño periods, with some local-effect delay to the large 1982–1983 event. However, there is no relationship at all to the 1987–1988 El Niño.

Natural kelp beds

The fluctuation of kelp coverage in the three natural reefs was determined from sonar records and plotted as total number of plants in each bed (Figure 3). In comparing these with seasonal precipitation data and local sea surface temperature anomalies, the five wettest seasons during the period 1980–1998 (1983, 1991, 1993, 1995, and 1998) were associated with sharp declines in all three kelp beds. Positive temperature anomalies correlate less with declining kelp growth, except for the large El Niño effects of 1997–1998.

These beds were further assessed using surface canopy area as calculated from aerial photographs (Figure 4). These results show that the area of the canopy was reduced dramatically by the 1997–1998 El Niño, somewhat reduced by the early 1990s and 1982–1983 El Niño, and dramatically increased in the 1989 La Niña. The
Figure 2. Temperature anomalies in °C according to the ENSO index, 1950–1998, and El Niño and La Niña Events, 1949–1998 (from NOAA-CIRES Climate Diagnostics Center).
1989 increase appears to be a function of an unprecedented series of natural events: an unusually severe storm on 18 January 1988 dislodged most of the adult kelp plants along the coast that were just recovering from the 1986–1987 El Niño and also created an abundance of bare substrate within the nearshore zone by moving large amounts of sand (North and Curtis, 1998). The availability of bare substrate allowed high recruitment of kelp plants and the La Niña conditions in 1989 stimulated the growth and survival of these new recruits and resulted in the largest kelp bed sizes observed in historical records (North et al., 1993; North and Curtis, 1998).

In a statistical analysis of the El Niño effect on kelp populations, both number of kelp plants and percent change in these numbers were correlated with sea surface temperature (SST) and SST anomalies. The SST values were computed by taking the average of the values 9 and 12 months earlier. The reasoning was that the effects of temperature are probably integrated by the plant and should emerge as a perturbation in the population only after a certain lag period. The resulting trend of decreasing kelp plants with increasing temperature anomalies was not significant and is therefore not shown. However, the general picture emerging from the assessment of kelp plant plots is a predominant influence of episodic recruitment events during short periods of favourable conditions. Recruitment events may occur during El Niño periods but usually they do not. Still, during the major El Niño periods from 1980 to the present, kelp populations in the three natural beds surveyed were substantially reduced.

Pendleton Artificial Reef
Periodic transect surveys on the Pendleton Artificial Reef from 1982 to 1984 to assess the status of transplanted kelp and to monitor natural recruitment revealed only intermittent kelp at very low densities (0.005 plants m$^{-2}$; Wilson et al., 1991). The qualitative surveys in the 1990s showed some limited kelp around
the edges and on the reef modules, but no persistent kelp populations.

Mission Beach Kelp Artificial Reef

The Mission Beach Kelp Artificial Reef was first surveyed in November 1994, three years after its construction. This initial qualitative survey showed that a dense population of *Macrocystis pyrifera* had developed with fronds reaching the surface. During the first quantitative survey in 1995, a diverse and abundant algal population was observed with adult *Macrocystis* densities similar to those observed in natural kelp beds. Populations of the kelps *Laminaria farlowii* and *Pelagophycus porra* were also found. The *Pelagophycus* populations were unusual in that they usually only occur in deeper (25 m) water at the outer edges of the Point Loma and La Jolla kelp beds. Subsequent surveys in June and December 1996 showed that the *Macrocystis* populations were still persisting at relatively high densities.

Between 25 August and 2 October 1997 (pre-El Niño), a total of 32 transects were surveyed by divers. A subset of 12 transects, representing those with the highest percentage cover of concrete, was chosen from the initial set for re-survey during the spring of 1998 (post-El Niño) and the data for this sub-set are compared in Table 1. The largest single decline in substrate cover was a 20% drop along one particular transect from 37% to 17%. The average for all transects, however, showed basically no change. The estimates of concrete cover made by the diver survey and those from sidescan sonar surveys showed good agreement. For example, five diver transects in areas where sidescan sonar indicated 50% to 80% cover had a mean coverage of 69%. The one diver transect in the sonar’s 30% to 50% class had a coverage of 40%.

In contrast to the substrate surveys, the pre- and post-El Niño surveys showed that *Macrocystis* densities were reduced severely (Table 1). Continuing qualitative diver surveys indicate that individual healthy kelp plants are persistently present.

**Table 1.** Summary of mean bottom cover (%) of exposed concrete and plant densities (N 10^{-2} m^{-2}) of *Macrocystis pyrifera* along twelve 30-m transects on the Mission Beach Artificial Reef during pre- and post-1997–1998 El Niño Surveys.

<table>
<thead>
<tr>
<th></th>
<th>Pre-</th>
<th>Post-</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean bottom cover</td>
<td>46.2%</td>
<td>46.9%</td>
<td>+0.7%</td>
</tr>
<tr>
<td>Adult (&gt;8 fronds)</td>
<td>6.0</td>
<td>0.6</td>
<td>−5.4</td>
</tr>
<tr>
<td>Sub-adult (&lt;8 fronds, &gt;1-m long)</td>
<td>29.6</td>
<td>1.5</td>
<td>−28.1</td>
</tr>
<tr>
<td>Juvenile (&lt;1-m long)</td>
<td>7.2</td>
<td>0.0</td>
<td>−7.2</td>
</tr>
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**Discussion**

Kelp population dynamics exhibit complex relationships among many factors, including light levels, temperature, nutrients, and wave energy. El Niño events generally affect these factors in ways that decrease kelp recruitment and increase mortality. For example, higher than normal water temperatures are associated with low nutrient conditions (Zimmerman and Kremer, 1984) that adversely affect adult growth and cause higher than normal adult mortality (North et al., 1982) and decrease the likelihood of recruitment of sporophytes (Deysher and Dean, 1986).

Kelp density estimates and surface canopy area data point to a relationship between major El Niño/La Niña cycles and changes in kelp on natural and artificial reefs in southern California. Specifically, major El Niño events appear to be associated with decreases in kelp populations. However, there may be a threshold level because little effect is observed for the minor El Niño events.

El Niño events can manifest in ways other than elevated temperature and reduced nutrients. Kelp beds appear to have reduced recruitment and reduced kelp growth in years with excessive precipitation. This might be caused by greater turbidity in nearshore waters owing to increased run-off, and leading to reduced light levels or increased sediment loading.

The kelp records also provide evidence that La Niña events, such as seen in 1989, may have positive effects on kelp growth, especially when preceded by a severe storm event ripping out much of the competing marine growth and clearing the way for a favourable recruitment episode. The cooler and more nutrient-rich water usually associated with the La Niña periods provides a good environment for the growth and survival of both juvenile and adult plants.
The high-relief Pendleton Artificial Reef has not persistently supported kelp and has not been favourably affected by either the 1989 or 1999 La Niña events. In contrast, the low-relief Mission Beach Artificial Reef, the only artificial reef persistently to support giant kelp, appears to respond to the El Niño/La Niña events similarly to natural kelp beds. Prior to 1997, there had been speculation that a major El Niño event would eliminate kelp from this reef and that the concrete substrate might become buried in the sand bottom. Although the reef lost most of its kelp during the winter storms of the 1997–1998 El Niño event, kelp seems to be recovering as the 1998–1999 La Niña progresses and the hard substrate of the reef has shown little change.

There appear to be a number of reasons why there was no strong correlation between the ENSO index and kelp abundance: (1) El Niños vary in both duration and amplitude; (2) El Niños are only one factor of many that affect kelp populations; (3) time-lags between an El Niño and the manifestation of its effects may vary as a function of its duration and amplitude; and (4) conditions immediately preceding and following each El Niño episode, i.e., the sequencing of La Niña–El Niño–La Nada (=normal) conditions, critically affects overall kelp response.

The effect of event timing is well illustrated by the different responses of kelp populations in the San Diego and Santa Barbara regions to the 1982 El Niño storms. These storms caused large declines in Macrocystis populations in the Pt. Loma kelp bed (Dayton and Tegner, 1984), but the same storms had apparent beneficial effects for Macrocystis on Naples reef in the Santa Barbara area (Ebling et al., 1985). Bottom surge generated by the storms cleared urchin populations from Naples reef that had previously removed most of the kelp. The loss of urchins allowed recruitment of a new kelp population on the reef.

The effects of island shadowing on the intensity of El Niño storm wave intensities (Pawka et al., 1984) also has the potential to create localized differences in storm effects on kelp populations.

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References


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