(Fig. 6), would provide valuable and timely information for a multi-agency oil-spill response effort until the NOAA HAZMET team could respond effectively.

When faced with an actual oil spill, or oil spill alert, the trained oceanographic forecaster will then use (1) the basic knowledge learned from the Santa Barbara Channel-Santa Maria Basin Circulation Study, (2) the latest satellite imagery of the area, (3) real-time oceanographic and meteorological data obtained from monitoring stations, (4) statistical models of Lagrangian trajectories (statistics from drifter trajectories), (5) results from the latest numerical circulation and oil-spill trajectory model runs, and (6) personal ability to synthesize the results into accurate estimates of surface trajectories of water/pollutant particles.

The oceanographic forecaster will then alert authorized field crews and appropriate government agencies to the land areas most vulnerable to oil contact within 3 hr of notification of the spill, and then will supply prediction updates to field crews and agencies as the climate changes.

When writing an environmental impact statement, real-time data would not be required to make a good statistical estimate for any particular shoreline to experience oil contact.

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Catalina Island Kelp Forests: 1992–1993

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Abstract. A monitoring project initiated in the spring of 1992 at the Catalina Marine Life Refuge focused on giant kelp (*Macrocystis pyrifera*), sea urchins (*Strongylocentrotus* and *Centrostephanus*), and water temperatures along 60-m longshore transects at depths of 4, 10, and 20 m. Quarterly assessment of plant size and density tracked a continuing decline in kelp abundance at the site coincident with elevated sea temperatures. Frond elongation fell precipitously through the summer of 1992 and reached a low in the winter of 1993. Growth remained depressed through the spring and summer of 1993. This contrasts with previously measured temporal patterns of growth at this site when rates were highest in winter and spring. Population densities of sea urchins were relatively constant. Diminishment of the kelp forest together with the appearance of pelagic red crabs, a juvenile green turtle, and several species of tropical fish at Catalina portrays effects of lingering worldwide "El Niño" conditions.

Keywords: Kelp forest; *Macrocystis pyrifera;* monitoring; temperature; sea urchin; El Niño; Catalina Island; nitrate.

Introduction

Forests of giant kelp (*Macrocystis pyrifera*) in southern California exhibit localized, often dramatic density changes. While many factors influencing the population biology of *Macrocystis* are known, information is lacking to explain their integrated effects over broad ranges of spatial and temporal variability. (For review see North 1971, 1994; Foster and Schiel 1985; and recent studies: Tegner and Dayton 1991; Dayton et al. 1992.) In southern California, the location of the Channel Islands-between northern cold-temperate and southern warm-temperate biogeographic provinces-provides a natural laboratory for kelp forest investigations. Monitoring projects, underway since the early 1980s, document kelp forest dynamics at specific locations around the northern (cold) and central (thermally intermediate) Channel Islands (Harold and Reed 1985; Davis 1989; Richards et al. 1993a, 1993b). A comparable database describing the typically warmer southern islands of San Clemente and Santa Catalina, which have higher percentages of species with tropical affinities (Murray et al. 1980; Seapy and Littler 1980; Engle 1994), is lacking.

The recurrence of anomalous hydrographic conditions over the past 10–15 yr and the possibility of long-term central pacific warming emphasize the importance of expanding databases to include a broad range of climates and species assemblages. Our objective was to initiate a database for kelp forest dynamics in the southern islands.

Methods and Materials

Study sites

To monitor populations of *Macrocystis* and urchins, 3 60-m permanent longshore transects were established at depths of 4, 10, and 20 m in the Catalina Marine Life Refuge in the winter of 1991–1992 (Fig. 1). In August 1993, a second study site was selected on the windward side of the island just west of Little Harbor (Fig. 1).

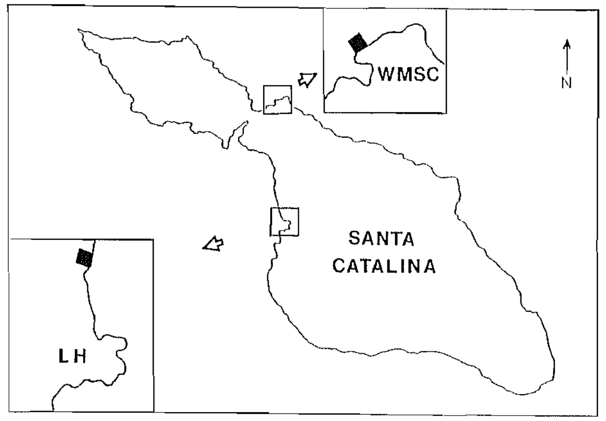


Figure 1. The Marine Life Refuge and Little Harbor study sites at Catalina Island. Black rectangles indicate transect locations. The refuge, including Big Fisherman Cove, is located adjacent to the Wrigley Marine Science Center (WMSC). Upper inset: Marine Life Refuge site; lower inset: Little Harbor site (LH).

Species composition at the refuge and Little Harbor sites were generally similar although relative abundances differed. Several species, most notably, the orange cup coral (*Balanophyllia elegans*), were observed only at the Little Harbor site.

Temperature

Mean monthly ocean temperatures prior to August 1992 were estimated from temperatures taken once a day from the surface to 30 m depth at 5-m intervals using a calibrated thermistor in Big Fisherman Cove (Fig. 1). On 1 August 1992, Ryan thermographs were placed at depths of 4, 10, and 20 m at the west end of each permanent transect. In June 1993, a fourth thermograph was installed at 33 m depth. At the Little Harbor site, thermographs were placed at 4, 10, and 20 m depth in July 1993. Thermographs recorded water temperature at intervals of 5 or 30 min. From 31 October to 3 November 1993, a vertical array of thermographs compared benthic with water column temperatures obtained at the same depth.

Kelp population structure and growth

In December 1991, the average size of *Macrocystis* was assessed in the refuge by counting the number of stipes taller than 1 m for 100 adult plants along the 3 60-m transect lines without making a density assessment. A plant was considered adult if it had 1 or more fronds > 1 m in height. Beginning in May 1992, plant size and density of adults were assessed quarterly by counting stipes on all of the adult plants along a 1-m band (120 m²) on either side of the 60-m transect lines. At Little Harbor, stipes were counted along a 1-m band on either side of a 60-m tape laid at 10- and 20-m depths in August 1993 and at 10 m in October 1983. At each census, counts at Little Harbor began at the same point and extended in the same compass direction.

The rate of frond elongation (RFE) at 10 m was used to index *Macrocystis* growth. At each census, the distal 1 m of 19–26 fronds 4–8 m long was flagged and remeasured 9–12 dy later (Zimmerman and Kremer 1986). Only fronds with active meristems (proliferating blades) were flagged.

To adjust for possible morphometric differences between fronds growing at the 2 sites, we compared biomass production. The absence of many blades along the lower stipe made it impossible to evaluate weights for entire fronds. Instead, we weighed the apical sector (2 m) where blades were generally intact. We estimated rates of biomass production by multiplying biomass (wet weight) of the apical sector (gm per cm) by the rate of elongation (cm day⁻¹).

Sea urchins

Densities of purple (*Strongylocentrotus purpuratus*), red (*S. franciscanus*) and black (*Centrostephanus coronatus*) sea urchins in the refuge were assessed by counting individuals within a 1-m band (120 m²) on either side of the 3 60-m transect lines. At Little Harbor, urchins were counted at 10-m depth in the same 120 m² area as *Macrocystis*. Counts were non-disruptive; we used flashlights to search crevices without moving rocks or urchins.

Results

Temperature

Temperatures for 1992 in the refuge were similar to temperatures recorded at the same depth at Santa Catalina during the 1982–1983 El Niño (Fig. 2). At 10 m, 81% of the records for August 1992 were ≥ 20° C. None were below 15° C. Sea surface temperature (SST) for August 1992 was 22.7° C, the highest monthly mean over 23 yr (Fig. 3). Warm temperatures lingered through the winter and early summer of 1993 followed by cooling in late summer and fall. In contrast to 1992, during 1993 less than 25% of the temperature records for August exceeded 20° C. Average temperatures and temperature distributions for September and October 1993 were about 1° cooler than in 1992.

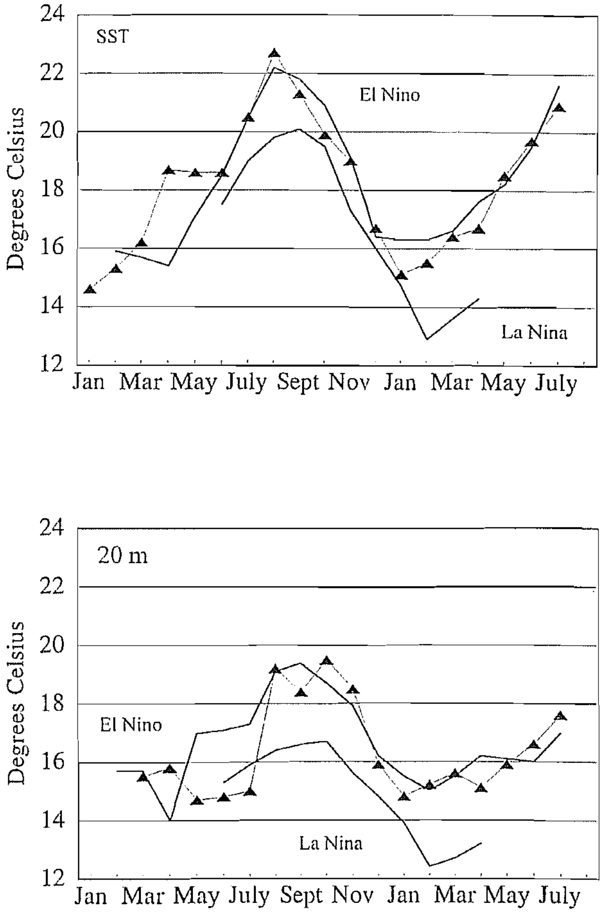


Figure 2. Comparison of the mean monthly SSTs at 3 depths for 1992/1993 with the El Niño of 1982/1983 (upper graph) and the cooler "La Niña" of 1988/1989 (lower graph). Black triangles are 1992/1993 mean monthly temperatures.

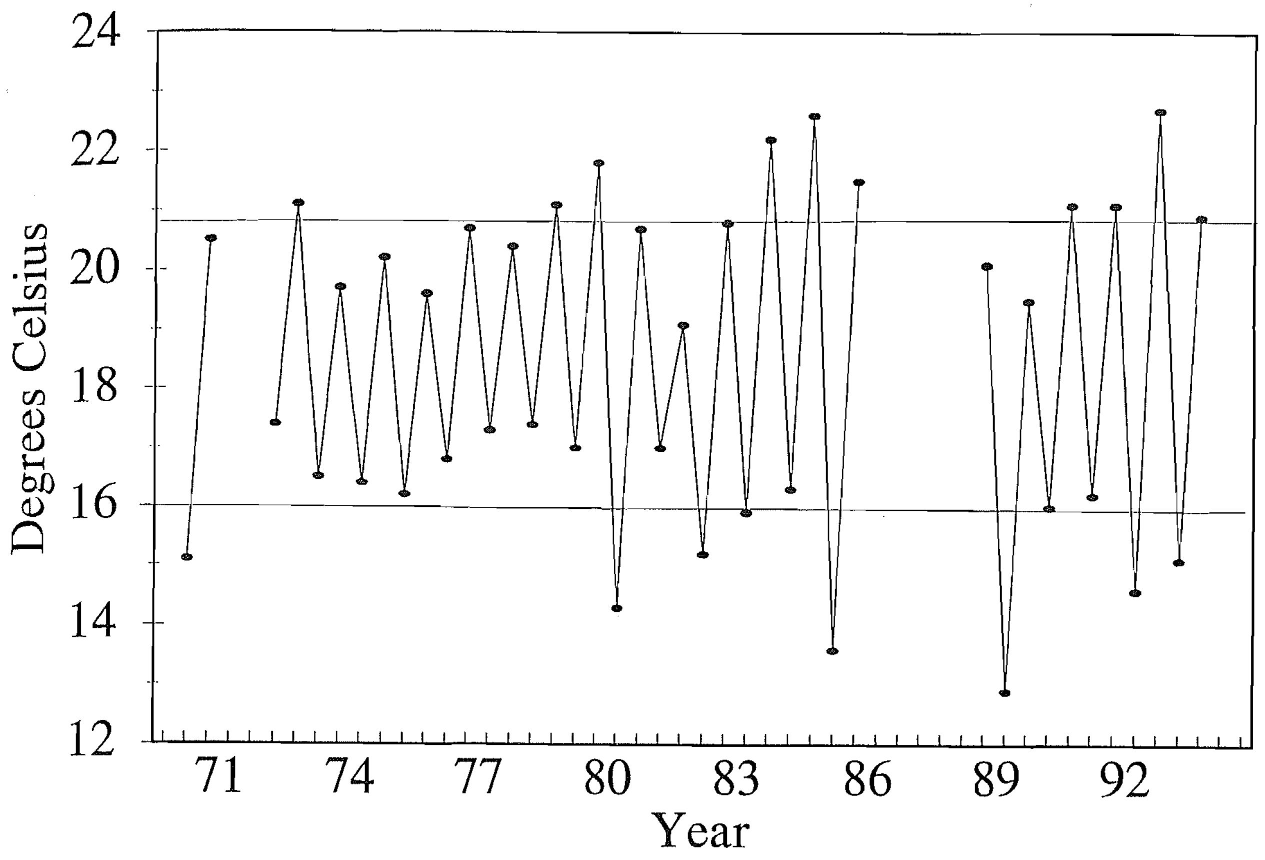


Figure 3. Long-term sea surface temperatures at Big Fishermans Cove, Catalina Island. Filled ellipses are the mean monthly highest and lowest temperatures for each year from 1970 through 1993. Horizontal lines are the mean values for the highest (20.8 ± 1 [SD]) and lowest (15.9 ± 1.3 [SD]) temperatures. In 13 out of 21 yr, the highest monthly SST occurred in August, and the coldest mean monthly SSTs occurred in January (10 of 21) and February (7 of 21).

Tidal effects

Periodic analysis of temperature records during a time of maximum temperature oscillation in August 1993 yielded a dominant cycle of 12.44 hr, consistent with semidiurnal tides, which agrees with the period of 12.5 hr reported by Zimmerman and Kremer (1984). The greatest variances in mean monthly temperatures for 1992–1993 were observed from April through August, emphasizing the development of strong seasonal thermal stratification at the site. In April 1993, tidal forcing introduced temperatures considerably below the 1992–1993 winter means and signaled an upward movement of the thermocline (Fig. 4). Although tidally forced temperature oscillations increased with depth at least to 30 m (our deepest deployed thermograph, not shown in Fig. 4), episodic exposure to colder potentially nutrient-rich water during summer and fall of 1992 and 1993 was infrequent. Only 0.3% of temperatures at 10 m from August to October 1992 (n = 7,844) and 4% of the records from June through October 1993 (n = 7,246) were < 15° C.

Bottom vs midwater temperatures

Do temperatures recorded on the bottom at a given depth reflect temperatures recorded at the same depth offshore? To provide an answer, thermographs were deployed on the bottom and also in midwater at the same depth(s) as the thermographs on the bottom. Thermographs at the same depths yielded similar temperatures, whether deployed on the bottom or in midwater: (M ± SD); 4 m bottom = 18.79 ± 0.26, rg. 18.1–19.2; 4 m midwater = 18.85 ± 0.25, rg. 17.9–19.3; 10 m bottom = 18.51 ± 0.37, rg. 17.3–19.0; and 10 m midwater = 18.54 ± 0.39, rg. 17.0–19.0; 20 m bottom = 17.86 ± 0.64, rg.

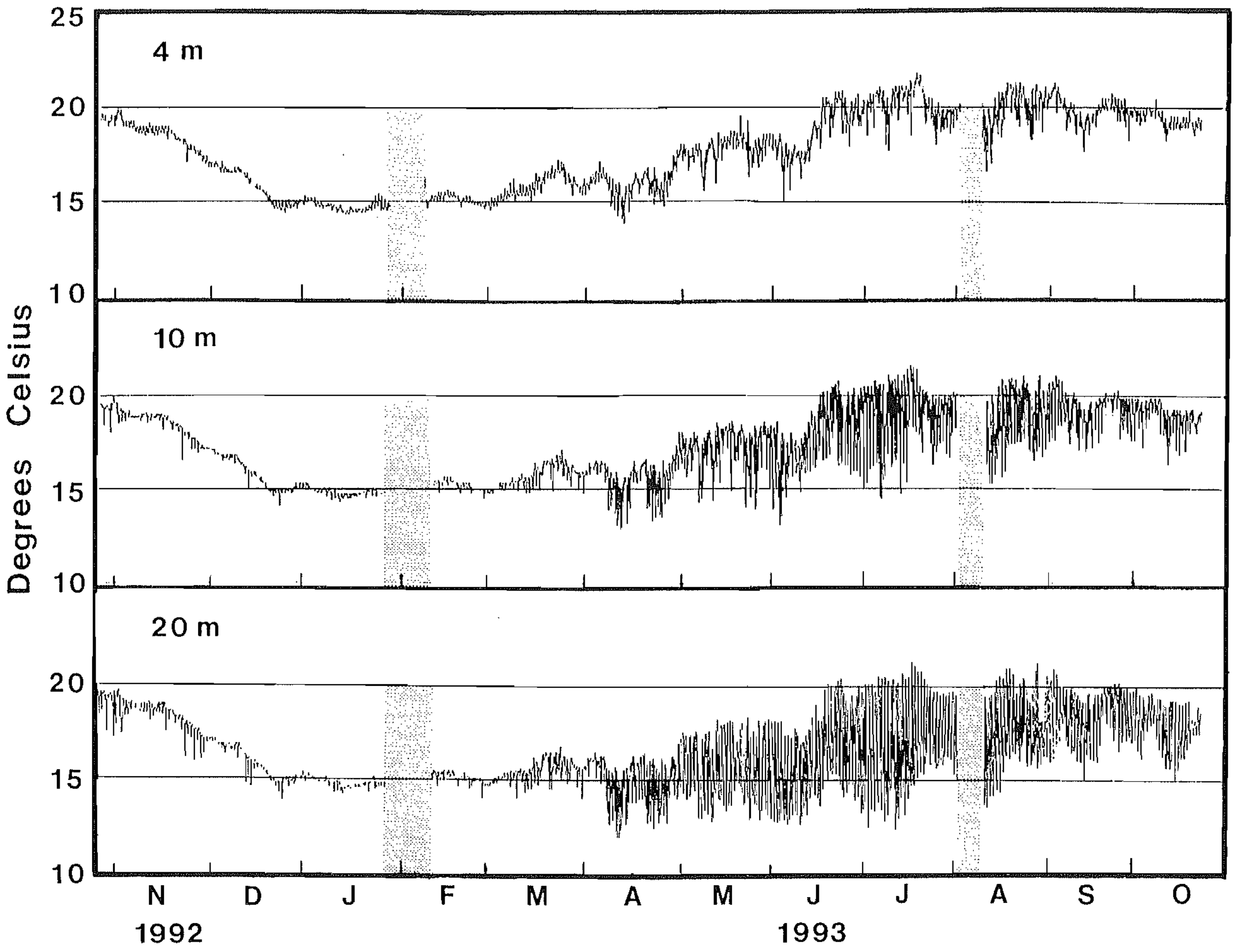


Figure 4. Continuous yearly bottom-temperature records in the Catalina Marine Life Refuge from 27 October 1992 through 26 October 1993. Sampling interval 30-min. Stippled areas are periods of shorter sampling intervals (5 min) when kelp growth was measured. Horizontal lines are 15 and 20° C.

Table 1. Comparison of different rates of sampling temperature. Statistics are based on an 18-dy record from 1–18 August 1993.

Sample rate	Mean	± 1SD	(Range,	variance,	n)
5 min	16.90	± 1.70	(13.6–21.1,	2.90,	5029)
30 min	16.90	± 1.70	(13.6–21.0,	2.90,	838)
1 hr	16.91	± 1.70	(13.6–21.0,	2.89,	419)
3 hr	16.85	± 1.69	(13.6–21.0,	2.87,	140)
4 hr	16.92	± 1.68	(13.9–21.0,	2.83,	104)
6 hr	16.96	± 1.60	(14.2–21.0,	2.55,	70)
12 hr	16.41	± 1.61	(14.2–21.0,	2.60,	35)
24 hr*	15.57	± 1.01	(13.8–18.0,	1.03,	18)

* Variance significantly different at $p < 0.01$, F-test against the 5-min. sampling rate, F = 2.82.

16.3–19.0; 20 m midwater = 17.86 ± 0.85, rg. 15.7–18.9 (n = 181 records per thermograph). Thus, benthically deployed thermographs can provide as detailed a vertical temperature profile as an array suspended within the bed over the same depths.

Temporal resolution

During periods when kelp elongation rates were measured, temperature was logged every 5 min. From these high resolution records we evaluated the effect of sample interval on the mean and variance of temperatures at intervals from 5 min to 24 hr. Sampling rates of less than 24 hr yielded similar descriptive statistics (Table 1). Sorting temperatures into frequency intervals of 1° from 13–21° C yielded significantly different distributions at sampling intervals greater than 4 hr (X^2, df = 8, at 6, 12 and 24 hr p's < 0.001). The distribution of temperature for the 3- and 4-hr intervals, although not significantly different, had intermediate probabilities (X^2, df = 8, at 3 hr p ≈ 0.46, at 4 hr p ≈ 0.09).

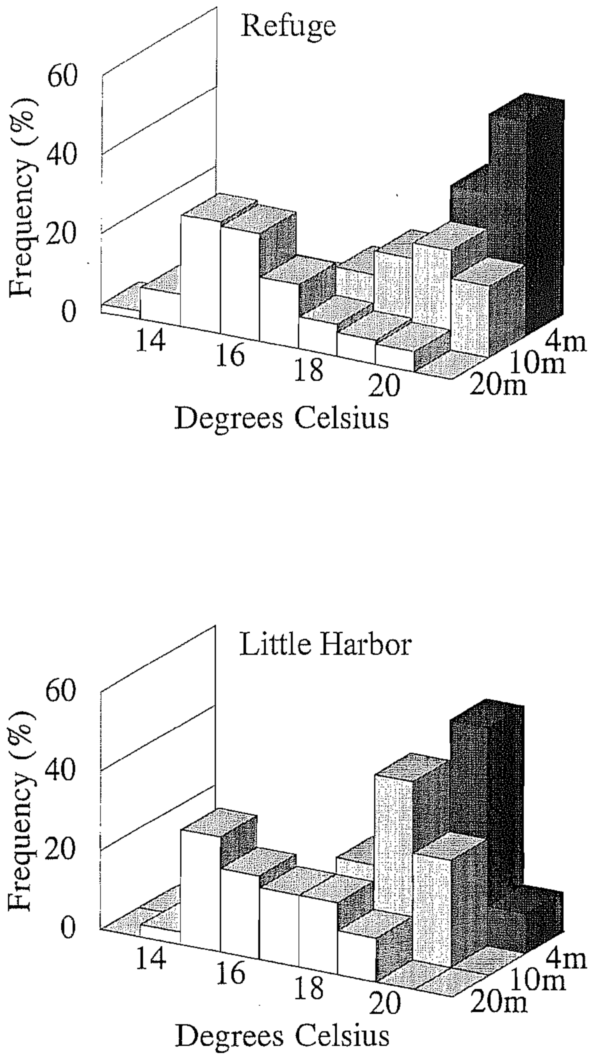


Figure 5. Comparison of temperature distributions between the leeward (Refuge) and windward (Little Harbor) sites on Catalina Island. Temperatures were logged every 5 min at each depth from 7–18 August 1993. Mean temperatures at the Marine Life Refuge were 20.7° C at 4 m, 19.3° C at 10 m, and 16.6° C at 20 m. Mean temperatures at the Little Harbor study site were 20.1° C at 4 m, 19.3° C at 10 m, and 16.9° C at 20m.

Temperatures on the leeward vs windward side of Catalina Island

Comparison of records from thermographs deployed within the refuge and at the Little Harbor site reveal different thermal regimes (Fig. 5). The diminished range and variance of temperatures at the windward site reflects near-surface mixing. On most days, the Little Harbor site experiences episodes of strong waves and surge, which on 1 occasion beached our inflatable and on another destroyed a thermograph. In contrast, to leeward, the refuge is rarely subject to strong wave action and surge, although tidal currents can exceed 1 m sec^{-1}.

Kelp forest dynamics

Surface canopy covering 90% of the refuge reef in January 1991 was absent at the beginning of November 1992. By spring 1993, surface canopies had disappeared around most of the island, especially on the leeward side. In July 1993, a scattered surface canopy still covered 10–15% of the forest area at the Little Harbor site, but only a few fronds remained in October 1993. Fronds terminated 3–4 m below the surface at the refuge and, slightly shallower, at 1–2 m depth at Little Harbor. Subsurface fronds, especially in the refuge were generally faded and fragile; most of the oldest blades were eroded or missing.

Macrocystis decreased in abundance and size in the refuge, especially after August 1992 (Fig. 6). At 4 m, adult plants were gone by October 1993. At 10 m, counts declined from 1,475 to 194 stipes and from 107 to 14 adult plants. At 20 m, total stipes declined from an August 1992 high of 592 to 327, as adult plants increased from 22 to 78. Losses were mitigated by growth of juvenile plants at 20 m and, to a lesser extent, at 10 m in August and October of 1993, . Young sporophytes, observed at all depths in May and June 1993, were generally absent by October 1993.

Between August and October 1993, the density of *Macrocystis* at Little Harbor decreased from 0.33 to 0.16 plants m^{-2}, and plant size changed slightly (M ± SD August 1993 = 19.8 ± 5.9 and October 1993 = 15.4 ± 6.8 stipes; Rank Sum Test, Z = 1.59, ns). August counts at 20 m yielded 0.34 plants m^{-2} and a mean plant size of 21.9 ±8.3 stipes. In both surveys, young sporophytes and juveniles were abundant at 10 m depth.

At 10 m depth within the refuge, RFE exhibited a continuous decline from May 1992 to February 1993 and remained depressed through summer 1993 (Table 2). A slight increase in RFE occurred in October 1993 (Rank Sum Test, Z = 2.76, p = < 0.01). In August 1992 and 1993, RFEs increased significantly with depth (Table 2). At 10 m RFEs from Little Harbor were similar to the refuge (Rank Sum Test, August 1993 Z = 0.03, ns; October 1993 Z = 0.51, ns). At 20 m, RFE at Little Harbor was significantly less than in the refuge (Rank Sum Test, Z = 3.42, $p < 0.001$). Mean RFE was not correlated with mean monthly temperatures at the depths at which fronds were growing ($r^2 = 0.003$, ns, n = 13).

Biomass production was not significantly different at the Refuge and Little Harbor sites (gm cm^{-1} day^{-1} M ± SD = 14.5 ± 1.6, rg. = 4.2–25.6 at the refuge and 15.2 ± 5.2, rg. = 5.7–26.9 at Little Harbor; Rank Sum Test, Z = 0.21, ns). The lengths of flagged fronds and the initial depth of meristems were similar at the 2 sites (Rank Sum Tests, frond length Z = 0.19, ns; meristem depth Z = 1.12, ns).

In October 1993, of 23 fronds flagged at Little Harbor, all were proliferating blades; the mean number of blades on the meristem was 22.0 ± 8.4. In contrast, 65% of the meristems on fronds in the refuge had produced the

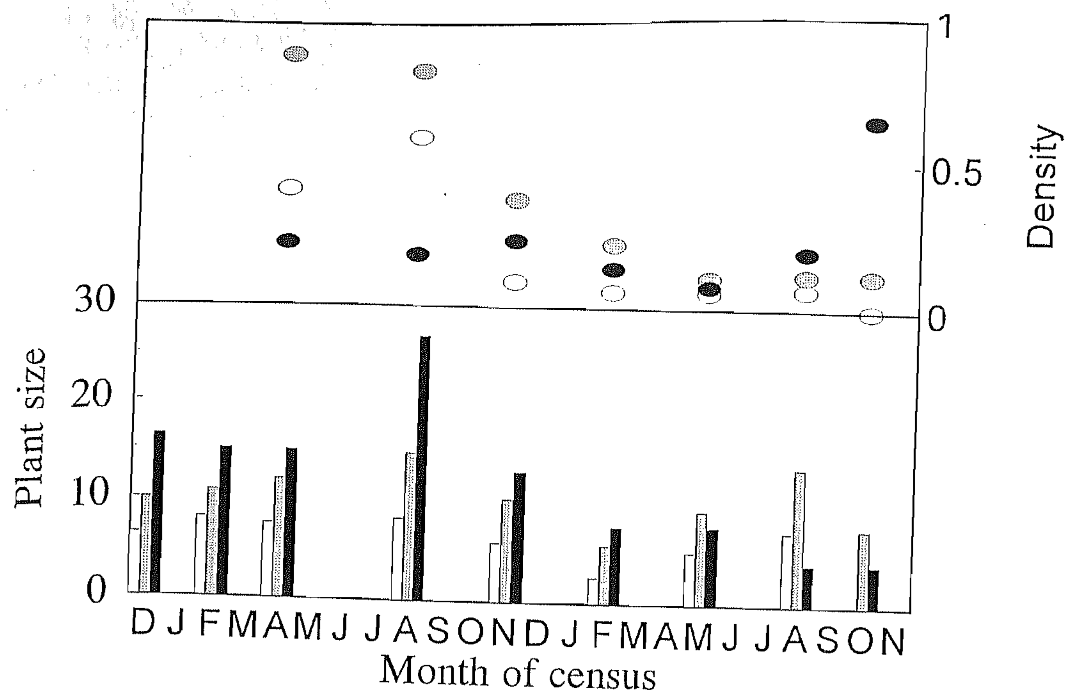


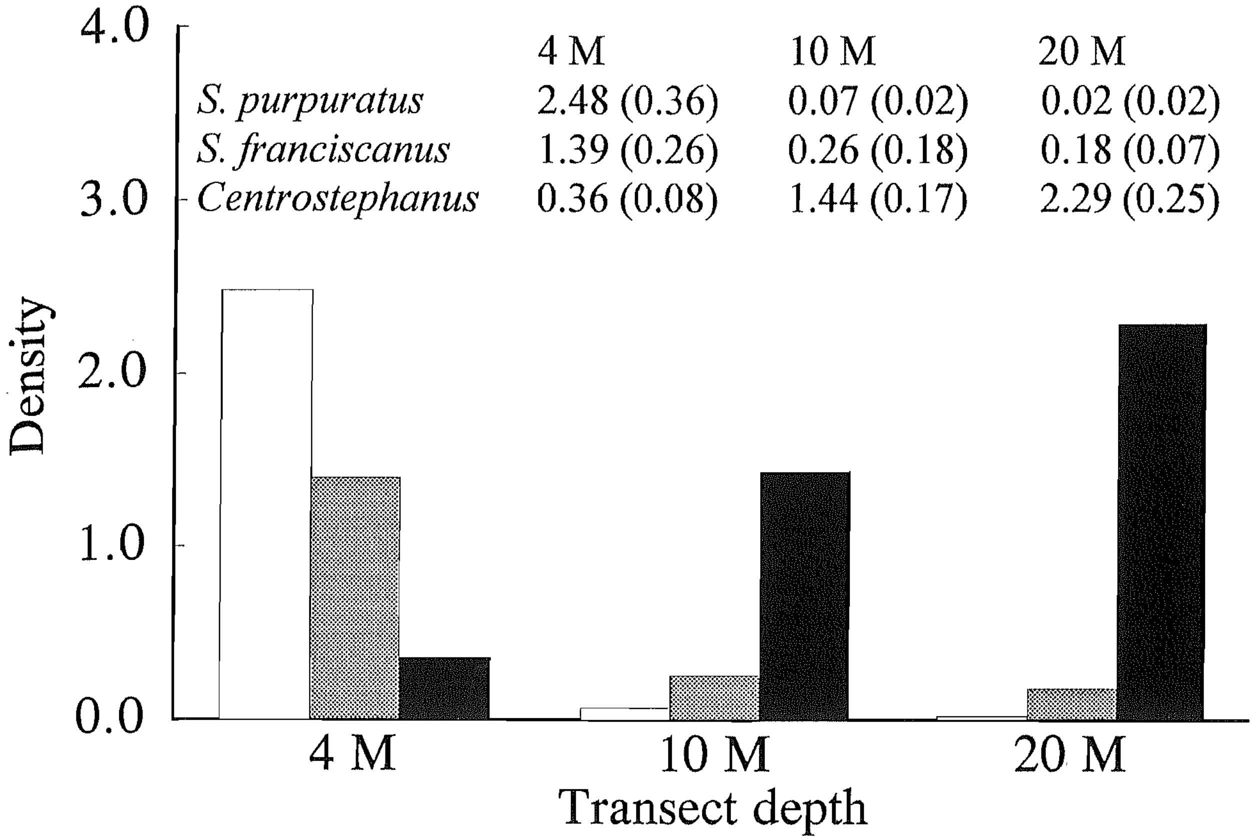
Figure 6. Seasonal density and the number of stipes for giant kelp along the 4-, 10- and 20-m transects within the refuge. The upper graph shows plants per m^{-2}: open ellipse—4 m; shaded ellipse—10 m; solid ellipse—20 m. The lower graph shows mean number of stipes per plant: open bar—4 m; shaded bar—10 m; solid bar—20 m.

Table 2. Seasonal fluctuations in rates of frond elongation (M ± SD cm day^{-1} [N]) for *Macrocystis pyrifera* growing at Santa Catalina Island, California; May, 1992–October 1993.

		Depth of holdfast		
		4 m	10 m	12 m
Refuge				
1992	May		14.2 ± 3.5 (26)	
	Aug	3.9 ± 3.7 (5)	7.4 ± 1.6 $(26)^{++*}$	9.3 ± 1.0 $(6)^{**}$
	Oct		4.4 ± 2.8 $(20)^{+}$	
1993	Feb	1.3 ± 1.1 $(26)^{+}$		
	May		4.0 ± 1.9 $(22)^{+}$	
	Aug	1.6 ± 1.0 (8)	4.4 ± 3.3 $(24)^{**}$	9.9 ± 3.4 $(19)^{**}$
	Oct		6.9 ± 2.9 $(16)^{+}$	
Little Harbor				
1993	Aug	4.1 ± 2.0 (23)	7.2 ± 2.2 $(28)^{**}$	
	Oct		6.9 ± 1.9 $(23)^{+}$	

Rank Sum Test for consecutive seasons: $^{+}$ = $p < 0.05$, $^{++}$ = $p < 0.001$.

Rank Sum Test for consecutive depths: * = $p < 0.05$, ** = $p < 0.001$.



	4 M	10 M	20 M
S. purpuratus	2.48 (0.36)	0.07 (0.02)	0.02 (0.02)
S. franciscanus	1.39 (0.26)	0.26 (0.18)	0.18 (0.07)
Centrostephanus	0.36 (0.08)	1.44 (0.17)	2.29 (0.25)

Figure 7. Mean densities (1SD) of sea urchins within the refuge. Statistics are based on counts for 120 m^2 along each transect. Open bar—*S. purpuratus*; shaded bar—*S. franciscanus*; solid bar—*Centrostephanus*.

final blade by the time they were re-measured; the mean was 9.5 ± 8.6 (n = 16), significantly less than at little Harbor (Rank Sum Test, Z = 3.03, $p < 0.01$).

Sea urchins

Population densities of sea urchins did not change significantly in the refuge during 17 mo (ANOVA, F = 0.09, df = 5, p's > 0.98), but species distributions correlated with depth (ANOVA F = 113, df = 10, p = 0.0001; Fig. 7). At each census, we found a few diseased urchins and empty tests, mostly *S. purpuratus* and *S. franciscanus*.

Counts in October 1993 at the Little Harbor site yielded densities for purple, red, and black urchins of 0.43, 0.89, and 0.14 m^{-2}, respectively. The density of reds reached 2 m^2 in a denuded area at the western edge of the site.

El Niño, 1992–1993

Indications of El Niño around Catalina Island in 1992–1993 included the appearance of more southerly species. Pelagic red crabs (*Pleuroncodes planipus*) appeared from fall through early spring 1992–1993; a spotted pufferfish (*Diodon histrix*) was collected at Isthmus Cove (author's observation); sergeant major fish (*Abudefduf saxatilis*) were sighted near the refuge and at Avalon Harbor (M. Steele and B. Snodgrass 1993, pers. comms.); and a green turtle was observed in the refuge (author's observation).

Discussion

Temperature

What data-logging schedule should be used to adequately track thermal changes produced by tidal changes, and to ascertain the average daily, weekly, and monthly temperature? For an accurate picture of mean temperatures, sampling rates of more than 6 hr can lead to inaccuracies (dependent on the resolution required). A single daily record when tides force temperature fluctuations could be misleading, because a single measurement might record only the maximum or minimum daily temperature. This holds true, especially when the temperatures are measured at a fixed location (on the bottom or over the bottom). To resolve cyclic events, the minimum sampling interval is one-half of the cycle. Thus at

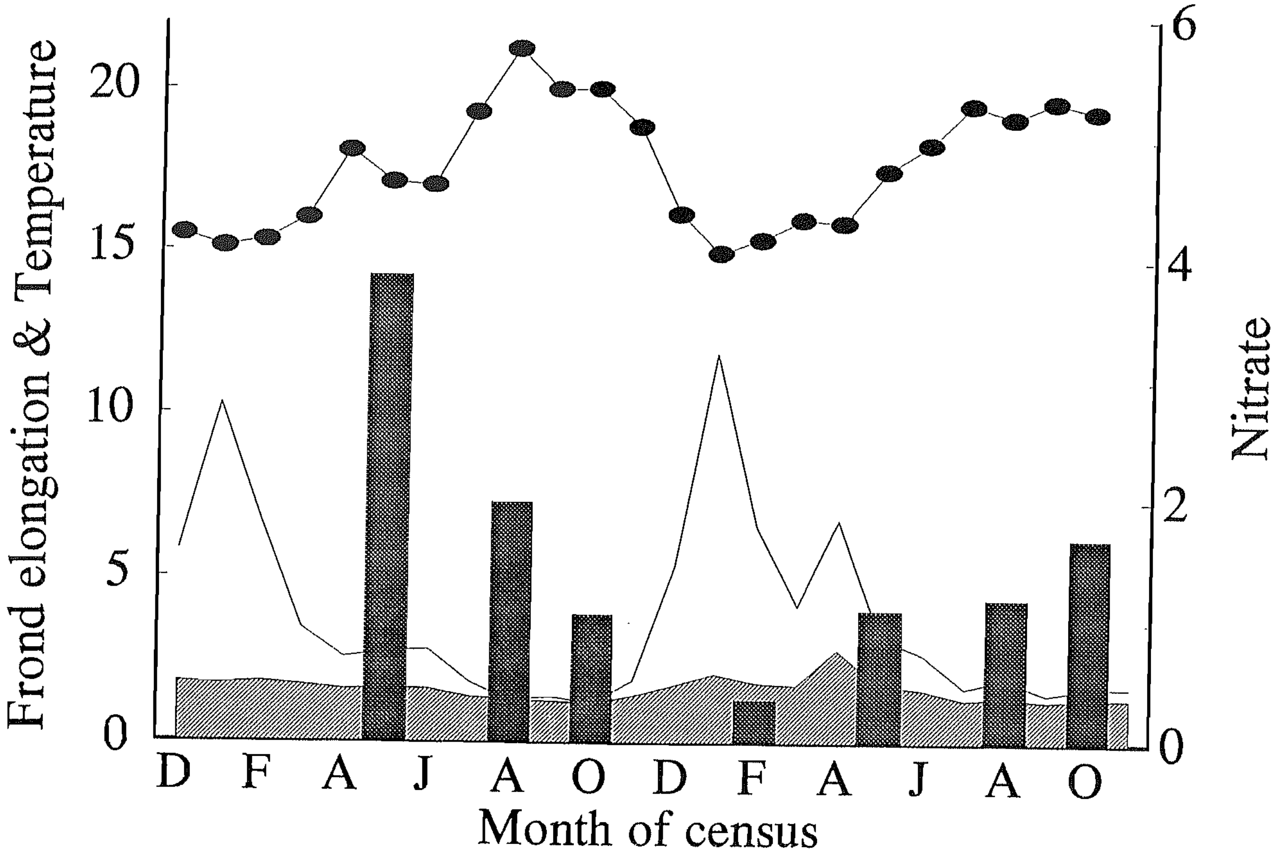


Figure 8. Mean monthly temperatures at 10 m, rates of frond elongation, and the calculated mean monthly nitrate concentrations for the refuge for warm, 1982–1983 (El Niño), and cooler conditions (1980–1981). Black bars—frond elongation in cm/day^{-1}; blackened ellipses—mean monthly temperatures in Celsius; stippled areas—nitrate concentration in micromoles l^{-1} for warm conditions; open area—nitrate concentration for cooler conditions.

Catalina Island, where the tides have a peak-to-valley period of about 6 hr, sampling should be equal to or less than 3 hr, in agreement with the statistical result (Table 1).

Some subsurface temperatures and SST have been measured with few gaps at Big Fisherman Cove since 1970 (McFarland and McAlary 1992). Mean monthly SSTs clearly indicate summers and winters that were above and below the long-term average temperatures (Fig. 3). During the 23-yr period, however, on only 3 occasions did both summer and winter mean SSTs exceed the long term averages (1979–1980, 1983–1984, and 1991–1992). Of the 3 only 2 are associated with strong El Niños (1982–1983 and 1991–1992).

Kelp forest dynamics

Changes in plant size and density during 1992 and 1993 document the regression of kelp forests in the refuge and at the Little Harbor site. At the refuge, comparisons of responses in 1992 with 1983 (Zimmerman and Robertson 1985) suggest that the initial impact of the 1992 El Niño on *Macrocystis* was not as severe in shallow areas but was more pervasive at depth than in 1983. In August 1992, average daily rates of frond elongation at 4 m and 10 m were 3–6 cm above rates at 7 m in 1983. In 1983, *Macrocystis* was eliminated to 7 m by late fall. In contrast, *Macrocystis* persisted in shallow waters for another full year following the summer of 1992. At 20 m, frond production compensated for frond losses in the summer and fall of 1983, but not in 1992 when the average size of *Macrocystis* declined at all depths.

As thermal anomalies persisted into 1993, seasonal fluctuations in growth rates of *Macrocystis pyrifera* were a mirror image of 1980–1981 growth rates (Zimmerman and Kremer 1986). Failure of *Macrocystis* to increase production during the winter and their less- than-maximum rates in the spring of 1993 left the population vulnerable (low density, small plant size). Despite significantly cooler water temperatures in the summer of 1993, rates of frond elongation were less than in 1992. To compare fluctuations in growth rates and nutrients, we calculated nitrate concentrations using temperature-nitrate regressions and data given by Zimmerman and Robertson (1985) for the 1982–1983 El Niño and by Zimmerman and Kremer (1984) for 1980–1981, a higher nutrient period (Fig. 8).

The low rates of kelp growth observed after May 1992, especially in the winter of 1993, are consistent with nutrient limitation. A single series of hydrocasts in February 1993 produced a nitrate-temperature regression similar to 1983 El Niño conditions (J. Kremer 1993, pers. comm.). In May 1992, however, calculations yielded nitrate levels well below the threshold for maximum growth, yet frond elongation rates were as high as the maximum rate observed in 1980–1981 when nitrate was not limiting (e.g., nitrate limiting below $1.5\mu m\ l^{-1}$, Zimmerman and Kremer 1986). Even calculations using 1980–1981 temperature nitrate regressions yielded nitrate levels below threshold for saturated growth in May 1992 and for the preceding 2 mo. Nitrogen stores would not be expected to sustain maximum growth for more than 1 mo (Gerard 1982, 1984; Zimmerman and Kremer 1986). Adequate nutrients must have been available. One possibility is that the heavy runoff into the refuge from winter rainstorms of 1992 augmented the local supply of nutrients (North et al. 1982).

Comparison of kelp forests at the refuge and Little Harbor site.

Kelp at the Little Harbor site was healthier than kelp in the refuge (e.g., higher initial density, size of plants, and darker pigmentation). Rates of frond elongation and biomass production for fronds 4–8 m long were similar. A striking difference was that kelp in the refuge ceased blade production before kelp at the Little Harbor site. The earlier senescence of fronds in the refuge and deeper subsurface canopy were linked, perhaps, to the greater exposure of meristems to temperatures above 20° C at the refuge compared to Little Harbor (i.e., at 4 m depth in August 1992: 65% vs 34%, n = 508) (North and Zimmerman 1984).

Sea urchins

Clearly, the densities and depth distribution of urchins are different on the 2 sides of the island. The greater abundance of red and purple urchins and patches of overgrazing observed at the Little Harbor site may be influenced by differences in recruitment, habitat structure, exposure to wave energy, or food availability at the 2 sites (Tegner and Dayton 1991). In addition, the windward side of Catalina is open to commercial and sport harvesting of the 2 important predators of sea urchins, spiny lobster (*Panulirus interruptus*) and sheephead (*Semicossyphus pulcher*). Removal of these species favors increased densities of sea urchins (Cowen 1983; Tegner and Levin 1983). In contrast, species that prey on urchins or compete with them for food, are protected from harvest in the refuge.

Patchy areas of overgrazing by red urchins have been observed near the west end of Catalina Island in the past (T. Hobson and T. Chess 1993, pers. comms.), and small areas are currently overgrazed by purple urchins that exist on the windward side of the island (author's observation and J. Engle 1993, pers. comm.). But the vast denuded boulder-scapes dominated by urchins, observed in the northern islands (Richards et al. 1993a and 1993b) and along the mainland of southern California, are presently absent at Catalina Island.

Summary

Marine ecological monitoring programs usually do not include extensive hydrographic or physiological sampling. However, such information is essential to explain the biotic fluctuations observed within and between monitoring sites. The processes underlying community change through time are complex. This makes the selection of sampling parameters and temporal regimes difficult. We chose to monitor on a seasonal basis and to augment population profiles with high-frequency water temperatures and seasonal assessments of kelp growth. Adding quarterly temperature-chemical profiles would be desirable in getting at causality as well as a quantitative description of changes that occur through time. An effective monitoring program should be flexible enough to include a selective testing of hypotheses concerning changes in community dynamics. Our data suggest that thermal anomalies such as El Niño lead to the diminishment of kelp forests in southern California, not only by intensifying stressful conditions in summer (high temperatures, low nutrients) but also by limiting production during winter and spring.

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Effects of Disturbance on Population Dynamics of Selected Taxa in the Rocky Intertidal Zone of Channel Islands National Park, California

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Abstract. Changes in abundance following experimental, accidental, and natural disturbance of several rocky intertidal organisms were documented by biannual monitoring at the Channel Islands. During the last 10 yr, information on dominant cover was collected from permanent plots at 14 stations around Santa Barbara, Anacapa, Santa Rosa, and San Miguel Islands. While abundances of most organisms remained stable, there were differences between sites. Experimental trample and scrape plots at Anacapa showed slow recovery in the mussel (*Mytilus californianus*) and rockweed zones (*Pelvetia fastigiata/Hesperophycus harveyanus*). Accidental clearings by grounding of vessels or buoys at Santa Barbara Island showed rapid recovery. A natural influx of sea stars (*Pisaster ochraceus*) at Santa Rosa Island caused dramatic declines in the mussel population there. A mass mortality of black abalones (*Haliotis cracherodii*) was documented. We observed a parkwide decline of more than 90% from 1985 population numbers. While withered and weak abalone were frequently observed, no direct cause for the mass mortality was found.

Keywords: California Channel Islands; rocky intertidal; monitoring; black abalone; *Haliotis cracherodii*; algae; disturbance.

Introduction

Intertidal areas provide a glimpse into the marine world of our oceans and the interesting plants and animals that live there. Tidepools also provide a convenient look at the health of the marine ecosystem. Organisms of the rocky intertidal are subject to a variety of potential perturbations, including oil spills, vessel groundings, water pollution, harvest, and overuse (trampling) by people. Understanding the responses of intertidal organisms to disturbance is important to management of the resources.

The causes of variation in the species composition, abundance, and distribution of rocky intertidal organisms are complex and not well understood. A good review of the literature relevant to the causes of spatial and temporal patterns in the rocky intertidal can be found in Foster et al. (1988).

Undisturbed tidepools are unfortunately rare in southern California and the value of this resource was recognized as one of the special features mentioned in the enabling legislation for Channel Islands National Park. Long-term ecological monitoring of the rocky intertidal is one aspect of the marine monitoring program at Channel Islands National Park. The goals of the program are (1) to monitor trends in population dynamics, (2) to determine the normal limits of variation, (3) to discover abnormal conditions, (4) to provide remedies for management problems, and (5) to measure the success of management actions. The program itself is not designed to answer all the questions or to identify causes of all the problems, but rather to identify that there are questions or problems that need answers. The overall purpose of monitoring is to make recommendations to park management that may include further research into a problem (Davis et al. 1994, this volume).

Following the recommendations of Littler (1978), and the establishment of Channel Islands National Park in 1980, a monitoring design was developed in 1982 at Anacapa Island by VTN Oregon (VTN Oregon, Inc. 1983). Part of the original design included experiments to study the impacts from visitation. In 1985, the monitoring was expanded to other islands by park marine biologists, consulting with J. Engle. There are currently 14 permanent sites on Santa Barbara, Anacapa, Santa Rosa, and San Miguel Islands (Richards and Davis 1988).

The purpose of this paper is to describe changes in population dynamics of selected intertidal organisms following experimental, accidental, and natural disturbances.