Status of the Kelp Beds in 2016:

Ventura, Los Angeles, Orange, and San Diego Counties

Prepared for the Central Region Kelp Survey Consortium

and

Region Nine Kelp Survey Consortium

MBC *Applied Environmental Sciences*

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EXECUTIVE SUMMARY

Giant kelp beds have been mapped quarterly off Ventura, Los Angeles, Orange, and San Diego counties for both the Central Region (CRKSC) and Region Nine Kelp Survey Consortiums (RNKSC). The CRKSC was formed in 2003 as a result of regulations from the Los Angeles Regional Water Quality Control Board (LARWQCB). The program was based on the long-established RNKSC that formed in 1983 as a result of regulations promulgated by the San Diego Regional Water Quality Control Board (SDRWQCB). When combined, the two organizations provide continuous and synoptic monitoring for approximately 355 kilometers (km) of the 435-km coastline of the Southern California Bight (SCB), from Ventura Harbor to the Mexican Border. The annual reports from 2010 through 2016 are available online at http://kelp.sccwrp.org/reports.html.

Aerial imaging surveys of the giant kelp beds were conducted by MBC *Applied Environmental Sciences* (MBC) on April 18, June 20, September 24, and December 28, 2016. Digital color and color infrared photos were taken of the Central Region and Region Nine coastlines during each survey. (The airspace off North Island Naval Air Station and Coronado was restricted during the December survey, but this area does not support giant kelp.) These photos were then processed and the kelp depicted on each photo was transferred to base maps to facilitate intra-annual comparisons for ease of analysis (Appendices A, D, and E).

Monitoring Questions. One of the objectives of the CRKSC and RNKSC programs is to answer basic monitoring questions regarding the status of kelp beds within the two regions:

1. What is the maximum areal extent of the coastal kelp bed canopies each year?
    - Central Region - maximum total kelp canopy covered 4.757 km^2 in 2016;
    - Region Nine - maximum total kelp canopy covered 5.134 km^2 in 2016.
2. What is the variability of the coastal kelp bed canopy over time?
    - Central Region:
        - maximum total kelp canopy decreased in size in 2016 by 9.5% (from 5.255 km^2 to 4.757 km^2);
        - 6 kelp beds increased in size;
        - 14 kelp beds decreased in size (including 2 beds decreasing to zero);
        - 2 kelp beds remained the same size.
    - Region 9:
        - maximum total kelp canopy decreased in size in 2016 by 59% (from 12.667 km^2 to 5.134 km^2);
        - 3 kelp beds increased in size;
        - 19 kelp beds decreased in size (including 4 beds decreasing to zero).
3. Are coastal kelp beds disappearing? If yes, what are the factors that could contribute to the disappearance?
    - Central Region
        - 2 beds disappeared in 2016 that were visible in 2015 (Las Tunas and Topanga);
        - 4 beds continued not to be visible in 2016, two that disappeared in 2015 (La Costa and Las Flores), and two that have been absent historically (Horseshoe and Huntington Flats);

- Region 9
  - 4 beds disappeared in 2016 that were visible in 2015 (North Carlsbad, Agua Hedionda, Carlsbad State Beach, Del Mar) ;
  - 2 beds continued not to be visible in 2016, both having been absent historically (Santa Margherita and Torrey Pines).

Sea surface temperatures were warmer than normal for much of the year, upwelling was average, and the calculated nutrient quotient values were low in 2016. This was the fourth straight year of below-average nutrient quotient values. It is possible that reduced nutrient availability contributed to the disappearance of beds in the Central Region and Region 9. But within the Central region, it is hard to explain why the La Costa and Las Flores beds disappeared, yet nearby the Malibu Point kelp bed reappeared.

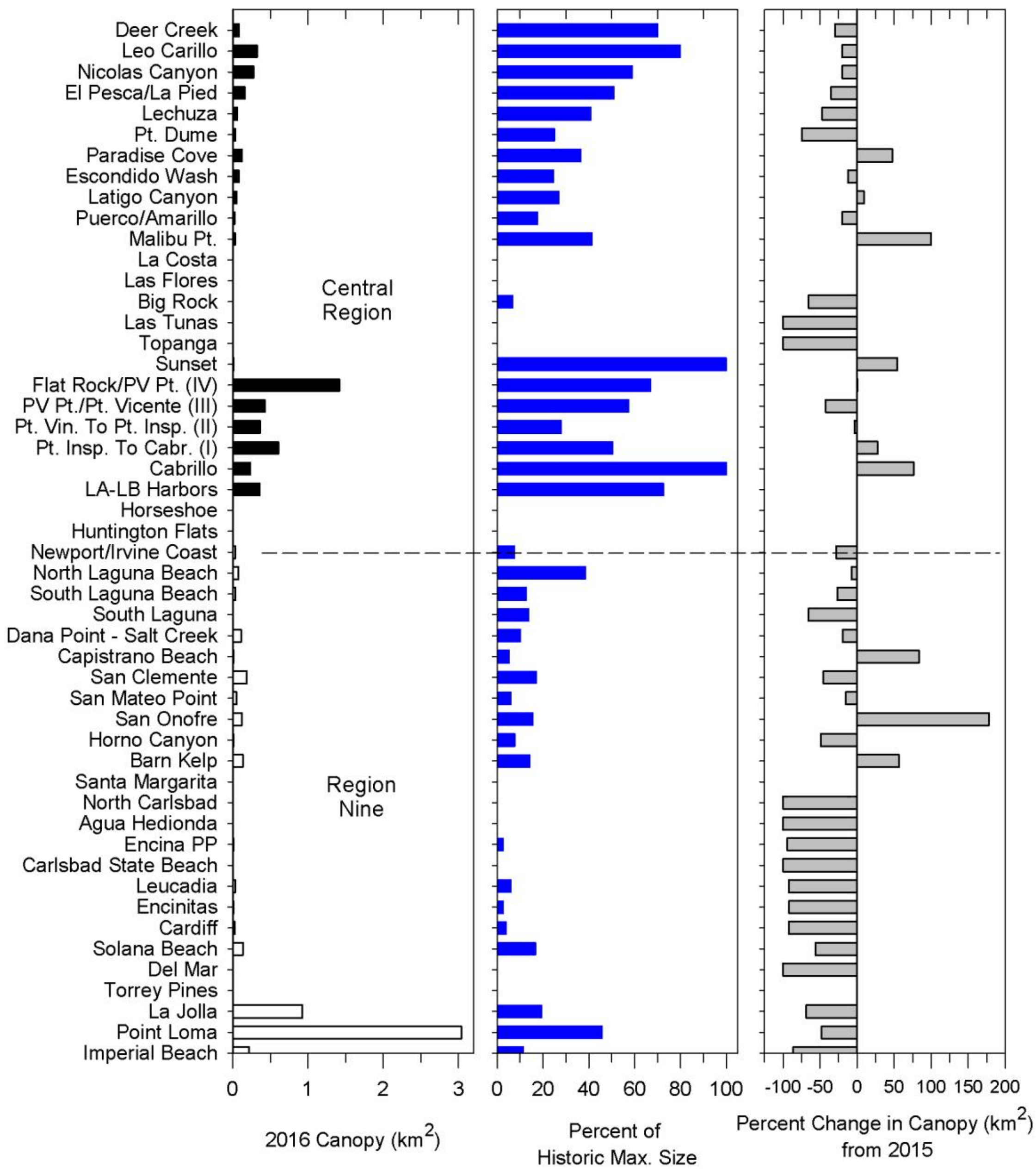
4. Are new kelp beds forming?
   - Central Region
     - 1 bed reappeared in 2016, following a one-year absence in 2015 (Malibu Point);
   - Region 9
     - No new beds appeared in 2016.

Total canopy size within the 50 kelp beds monitored as part of the CRKSC and RNKSC programs decreased 45% from the previous year. Two-thirds of the kelp beds in the Central Region lost canopy in 2016, and nearly all of the kelp beds in Region Nine decreased in size last year. Total canopy coverage for this survey year was 9.9 km^2, with 4.8 km^2 in the Central Region and 5.1 km^2 in Region Nine. There was no evidence to suggest that any of the two regions' various dischargers had any perceptible influence on the persistence of the giant kelp beds.

Central Region Results. The following changes occurred:

In 2016, 19 kelp beds displayed surface canopy, compared to 20 kelp beds with surface canopy in 2015 (two beds disappeared, but one reappeared in 2016). Although 14 kelp beds lost surface canopy, the maximum total area only decreased by 9.5% in 2016 (declining from 5.255 km^2 in 2015 to 4.757 km^2 in 2016). The total amount of kelp canopy in the central region peaked in 2009 (highest amount recoded since 1967), with 6.4 km^2 of canopy coverage, and it has ranged between 4.3 and 5.7 km^2 since then (Table 1, Figure 19 and Appendix B). The largest beds in the Central Region are the four Palos Verdes kelp beds, with the largest being PV IV Flat Rock/Palos Verdes Point (left panel in figure below). Half the kelp beds (13) in the Central Region are at or above 40% of their historic maximum size and 6 are at 70% or more (central panel in figure below). In the Central Region, 2 beds decreased in size by more than 75% (right panel in figure below).

The Sunset and Cabrillo kelp beds both gained canopy in 2016, and reached their maximum size as measured by the CRKSC (Table 1). The four Palos Verdes beds accounted for 59% (3.060 km^2) of the total Central Region kelp coverage in 2016, with one bed increasing in size, one remaining the same size, and two decreasing in size. The Paradise Cove, Latigo Canyon and Malibu Point kelp beds increased in size in 2016 (Table 1). Most of the beds in the Central Region reached their maximum extent by the April or June 2016 overflights.



Central Region (black) and Region Nine (white) kelp canopy coverage in 2016; percent of maximum size at Region Nine since 1983 and Central Region since 2003 (blue); and percent canopy coverage change since 2015 (grey).

Region Nine Results. The following changes occurred:

In 2016, 18 kelp beds displayed surface canopy, compared to 22 kelp beds with surface canopy in 2015 (4 beds disappeared in 2016). Nearly all of the kelp beds in Region Nine lost canopy in 2016 (19 of 22 kelp beds visible in 2015), resulting in a decrease of 59% (from 12.667 km^2 in 2015 to 5.134 km^2 in 2016). This continues the downward trend observed over the past three years, with the total kelp canopy area decreasing 70% from 17.064 km^2 in 2013 to the current level of 5.134 km^2. The 2016 total kelp canopy area was the lowest observed since 2008 (Table 2, Figure 27 and Appendix B). The largest beds in Region Nine are the Point Loma and La Jolla kelp beds (left panel in the figure above). Only 2 of the kelp beds in Region Nine are at or above 40% of their historic maximum size (central panel in figure above). Nine of the kelp beds in Region Nine decreased in size by more than 75% in 2016 (right panel in figure above).

The La Jolla and Point Loma kelp beds remained the largest beds in Region Nine, accounting for 77% (3.96 km^2) of the total canopy area in 2016 (Figure 28). However, current canopy areas at the La Jolla and Point Loma kelp beds were the smallest since 2006, while canopy area at Imperial Beach (the third largest bed in Region Nine in 2014 and 2015) was the smallest since 2011 (Table 2). Only three kelp beds increased in size in 2016 (Capistrano Beach, San Onofre, and Barn kelp beds), but these three are relatively small beds (Table 2). Most of the Region Nine kelp beds reached their maximum extent during the December survey.

Environmental Variables. Sea surface temperatures (SSTs) during the first three months of 2016 were above average throughout southern California (Figure 7 and 8). A 2°C temperature decrease coincided with a storm between January 31st and February 2nd. Beginning in March, there were several influxes of cold water between Point Dume and Point Loma. Strong cold-water pulses were evident in both regions from April through September. The upwelling index, calculated for a location 161 km offshore of Solana Beach, indicated above-average upwelling during six months (March, July, August, October, November and December) and below-average upwelling during six months (January, February, April, May, June and September) in 2016 (Figure 10). The SSTs throughout the region oscillated above and below the long-term Scripps Pier average in 2016, with warmest temperatures recorded in July and August.

The calculated Nutrient Quotient values have been below average throughout southern California since 2013 (Figures 5 and 6). Nutrient Quotient values are based on monthly mean temperatures, and may not adequately capture multiple, brief periods of cold-water influx. At Scripps Institution of Oceanography Pier (Scripps Pier or SIO Pier), the number of days with low water temperatures (i.e., <14°C) has been below average the last three years, and the number of days >16°C has been above average, suggesting a shift to warmer temperatures (Figure 37). At Point Dume, the number of days <13–14°C has been below average the last five years, and the number of days >16–20°C has been above average the last five years, also indicative of warmer temperatures. At Newport Beach, the number of days with relatively warm temperatures (>16–18°C) has been higher than average the last three years.

The effects of other environmental variables (rainfall/runoff, algal blooms, and large waves) appeared to have had little effect on southern California's kelp beds in 2016. Rainfall was below average for the sixth straight year in Los Angeles and Orange Counties, but near average in San Diego County, so effects from runoff were negligible (Figure 17). Nearshore turbidity near the Portuguese Bend landslide area was visible during all four surveys, and relatively high during April and June (Figure 38). Nearshore waters were also turbid during the

September and December surveys at Point Loma (Figure 39). Persistent turbidity at Palos Verdes could have affected surrounding beds (i.e., PV I and PV II at a minimum). There were no media reports of red tide in the region, so effects due to reduced visibility, if any, were limited. The wave climate in 2016 was considered normal, with the largest waves arriving in February, March, and April (Figures 13 and 14). Wave heights exceeded four meters at all stations—and five meters at Point Loma—during a storm on January 31 and February 1, 2016. Most of the beds decreased in size between the June and September overflights, but the wave climate was mild during that period, and beds often shrink in summer and fall.

Conclusions. Most kelp bed canopies decreased in size in 2016, although several beds increased in size. The reduction in canopies coincided with a third year of mostly above-average temperatures throughout the SCB, but average upwelling. There was no evidence of any adverse effects on the giant kelp resources from any of the region's dischargers. Total coverage in 2016 was still above average for the Central Region, but below average in Region Nine. The six beds at the upcoast extent of the Central Region and the twelve beds at the downcoast extent of Region Nine all shrank in 2016. Between these extremes, only 10 of the 32 kelp beds increased in size in 2016. Reasons for variable canopy increases/decreases are unknown, but suggest that physical and/or biological factors affected the kelp beds on a smaller scale such that adjacent beds performed differently. El Niño and ENSO-neutral conditions are equally favored in summer and fall, confounding predictions for 2017.

INTRODUCTION

Giant kelp (*Macrocystis pyrifera*) beds along most of the southern California mainland coast have been mapped quarterly by the Central Region Kelp Survey Consortium (CRKSC) since 2003 and by the Region Nine Kelp Survey Consortium (RNKSC) since 1983. The CRKSC covers kelp beds from Ventura Harbor to Newport Beach (Figure 1), and the RNKSC covers Newport Beach to the Baja California border (Figure 2). The upcoast extent of the RNKSC is Abalone Point (Laguna Beach). However, historical surveys have examined the kelp beds from the Newport Harbor entrance to the U.S./Mexico border. It was agreed among the funding participants that the monitoring programs would be methodologically based upon aerial kelp surveys that were conducted since 1967 by the late Dr. Wheeler J. North. With the formation of the two monitoring programs, continuous coverage is provided of the kelp beds along approximately 354 of the 435 km (220 of the 270 miles) of the southern California mainland coast from Ventura Harbor to the U.S./Mexico Border. The geographical ranges and the ocean dischargers located within the CRKSC and RNKSC are shown in Figures 1 and 2, as well as Appendices A and D.

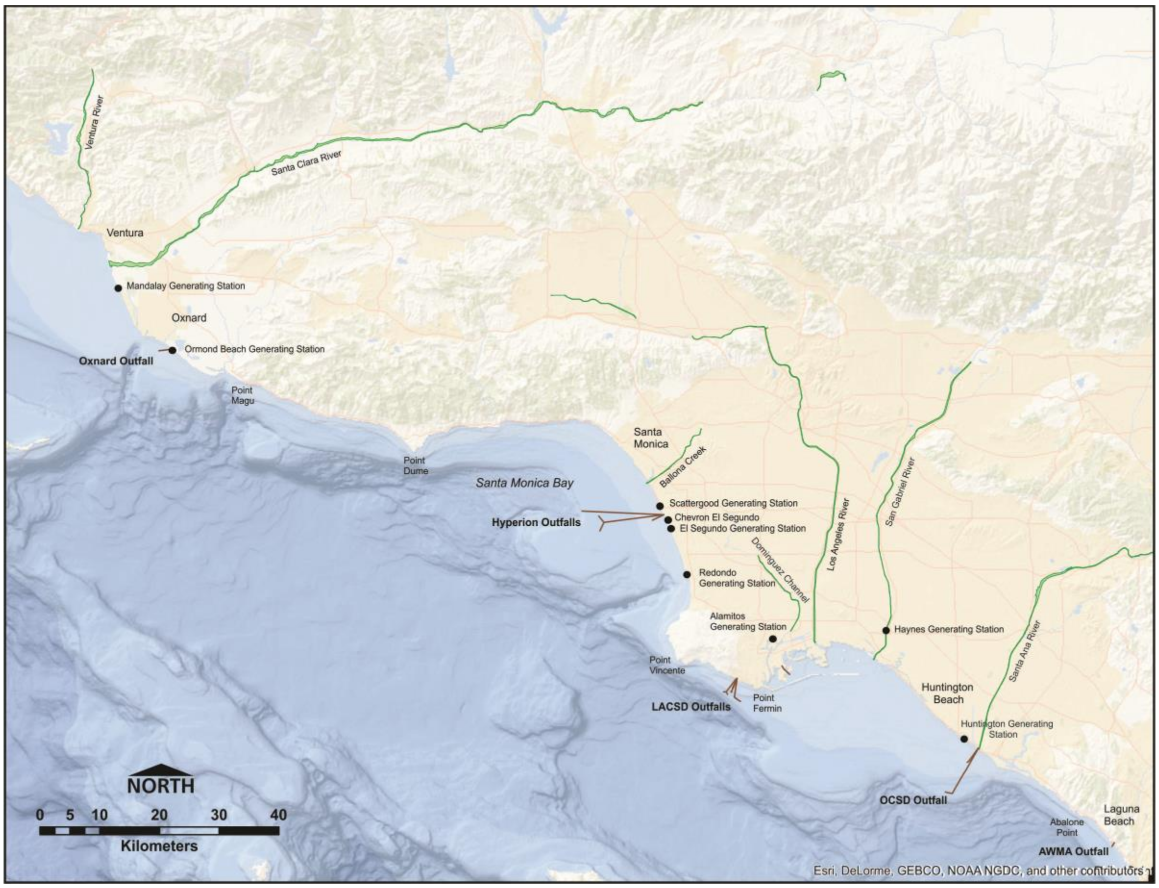


Figure 1. Ocean discharges located within the Central Region kelp survey area.

Figure 2. Ocean discharges located within the Region Nine kelp survey area.

HISTORICAL KELP SURVEYS 2003–2016

Estimated canopy coverages of each kelp bed for the period from 2003 to 2016 are presented in Tables 1 and 2. Information on the life history of giant kelp, and the factors affecting kelp growth and distribution, as well as information on the first surveys of giant kelp along the coast of southern California are presented in Appendix B.

Table 1. Canopy coverage (km^2) of the kelp beds from Deer Creek to Newport/Irvine Coast from 2003 through 2016. Areal estimates were derived from infrared aerial photographs. Red denotes warm-water years, blue denotes cold-water years, and neutral years are in black.

	Canopy Area (km^2)													
Kelp Bed	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Deer Creek	0.089	0.107	0.053	0.026	0.046	0.074	0.105	0.062	0.055	0.041	0.104	0.103	0.124	0.087
Leo Carillo	0.318	0.399	0.171	0.150	0.145	0.207	0.255	0.232	0.226	0.337	0.366	0.261	0.408	0.326
Nicolas Canyon	0.308	0.362	0.195	0.038	0.473	0.268	0.433	0.291	0.130	0.240	0.369	0.288	0.347	0.279
El Pesc/La Piedra	0.243	0.314	0.141	0.063	0.255	0.173	0.238	0.164	0.136	0.173	0.236	0.244	0.246	0.160
Lechuza	0.105	0.104	0.041	0.022	0.106	0.075	0.105	0.096	0.096	0.066	0.154	0.137	0.119	0.063
Total F&W 17	1.063	1.286	0.600	0.298	1.025	0.797	1.136	0.844	0.642	0.857	1.229	1.034	1.244	0.914
Pt. Dume	0.012	0.029	0.028	0.053	0.065	0.070	0.104	0.094	0.078	0.154	0.113	0.092	0.169	0.042
Paradise Cove	0.162	0.258	0.035	0.036	0.100	0.223	0.244	0.259	0.109	0.346	0.244	0.223	0.086	0.127
Escondido Wash	0.214	0.250	0.078	-	0.339	0.278	0.321	0.267	0.104	0.248	0.243	0.281	0.095	0.084
Latigo Canyon	0.125	0.161	0.032	0.007	0.186	0.124	0.195	0.142	0.070	0.202	0.133	0.212	0.052	0.057
Puerco/Amarillo	0.074	0.051	0.039	0.055	0.095	0.064	0.115	0.126	0.069	0.153	0.105	0.130	0.034	0.027
Malibu Pt.	0.011	0.013	0.008	0.008	0.016	0.011	0.012	0.066	0.074	0.084	0.060	0.039	-	0.035
Total F&W 16	0.598	0.762	0.220	0.158	0.801	0.769	0.991	0.954	0.504	1.189	0.897	0.976	0.436	0.372
La Costa	0.001	0.002	-	-	-	-	0.001	0.001	-	0.003	0.003	0.001	-	-
Las Flores	0.009	0.023	0.004	-	0.005	0.001	0.005	0.005	0.008	0.025	0.022	0.016	-	-
Big Rock	0.005	0.014	0.002	0.001	0.004	0.002	0.005	0.006	0.007	0.018	0.017	0.011	0.004	0.001
Las Tunas	0.003	0.018	0.004	-	0.008	0.005	0.019	0.015	0.007	0.030	0.029	0.012	0.004	-
Topanga	0.0002	0.002	0.0001	-	-	0.001	0.002	0.052	0.041	0.048	0.044	0.016	0.005	-
Sunset	-	-	-	-	-	-	0.004	0.008	0.007	0.008	0.010	0.010	0.010	0.015
Total F&W 15	0.017	0.059	0.010	0.001	0.017	0.009	0.035	0.087	0.069	0.131	0.123	0.064	0.022	0.017
Malaga Cove-PV Pt. (IV)	0.196	0.245	0.204	0.859	1.151	1.839	2.122	1.136	1.139	1.337	0.974	0.264	1.410	1.420
PV Pt-PT. Vic (III)	0.045	0.040	0.056	0.135	0.074	0.300	0.570	0.624	0.452	0.488	0.502	0.468	0.750	0.430
Total F&W 14	0.241	0.285	0.260	0.993	1.225	2.140	2.692	1.760	1.591	1.825	1.476	0.732	2.160	1.850
Pt Vic to Pt Insp (II)	0.059	0.023	0.034	0.082	0.034	0.108	0.163	0.222	0.238	0.295	0.279	0.224	0.379	0.366
Pt Insp to Cabr (I)	1.063	0.211	0.702	0.951	0.703	0.608	0.980	0.389	0.465	0.384	0.672	0.533	0.478	0.610
Cabrillo	0.062	0.070	0.102	0.161	0.100	0.060	0.163	0.124	0.103	0.095	0.174	0.158	0.133	0.235
Total F&W 13	1.184	0.304	0.838	1.194	0.837	0.776	1.306	0.734	0.805	0.774	1.124	0.915	0.990	1.210
Total PV	1.425	0.589	1.098	2.187	2.062	2.916	3.998	2.494	2.396	2.599	2.600	1.647	3.149	3.060
POLA-POLB Harbor	ND	ND	0.147	0.494	0.118	0.213	0.151	0.277	0.397	0.495	0.337	0.196	0.359	0.359
Horseshoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Huntington Flats	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Newport-Irvine Coast	0.002	0.002	0.000	0.023	0.054	0.089	0.095	0.161	0.419	0.395	0.428	0.366	0.045	0.036
Total F&W 10	0.002	0.002	0.147	0.517	0.172	0.302	0.246	0.438	0.816	0.890	0.765	0.561	0.404	0.395
TOTAL	3.105	2.698	2.075	3.161	4.076	4.793	6.406	4.817	4.427	5.665	5.614	4.283	5.255	4.757

ND = No Data: "-" = 0

Sources: Veisze et al. (2004); MBC (2004a-2012a, 2013-2016).

Table 2. Canopy coverage (km²) of the kelp beds from Laguna Beach to Imperial Beach from 2003 through 2016. Areal estimates were derived from infrared aerial photographs. Red denotes warm-water years, blue denotes cold-water years, and neutral years are in black.

Kelp Bed	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
N Laguna Beach	0.0004	-	-	-	-	0.002	0.005	0.093	0.147	0.192	0.142	0.120	0.080	0.074
S Laguna Beach	0.0002	0.008	-	-	0.001	0.025	0.058	0.098	0.221	0.214	0.273	0.165	0.048	0.035
South Laguna	0.004	0.009	0.003	-	0.004	0.023	0.017	0.023	0.018	0.017	0.038	0.031	0.016	0.006
Dana Pt/Salt Crk	0.303	0.278	0.123	-	0.302	1.068	0.892	0.839	0.442	0.607	0.835	0.528	0.137	0.110
Capistrano Beach	0.069	0.008	-	0.011	0.002	0.071	0.071	0.124	0.010	0.056	0.099	0.034	0.007	0.012
Total F&W 9	0.376	0.303	0.126	0.011	0.309	1.189	1.043	1.178	0.838	1.086	1.385	0.879	0.287	0.237
San Clemente	0.352	0.182	0.178	0.014	0.016	0.203	0.210	0.710	0.795	0.874	1.097	0.843	0.343	0.187
San Mateo Point	0.242	0.123	0.258	0.016	0.201	0.487	0.545	0.583	0.203	0.216	0.219	0.199	0.062	0.053
San Onofre	0.162	0.109	0.065	-	0.320	0.476	0.419	0.458	0.127	0.191	0.767	0.584	0.043	0.120
Total F&W 8	0.755	0.414	0.501	0.030	0.536	1.166	1.174	1.750	1.124	1.281	2.083	1.627	0.449	0.359
Horno Canyon	0.001	-	-	-	0.015	0.083	0.018	0.081	-	0.008	0.125	0.055	0.019	0.010
Barn Kelp	0.492	0.075	0.064	-	0.466	0.858	0.926	0.500	0.095	0.442	0.868	0.741	0.085	0.133
Santa Margarita	-	-	-	-	-	-	-	-	-	-	0.080	-	-	-
Total F&W 7	0.494	0.075	0.064	-	0.481	0.941	0.944	0.581	0.095	0.450	1.073	0.795	0.104	0.143
North Carlsbad	0.017	0.003	0.013	-	0.026	0.108	0.135	0.078	0.017	0.052	0.125	0.086	0.047	-
Agua Hedionda	0.002	0.001	0.008	-	0.016	0.080	0.092	0.031	0.022	0.046	0.102	0.065	0.016	-
Encina Power Plant	0.178	0.067	0.001	-	0.081	0.306	0.215	0.176	0.084	0.216	0.352	0.221	0.159	0.009
Carlsbad St. Bch	0.002	0.0001	-	-	0.064	0.121	0.127	0.069	0.024	0.058	0.178	0.065	0.061	-
Total F&W 6	0.199	0.070	0.023	-	0.187	0.615	0.569	0.354	0.147	0.372	0.757	0.437	0.282	0.009
Leucadia	0.185	0.048	0.001	0.016	0.233	0.421	0.429	0.215	0.119	0.232	0.541	0.279	0.414	0.033
Encinitas	0.050	0.016	-	0.002	0.205	0.346	0.205	0.128	0.124	0.260	0.231	0.112	0.113	0.009
Cardiff	0.202	0.045	-	0.004	0.286	0.484	0.520	0.213	0.395	0.459	0.590	0.299	0.318	0.024
Solana Beach	0.245	0.022	0.093	0.0003	0.457	0.823	0.505	0.328	0.504	0.442	0.606	0.504	0.316	0.138
Del Mar	0.030	-	-	-	0.037	0.057	0.044	0.038	0.074	0.024	0.056	0.027	0.034	-
Torrey Pines	-	-	-	0.010	-	0.001	0.0004	0.003	0.031	0.034	0.081	-	-	-
Total F&W 5	0.712	0.131	0.094	0.032	1.218	2.133	1.703	0.925	1.247	1.452	2.106	1.221	1.195	0.204
La Jolla F&W 4	3.444	1.029	0.873	0.117	2.750	4.145	2.274	2.776	2.565	1.569	4.006	2.790	2.968	0.927
Point Loma F&W 3&2	4.509	1.924	2.152	1.767	3.616	6.623	4.909	3.977	4.212	5.340	5.127	5.121	5.806	3.037
Imperial Beach F&W 1	0.083	0.191	0.400	0.400	1.493	1.895	0.861	0.004	0.152	0.333	0.526	1.183	1.576	0.217
TOTAL	10.572	4.136	4.233	2.358	10.591	18.706	13.476	11.545	10.379	11.882	17.064	14.053	12.667	5.134

"-" = 0; Tr = Trace <100 m²

Sources: MBC 1994-2003; 2004b-2012b, 2013-2016.

DESCRIPTION OF THE CENTRAL REGION KELP BEDS

The CRKSC program area extends from Ventura Harbor (also referred to as Ventura Marina) in Ventura County south to Abalone Point in northern Laguna Beach in Orange County, and recognizes 26 existing or historic kelp beds, including 3 (Sunset kelp, Horseshoe kelp and Huntington Flats kelp) that have been missing or greatly reduced since the first half of the 20th century (MBC 2004a–2012a). The kelp surrounding the breakwaters of the Ports of Los Angeles and Long Beach (POLA-POLB) was included in the CRKSC surveys upon realization in 2005 that considerable giant kelp was present in the Ports. One kelp bed, Sunset kelp (near Santa Monica), was reported as a very small bed during a 1989 survey (Ecoscan 1990), but it was not observed for several years following the initiation of surveys by the CRKSC in 2003. During the CRKSC surveys, despite the apparent presence of hard substrate offshore Will

Rogers State Beach Park, kelp at Sunset only has been observed at the submerged breakwater off the Santa Monica Pier since 2009. One other historic kelp bed (Newport/Irvine Coast, previously Corona del Mar) reappeared following restoration efforts, after absences of one to several decades resulting from a series of El Niño events in the 1980s and 1990s.

Horseshoe kelp bed likely was buried during excavations of the POLA-POLB from the 1920s to the 1950s and dumping of the sediment at that location (Schott 1976). Sunset kelp bed declined due to the apparent burial of suitable substrate by natural sedimentation processes (which occurred at several other kelp beds removed from population centers). The loss of the Huntington Flats kelp bed probably was the result of increased turbidity due to the extension of the Long Beach breakwater, and the dredging of Alamitos Bay and Sunset-Huntington Harbors. All three of these beds had substantial canopies prior to 1950. Large declines and subsequent recoveries are common occurrences in the historical record (especially if all of the quarterly surveys are compared). Drastic reductions may simply be short-term fluctuations that are of little importance to the long-term welfare of a kelp bed. If, however, the decline is persistent, more evaluation may be needed to clarify the cause(s).

Most kelp beds recognized by the RNKSC and CRKSC are within California Department of Fish and Wildlife's (CDFW's) administrative kelp bed lease areas that may include more than one giant kelp bed. The CRKSC and RNKSC programs identify these individual beds either using local names or geographical references for the name.

Administrative kelp bed areas in California waters are numbered and have associated commercial harvesting regulations in the California Fish and Game Code. The California Fish and Game Commission designated 87 geographical kelp beds along the California coast and Channel Islands. Each of the 87 kelp beds falls within specific designations that were designed for optimal harvest while ensuring sustainable management of the resource and the species that depend upon kelp (Figures 3 and 4). The administrative kelp beds are designated as closed, leasable, leased (from the state), or open. Closed beds may not be harvested. Leased beds provide the exclusive privilege of harvesting to the lessee, and open beds may be harvested by anyone with a kelp harvesting license. No kelp harvesting is allowed in Marine Protected Areas. In 2016, only one administrative kelp bed was leased in the CRKSC and RNKSC areas: Bed Number 3 at Point Loma. However, mechanical kelp harvesting has been proposed in Beds 17 (between Mugu Lagoon and Point Dume) and 18 (off Oxnard) (Mastrup 2015).

Giant kelp has been harvested commercially along the California coast since the early 1900s. Since 1917, kelp harvesting has been managed by the CDFW under regulations adopted by the California Fish and Game Commission. Regulations currently allow kelp to be cut no deeper than four feet beneath the surface, although the surface canopy can be harvested several times each year without damaging the kelp beds. Kelp harvesting licenses are required to take kelp for commercial use. Kelp beds can be leased for up to 20 years; however, no more than 25 square miles or 50% of the total kelp bed area (whichever is greater) can be exclusively leased by any one harvester.

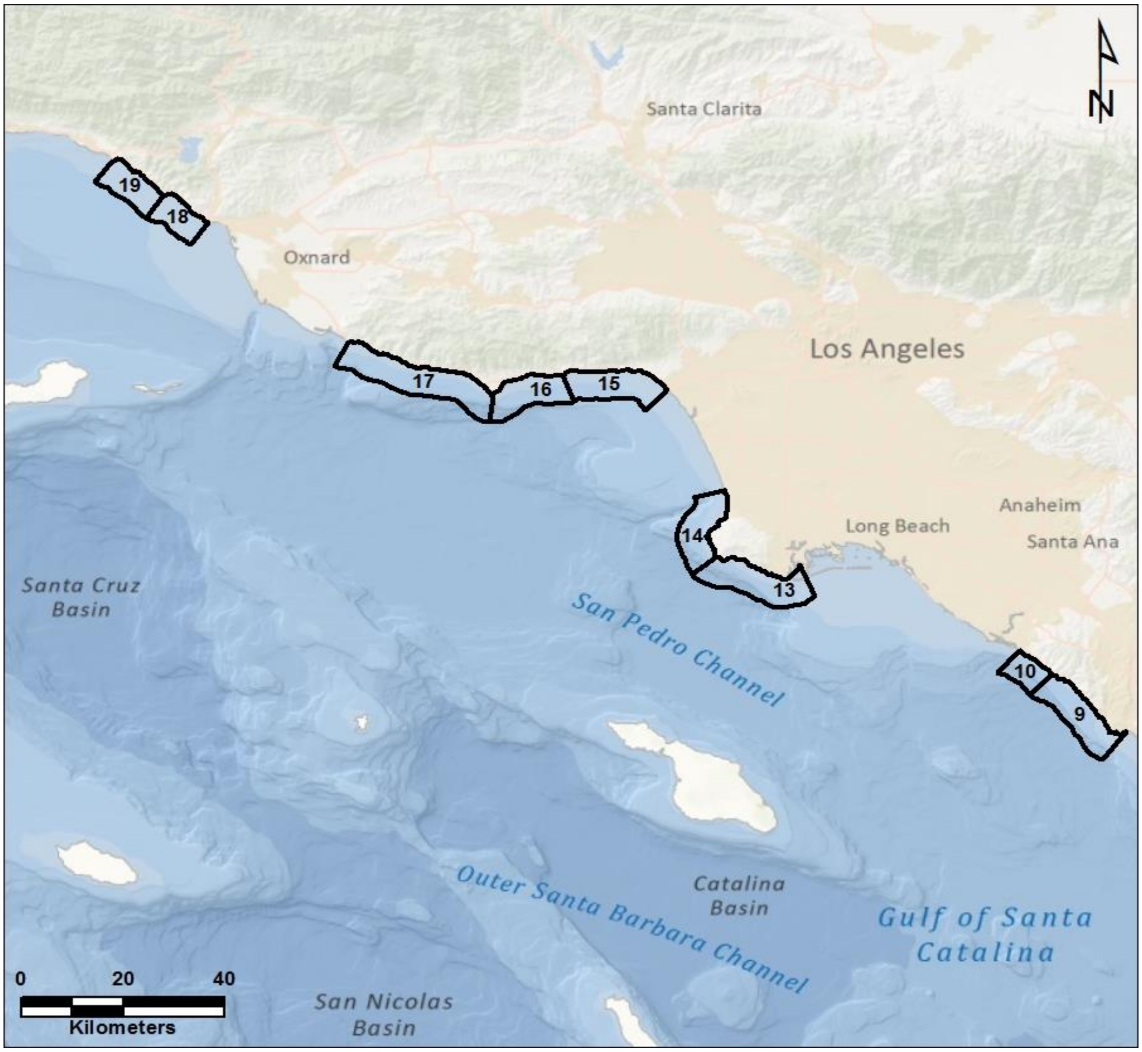


Figure 3. Administrative kelp bed leases in the Central Region study area. Beds 18 and 19 are upcoast from the CRKSC study area, and therefore not addressed in this report

Many of the kelp studies between 1911 and 1989 consolidated all local kelp beds into the CDFW Kelp Bed designations, making it difficult to discern patterns of specific sub-areas within the much larger CDFW lease areas. For example, CDFW Kelp Bed (lease area) No. 17 encompasses over 10 kilometers of coastline. Therefore, natural breaks in the beds were determined (as noted by either Crandall's 1911 survey or Ecoscan's 1989 survey) and assigned names that describe the location based on nearby canyon names, prominent features, or other local names in use. Descriptions of each CDFW kelp bed are provided in previous CRKSC reports (e.g., MBC 2014).

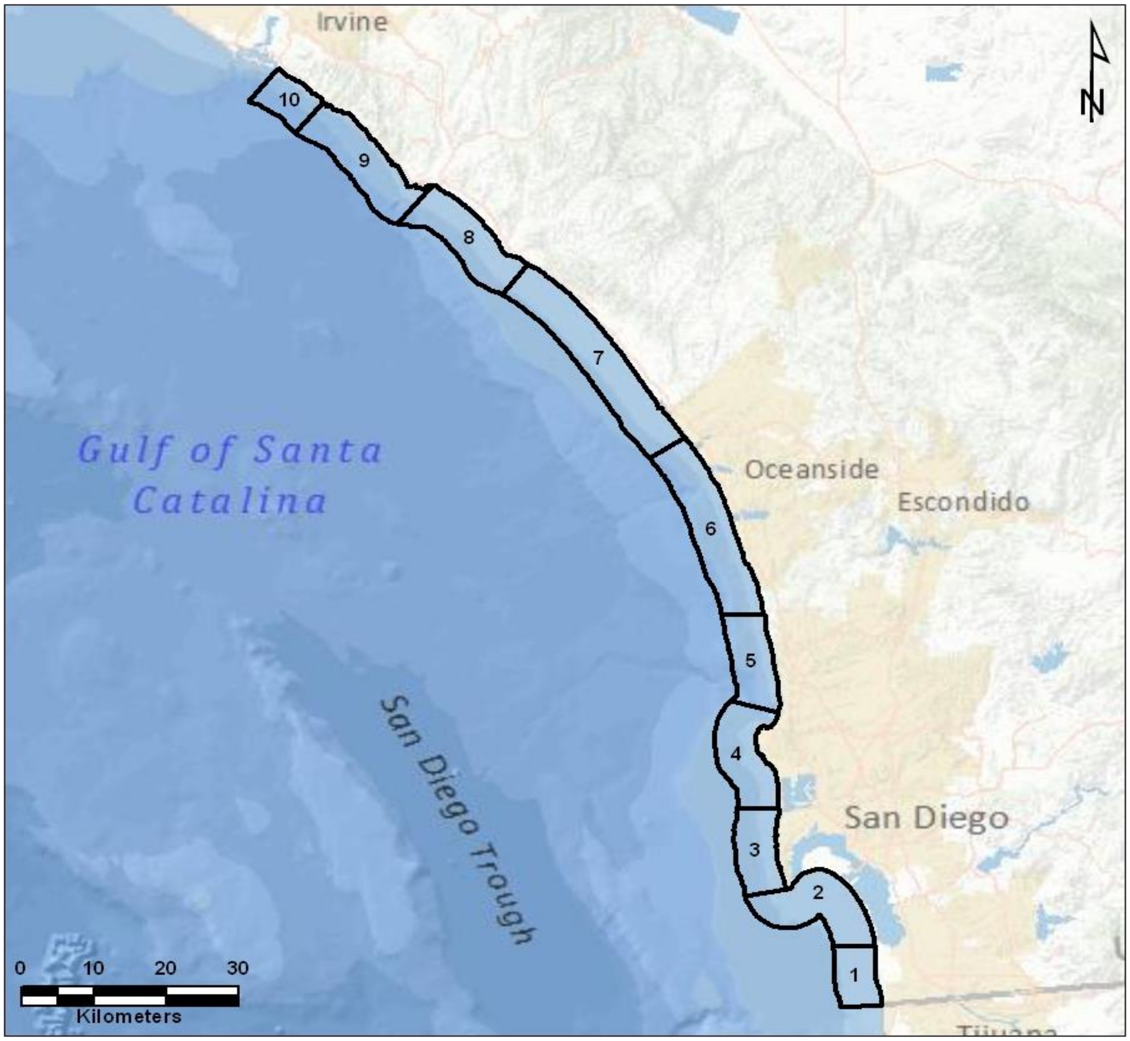


Figure 4. Administrative kelp bed lease areas in the Region Nine study area.

DESCRIPTION OF THE REGION NINE KELP BEDS

In the Region Nine kelp survey area, between Abalone Point in Laguna Beach (Orange County) and the U.S./Mexico Border to the south, the CDFW recognizes just 10 administrative kelp bed lease areas (Figure 4). In this same area, MBC has identified 26 kelp beds: 22 that are persistent and two other beds that appear ephemerally (Santa Margarita and Torrey Pines), and two that historically have been absent (Horseshoe and HuntingtonFlats), as well as four other areas of interest (marinas and small boat harbors) (MBC 1994–2003, 2004b–2012b, 2013-2016). The Consortium's monitoring began following a strong El Niño in 1982–1984, and this was followed by a very strong La Niña cold-water event in 1989–1990. Due in part to the impetus provided by this La Niña, all 24 of the kelp beds that have supported kelp in the last half of the 20th century were displaying canopy in 1991. Descriptions of each CDFW kelp bed are provided in previous RNKSC reports.

Region Nine supports what are usually the two largest kelp beds in southern California: the La Jolla, and the Point Loma kelp beds. Rocky substrate is prevalent offshore of La Jolla, and it supports giant kelp beds to a depth of at least 27 m. Sand predominates from Pacific Beach downcoast past Mission Bay, and there is very little hard substrate. Downcoast of Mission Bay, rocky substrate emerges and giant kelp can be found out to at least 30 m during favorable years. The Point Loma kelp bed extends along the length of the peninsula. About two kilometers downcoast from the entrance to San Diego Bay, sand is the dominant substrate, and this habitat continues to about the Imperial Beach Pier. There is a group of low-lying, mostly cobble reefs, from just upcoast and offshore of the Imperial Beach Pier to the international border, and out to a depth of 20 m. According to Crandall's 1912 survey map, a medium-density kelp bed at Imperial Beach extended past the border and several nautical miles into Baja California.

MATERIALS AND METHODS

Environmental Data. Oceanographic data from shore stations, data buoys, and thermistor strings were used to determine potential effects on kelp bed extent during the study year. These data sources included:

- Water temperature data from automated stations at Santa Monica Pier, Newport Pier, and Scripps Pier. At these locations, automated samplers measure conductivity, temperature, and fluorometry every one to four minutes. Samplers are mounted at a depth of 2 m Mean Lower Low Water (MLLW) at Santa Monica and Newport Piers, and at 5 m MLLW at Scripps Pier. These data are made available in real time via the Southern California Coastal Ocean Observation System (SCCOOS) website (www.sccoos.org).

- Water temperature data were provided by Los Angeles County Sanitation Districts from offshore monitoring stations on the Palos Verdes Peninsula (Stations PVS and PVN). Both stations are located at a depth of 23 m, with sensors at the surface and depths of 2 m and 11 m MLLW.

- Water temperature data also were provided by City of San Diego, Public Utility, Marine Biology and Operations, Point Loma, CA, from a thermistor string approximately 3.8 km west-northwest of Point Loma in 60 m of water (City of San Diego 2017). Sensors were placed at four-meter intervals from near the sea surface to a depth of 54 m MLLW.

- Water temperature data from the National Data Buoy Center (NDBC) Point Loma South and Point Dume are available in real time via the NDBC website (www.ndbc.noaa.gov). These data buoys record water temperature, and wave height, period, and direction every 30 minutes from approximately one meter below the waterline.

- Sea and swell height data from Coastal Data Information Program (CDIP) data buoys located off Ventura (Anacapa Passage), San Pedro, Oceanside, and Point Loma are available in real time via the CDIP website (cdip.ucsd.edu).

- Harmful Algal Bloom (HAB) data are available in real time for several locations via the SCCOOS website (www.sccoos.org).

Kelp Data Collection-Aerial Surveys. Beginning in the early-1960s, the surface area of coastal kelp beds was calculated by aerial photography by the late Dr. Wheeler J. North of the California Institute of Technology, and later by MBC using a methodology that followed that of Dr. North's, because it provided a consistent approach to determining kelp bed size (North 2001). MBC has used this methodology for the Region Nine surveys since inception of the program in 1983, and for surveys for the CRKSC since initiation in 2003.

Direct downward-looking photographs of the kelp beds were taken from an aircraft modified by Ecoscan Resource Data to facilitate aerial photography. Approximately 400 high-contrast digital color and infrared photos are taken during each survey. Ecoscan conducted quarterly overflights of the coastline for the Consortium from Ventura Harbor (Ventura County) to the U.S./Mexico border (Appendix D). Overflights were targeted as close to quarterly as possible. Due to prevailing weather conditions, it is not always possible to conduct them in the targeted months and, at times, multiple attempts are necessary to conduct the four quarterly surveys.

Prior to each survey, the flight crew assesses the weather, marine conditions, and sun angle to schedule surveys on optimum dates. The pilot targets the following:

- Weather: greater than a 15,000' ceiling throughout the entire survey range and wind less than 10 knots,
- Marine: sea/swell less than 1.5 m and tide less than +1.0' MLLW, and
- Sun angle greater than 20 degrees from vertical.

Kelp Data Analysis. All photographs were reviewed after each overflight and the canopy surface area of each kelp bed was ranked in size by subjectively comparing them to the average historical bed size and to each quarterly survey. The ranking scale ranged from 0.5 for minimal kelp, 1 for well below average, 2 for below average, 2.5 for average, 3 for above average, and 4 for well above average (Tables 4 and 5). Such ranking allows the archiving of the quarterly survey slides for later retrieval and assembly of a digitized photo-mosaic of each kelp bed that represents the greatest areal extent for each survey year. Individual beds in the composite were selected for detailed evaluation and the surface area of all visible kelp canopies in each distinct kelp bed was calculated.

All digital photographs from one of the four surveys that showed the greatest areal coverage were digitally assembled into a composite photo-mosaic that provided a regional view of whole kelp bed areas. If all of the kelp beds displayed the most canopy during a single survey, then the photographs from that survey would be used in the photo-mosaics. However, this rarely occurs. Data from one or two surveys usually are used to make the mosaics in order to provide a realistic estimate of the maximum canopy cover at any time (usually within about three months) during the year. The Photoshop mosaics were then transferred to Geographic Information System (GIS; ArcGIS 10.3.1) to geo-reference them, and to place them into specific CDFW geo-spatial shape files. Each mosaic was geo-referenced to match several prominent features (usually more than three) on the map and converted to Universal Transverse Mercator (UTM) or other acceptable coordinate system, and ultimately converted to a geo-referenced JPEG file. Surface canopy areas were calculated using the image classification function, an extension to the ArcGIS program. The kelp beds from the photos were then layered on standard base maps to facilitate inter-annual comparisons. The “Hard Substrate” layer on the base maps was obtained through the CDFW Biogeographic Information and Observation System.

The “Average Bed Area Per Year” (ABAPY) was plotted with results from individual beds to compare canopy sizes and patterns of growth/decline to averages for particular regions. Those regions were: the northern and central portions of the Central Region (upcoast from Palos Verdes); the area from Malibu Point to Sunset; Orange County; and San Diego County (excluding La Jolla and Point Loma). Kelp beds off Palos Verdes, La Jolla, and Point Loma were treated separately because they are typically larger beds and react differently than the other beds within their regions. Each ABAPY was calculated by summing the annual canopy estimates for the relevant beds during each year, and dividing the total by the number of beds included.

Vessel Surveys. Once per survey year, typically targeted in December, a vessel survey is conducted of all of the Region Nine kelp beds. Due to persistent large swells that forced delays (Figures 13 and 14), the vessel survey for the 2016 survey year was conducted from Imperial Beach to San Onofre on March 13, 2017, and from San Mateo Point to Newport Harbor on

March 29, 2017. The same issue occurred during the 2015 survey year and the vessel survey was conducted in February 2016 (MBC 2016). During each vessel survey, biologists visually located the main canopies (or during poor years by latitude and longitude coordinates of the last remaining canopy) and determined the depth of the inshore and/or offshore edge of the kelp beds. Once located, there was a focused examination of kelp health that included documentation of:

- Extent and density of the bed;
- Tissue color - tissue colors range from pale yellow (indicating poor nutrient uptake) to dark brown (indicating good nutrient intake);
- Frond length on the surface;
- Presence/absence of apical meristem (scimitar = growing tips);
- Extent of encrustations of hydroids or bryozoans;
- Sedimentation on blades;
- Any evidence of disease - holes or black rot; and
- Composition of fronds - young, mature, or senile.

During the vessel survey, two or three beds usually are selected for focused biologist-diver surveys. Typically, these surveys investigate apparent causes of a bed’s atypical condition (where it disappeared or was greatly reduced) during a period when closely aligned regional beds were increasing. For example, a persistent hole in the San Mateo kelp bed was investigated and urchin grazing was found to be the cause.

RESULTS

WATER TEMPERATURES AND NUTRIENTS

Temperatures at the sea surface (SST) are a useful surrogate for nutrient availability (water temperature is inversely related to nutrient availability). Additionally, there appears to be good evidence that seawater density can be used as a surrogate, and in some cases, may predict nutrient availability better than temperature. However, long-term measurements of density on smaller scales than the SCB have not been available in the past. In contrast, nearshore temperature measurements have been ongoing for decades, resulting in readily accessible data sets. Two temperature/nutrient indices—one for each region—are presented in Figures 5 and 6. Based on the monthly Nutrient Quotient (NQ) Index described by North and MBC (2001), the average, early-morning SST at each station was correlated with the amount of nitrate that is theoretically available for uptake by kelp (in micrograms-per-gram per-hour) (Haines and Wheeler 1978; Gerard 1982).

The value for each month was summed for the indexed year. For example, a month with an average temperature of 14.5°C has an NQ value of 4, while a temperature of 12°C corresponds to a value of an NQ value of 14. This method allows for an inter-annual comparison of the nutrients available to kelp, making it possible to pinpoint those years when nutrients were abundant or depleted, and to establish possible temporal trends. Sea surface temperatures from Point Dume, Santa Monica Pier (SM Pier), Newport Pier, San Clemente Pier (SC Pier), Scripps Pier in La Jolla, and the Point Loma South CDIP buoy were used to determine the theoretical availability of nutrients in the region. Graphs of SSTs at all of these locations are presented in Appendix C.

In general, southern California waters were warmer than average from January through March 2016, and then temperatures fluctuated above and below average from April through December (Figures 7 through 9). Upwelling was average for the region, although spring upwelling was lower than normal (Figure 10). Chlorophyll a values from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area off southern California were among the lowest on record from July 2014 through July 2016 (McClatchie et al. 2016).

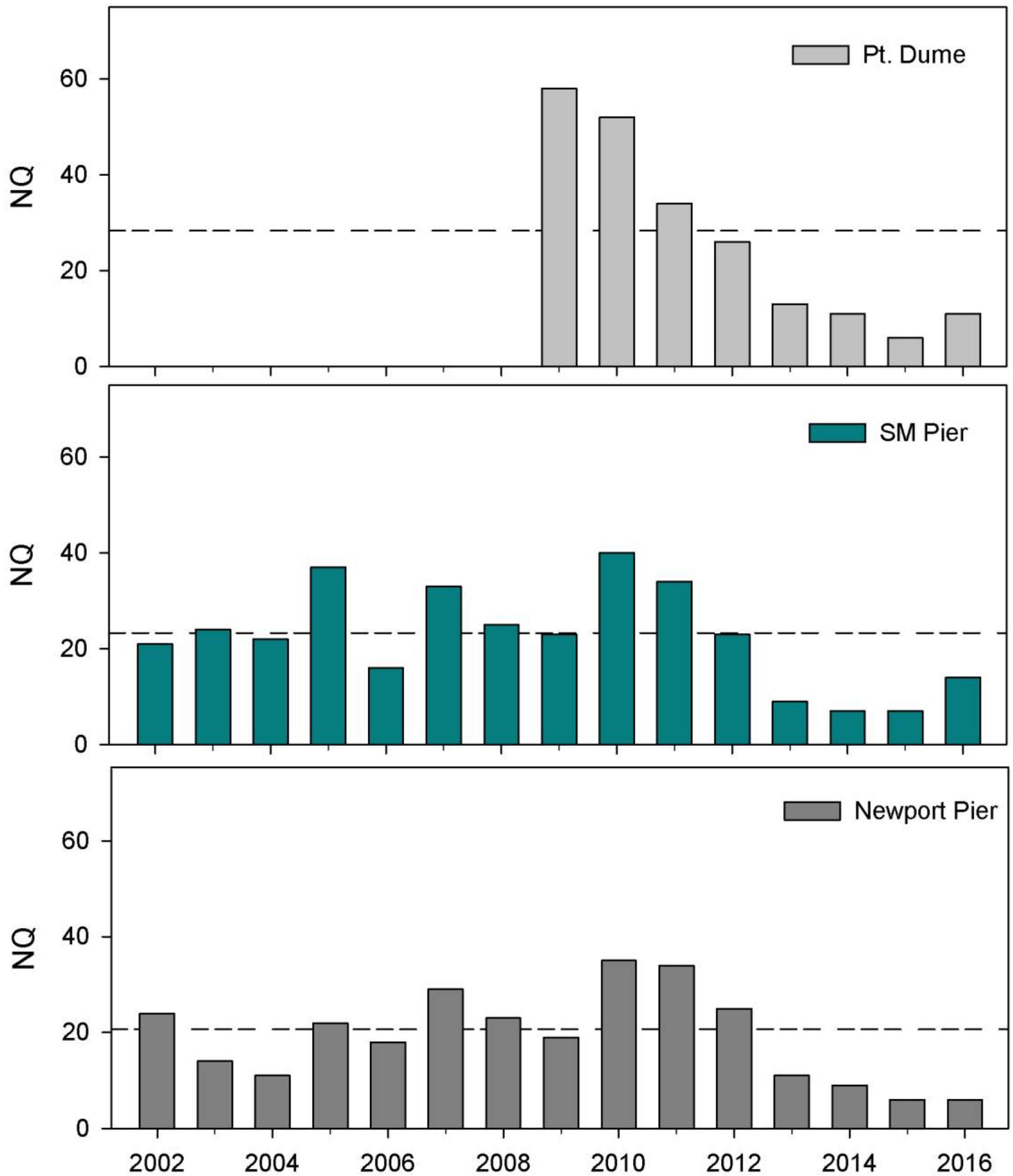


Figure 5. Nutrient Quotient (NQ) values in the Central Region, 2002–2016. "NQ values are calculated from SSTs collected from these locations: Point Dume (Pt. Dume), Santa Monica Pier (SM Pier), and Newport Beach (Newport Pier). Dashed line is the mean NQ for the years shown.

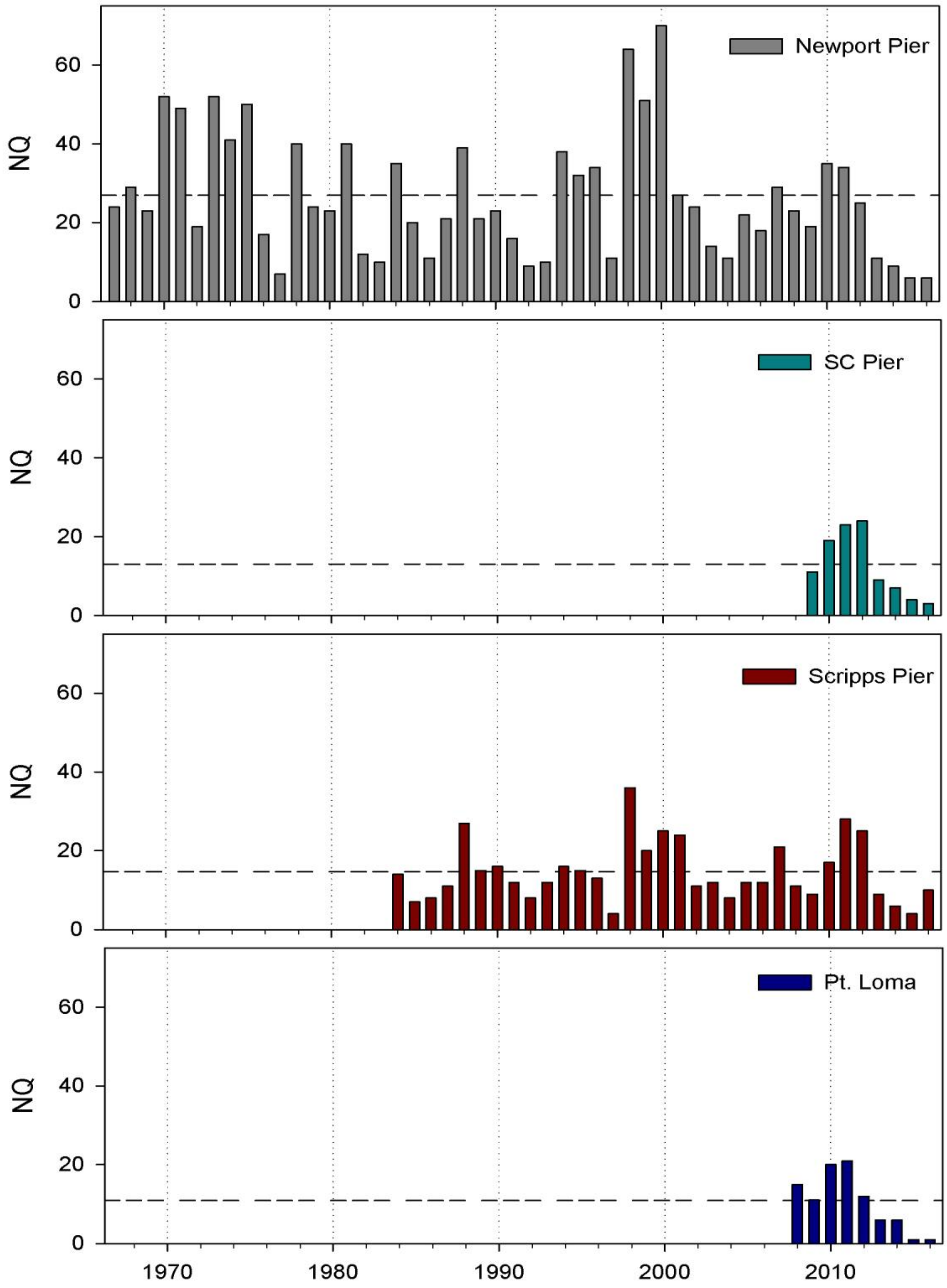


Figure 6. Nutrient Quotient (NQ) values in Region Nine, 1967–2016. NQ values are calculated from SSTs collect at these locations: Newport Beach (Newport Pier), San Clemente Pier (SC Pier), Scripps Pier (La Jolla) and the Point Loma South CDIP Buoy (Pt. Loma). Dashed line is the mean NQ for the years shown.

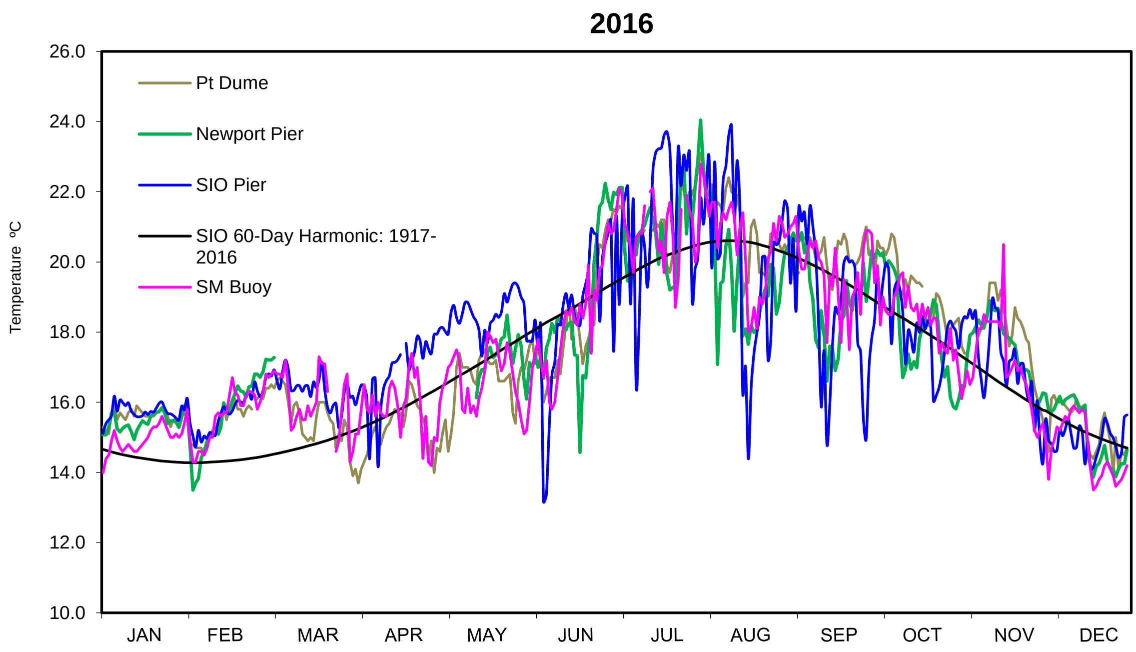


Figure 7. Daily sea surface temperatures (SSTs) at Point (Pt.) Dume, Santa Monica (SM) Pier, Newport Pier, and Scripps (SIO) Pier for 2016, and the long-term (1917-2016) harmonic mean from SIO Pier.

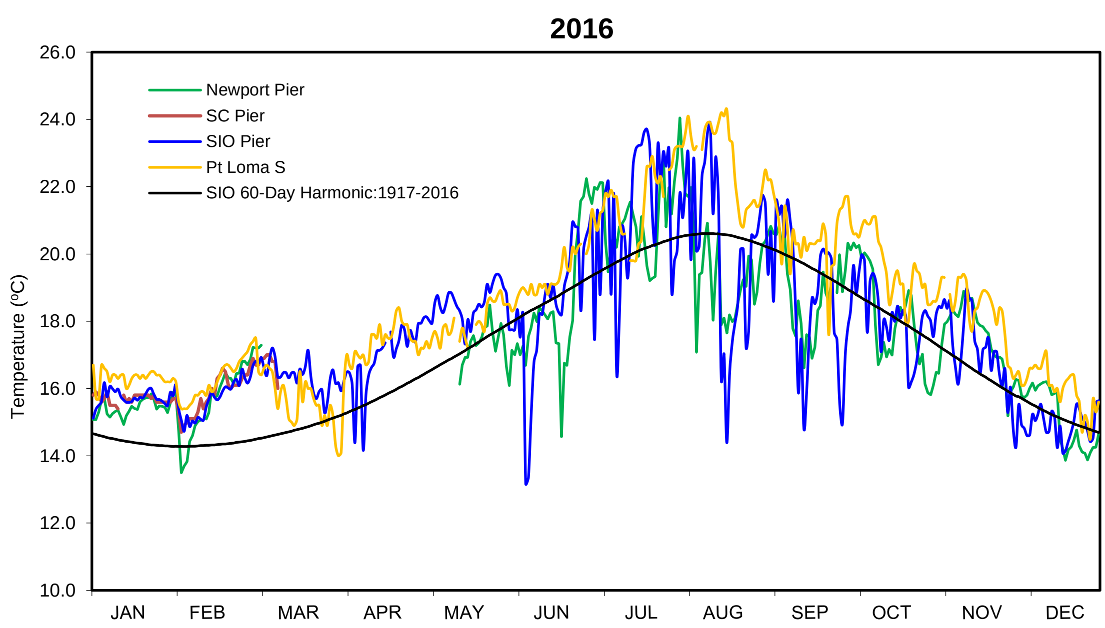
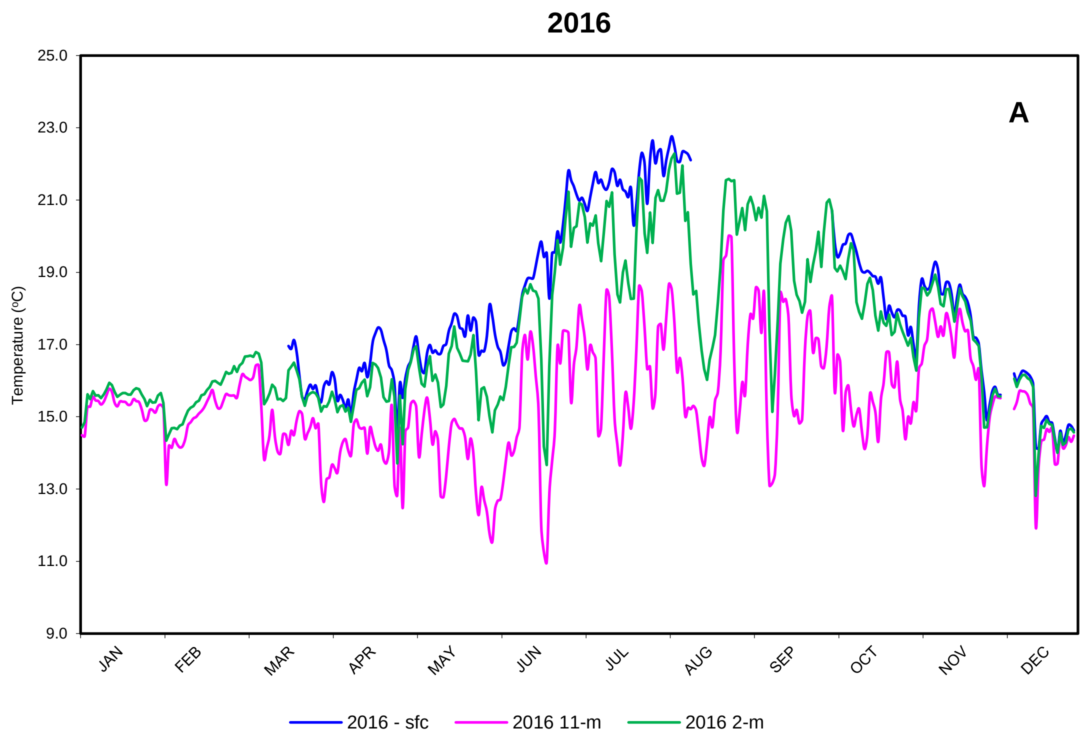


Figure 8. Daily sea surface temperatures (SSTs) at Newport Pier, San Clemente (SC) Pier, Scripps (SIO) Pier, and Point (Pt.) Loma South (S) for 2016, and the long-term (1917-2016) harmonic mean from SIO Pier.



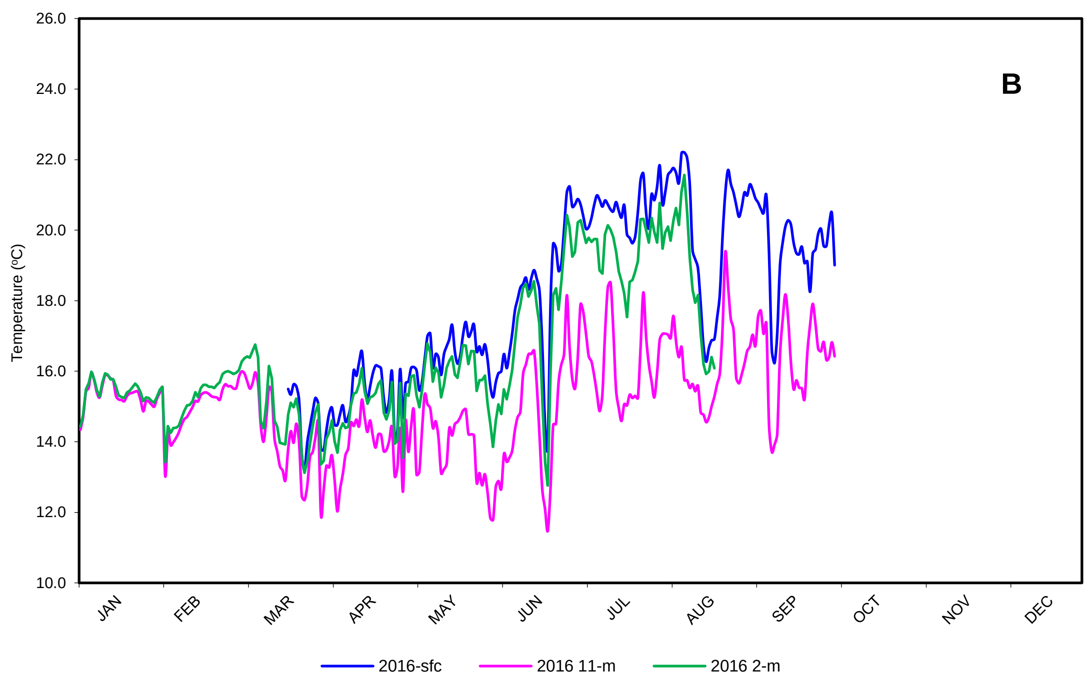


Figure 9. Daily sea surface temperatures (SSTs) off Palos Verdes at (A) Station PVN and (B) Station PVS in 2016. Source: LACSD (2017).

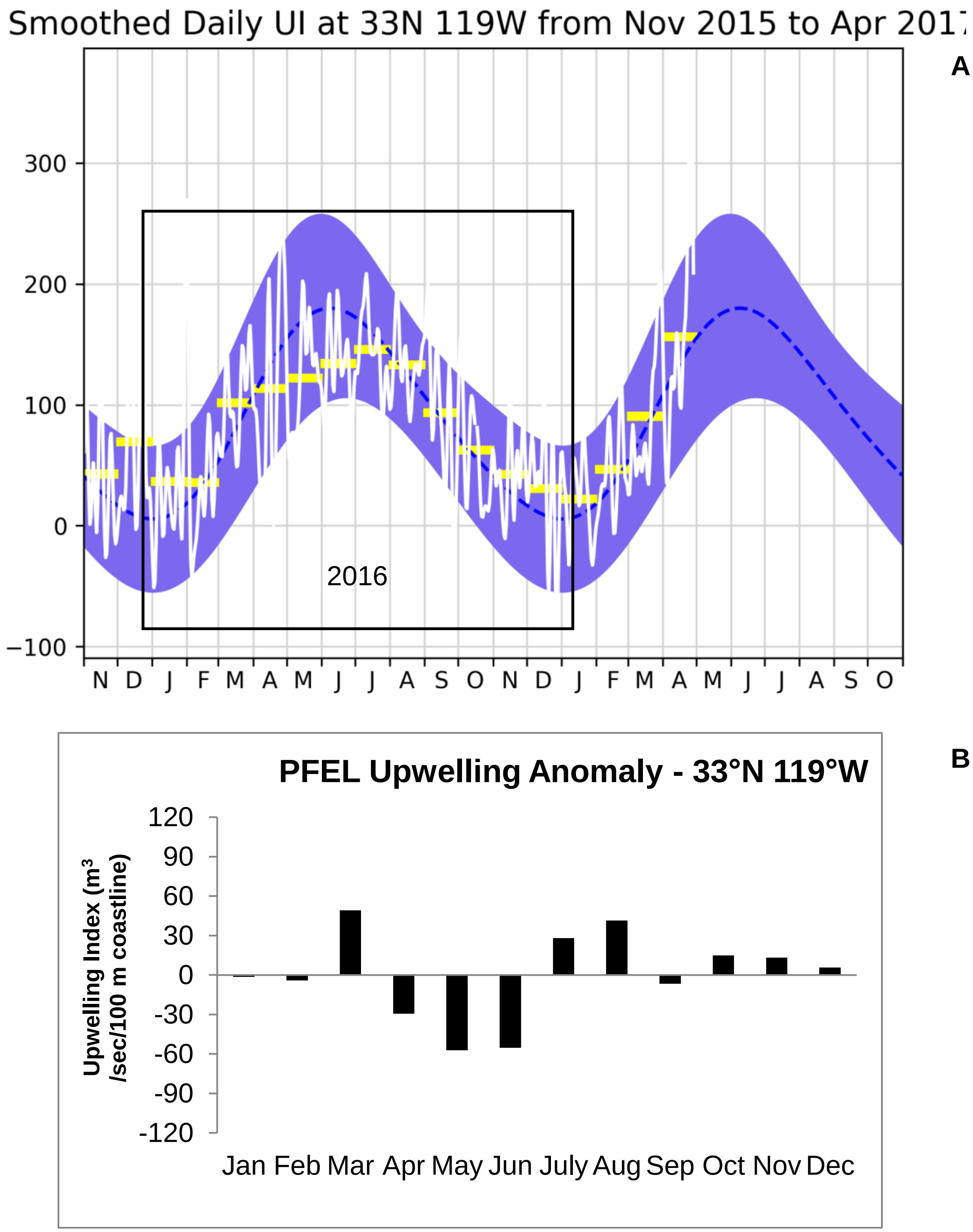


Figure 10. (A) Daily Upwelling Index (UI) at 33°N 119°W. The dashed curve is a smoothed biharmonic fit to the daily UI from 1967–1991. The purple area represents one standard error, and the yellow bars are monthly means. Units are cubic meters per second per 100 meters of coastline. (**B) UI anomaly at 33°N 199°W (2016) compared to the 70-year monthly mean from 1946–2015).** Source: (NOAA PFEG 2017).

Water temperatures in southern California were warmer than average from January through March, and from August through December. However, there were multiple periods of cold-water influx (likely from upwelling) from April through September. Estimated upwelling and upwelling anomaly values from a location approximately 161 km west of Solana Beach are presented in Figure 10. Upwelling was most pronounced at the Scripps and Newport Piers during this period, and less so at Point Loma, San Clemente, and Point Dume. Region-wide upwelling was calculated to be above average during six months (March, July, August, October, November and December), and below average for six months (January, February, April, May, June and September) (Figure 10).

Sea surface temperatures were warmer than average from August 2015 through March 2016. Steep declines in temperature occurred from April through September, but SSTs were mostly above average in both regions in June, July, and August, and periodically thereafter. The 2015 and 2016 NQ values at most stations in both regions were among the lowest on record during 2015 and 2016 (Figures 5 and 6). Coolest SSTs were recorded in February at Newport Pier (13.5°C), in June at Scripps Pier (13.2°C), and in December in Santa Monica Bay (13.5°C) (Figures 7 and 8). The NQ at Santa Monica Pier was the lowest on record (Figure 5).

Two temperature monitoring stations were located off the Palos Verdes peninsula (Figure 9): Station PVN was in the northern section near Lunada Bay, and Station PVS was in the southern end at Royal Palms. Both stations are at a depth of 23 m. At a depth of two meters, temperatures were similar (within 2°C) between the two stations from January through May 2016. Beginning in June, temperatures were up to 5°C higher at Station PVS than at Station PVN, highlighting the difference in oceanographic conditions at relatively close locations at Palos Verdes. By August, the temperatures at PVS were up to 8°C higher than at PVN. There were periods of cool-water influx throughout the year at Palos Verdes (Figure 9). At a depth of 11 m, there were decreases of 2–3°C per day during several months, particularly from June through December.

At the juncture of the Central Region and Region Nine, SSTs at Newport Pier were generally well above average in January and February, and from May through July (Figures 7 and 8). Data were not available for March and April. From August through December, temperatures varied from above to below average at an inconsistent interval (Figures 7 and 8). The NQ value of 6 at Newport Pier in 2015 and again in 2016 was the lowest value recorded since 1992–1993 (Figure 6). Newport Pier is located near the mouth of Newport Canyon, and strong upwelling usually occurs in distinct pulses at this location.

Data from San Clemente Pier, in the mid-section of Region Nine, were only available for the first two and a half months of 2016, but were above average during that period (Figure 8). The SSTs at Scripps Pier were the most variable in Region Nine in 2016, with marked upwelling events from April through September. The southern portion of Region Nine was tracked by the Point Loma South buoy, and by a thermistor string deployed off Point Loma by the City of San Diego, Public Utility, Marine Biology and Operations group (City of San Diego 2017) (Figure 11). Similar to previous years, variability in Point Loma SSTs was muted in comparison to that at the Scripps and Newport Piers. However, the Point Loma South buoy is farther offshore than the other stations, and is moored at a water depth of 1,100 m.

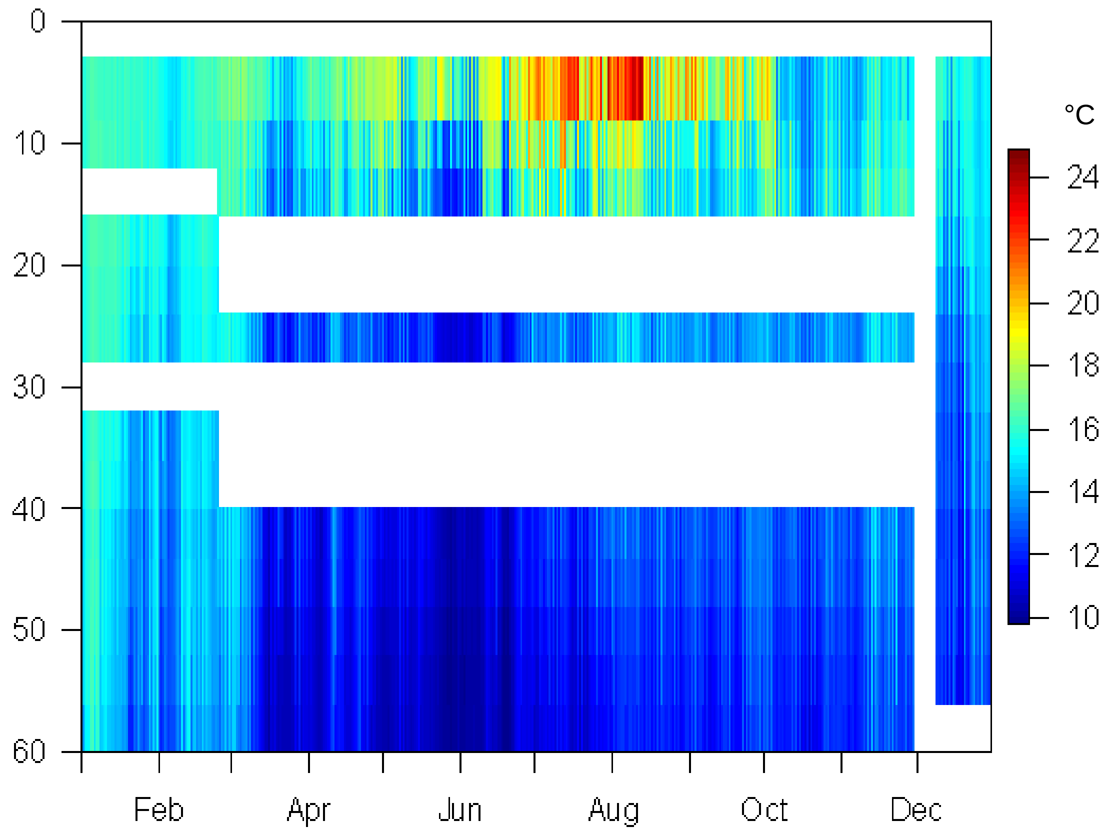


Figure 11. Temperatures (°C) throughout the water column (near surface to a depth of 60 m) off Point Loma during 2016. White bars indicate no data available. Source: CSD (2017).

The long-term average NQ values at Scripps Pier (15), Point Loma South (11), and San Clemente Pier (13) were relatively low compared to those at Newport Pier (27) and Santa Monica Bay (24), and suggested nutrient availability was comparatively low at the kelp beds from San Clemente to San Diego (Figure 6). The NQ values in Region Nine were below average at all stations from 2013 through 2016. The long-term average NQ at Newport Pier (1967–present) was substantially higher than at the other stations, and highlights the variability of nutrient supply in southern California from year to year. The nutrient climate shifted from waters with sufficient nitrate prior to the 1976–1977 regime shift, to depleted conditions afterward (Parnell et al. 2010). The response of giant kelp beds to nutrient replete years before the regime shift was dampened compared to their response afterward. The sensitivity of kelp canopies to nutrient limitation appears to have increased after 1977, and this intensification of physical control (as opposed to biological control) after 1977 is evident in the strong correlation of seawater density (δ_t) and density of giant kelp (Parnell et al. 2010).

Seawater density (δ_t) values were calculated from available temperature, salinity, and pressure data at Newport Pier (www.sccoos.org/data/piers). Density values were mostly <25 kg/m^3 throughout the year, but highest values (>24.5 kg/m^3) were reported in February, June, and during several days from September through December. Densities were variable the second half of the year, but trended upward through December. Because these data were collected near the sea surface, they are likely not indicative of densities on the sea floor. However, they are useful in highlighting seasonal variability in seawater density.

The NQ index recorded during the 1997–1998 El Niño indicated a particularly bad year for kelp beds in the SCB. During that season, NQ values ranged from 3 to 11. In contrast, during 1988–1989 (a year in which kelp beds reached their maximum extents in several decades) NQ values ranged from 27 to 39 (Figure 6). The NQ values at all stations in both regions were above average in 2012–2013, but below average each of the last three years. Values throughout the region in 2016 ranged from 1 to 14. The variability in SSTs and nutrients is driven by prevailing flow characteristics and bathymetric features that result in periodic upwelling along the rocky shores of the coastline, particularly from Deer Creek to Point Dume, along the Palos Verdes Peninsula, and at the Dana Point, La Jolla, and Point Loma kelp beds.

INDICES

The Multivariate ENSO Index (MEI) and the Pacific Decadal Oscillation (PDO) changed phase about the same time; the MEI transitioned from negative to positive in April 2014, and the PDO went positive in January 2014 (Figure 12; Mantua 2017; and NOAA-ESRL 2017). The MEI transitioned back to negative in September 2016, but the PDO remained positive. The North Pacific Gyre Oscillation (NPGO) changed from positive to negative in October 2013, and has stayed negative for most of the time since then, although it was positive for five months in 2016 (Di Lorenzo 2017). All three indices changed phase at some point during the winter of 2013/2014. The MEI changed to positive, signaling the pending arrival of an equatorial El Niño. Based on peak MEI value in August–September 2015, the 2015–2016 El Niño was the third largest since 1950. The PDO transition indicated warmer temperatures in the North Pacific, while the NPGO transition was indicative of lower productivity along the coast (Di Lorenzo et al. 2008; Leising et al. 2015).

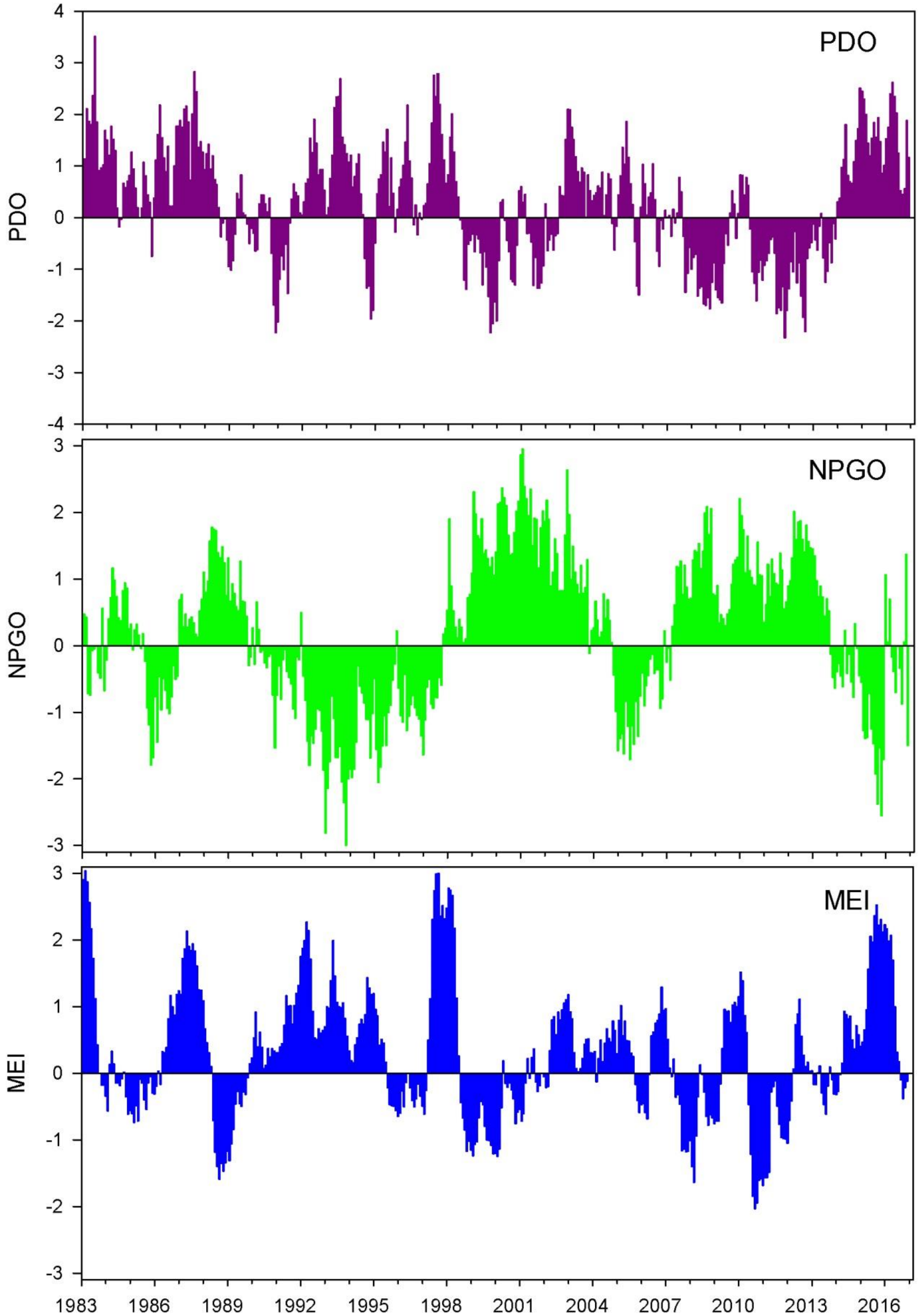


Figure 12. The PDO, NPGO, and MEI from Jan. 1983–Dec. 2016. Data from Di Lorenzo (2017), Mantua (2017) and NOAA-ESRL (2017).

WAVE HEIGHTS

Typical swell sizes and directions were observed through most of 2016. At the upcoast portion of the region near Port Hueneme (Anacapa Passage), waves approached from the west to southwest about 85% of the time (Figure 13). Off San Pedro, waves originated out of the west about 60% of the time, the southwest 15% of the time, and the south about 20% of the time (Figure 13). Offshore of Point Loma, waves were from the south (20%), southwest (25%), and west (55%) (Figure 14).

High-energy waves that negatively affect kelp beds usually are low-frequency, high-amplitude waves approaching from the west. Significant wave heights (H_s) at Anacapa Passage (CDIP Buoy 111 off Ventura) exceeded four meters on February 1 and March 8, 2016 (Figure 13). At the San Pedro Bay Buoy (092), H_s exceeded five meters on February 1, and three meters on several other days. Gale force winds and minor rainfall (<0.25 inch) coincided with high waves January 31 and February 1. At Oceanside (CDIP Buoy 045), wave heights exceeded five meters on February 1, but the data stream ended in late-October (Figure 14). Off Point Loma (CDIP Buoy 191), wave height reached 5.9 m (19 ft) on February 1 (Figure 15). Wave heights at Point Loma exceed four meters on March 8 and April 26. The large swell on January 31 and February 1 originated from the northwest, and was so large that the island shadow effect still resulted in large nearshore waves (Figure 15). Large waves on March 8 originated from the west-northwest (Figure 16). Large swells become breaking waves as they approach shallow coastal waters and can rip loose kelp holdfasts and cause the loss of entire kelp beds (as recorded at La Jolla and Point Loma during several large storms) (Seymour et al. 1989).

RAINFALL AND PHYTOPLANKTON

Periods of sustained high turbidity in southern California waters often result from high rainfall; however, rainfall was well below average for the sixth straight year in Los Angeles and Orange Counties (Figure 17). Therefore, turbidity from storm runoff did not likely play an important role in kelp health last year. Rainfall totals varied by location, with more rain in San Diego than in Costa Mesa and Los Angeles.

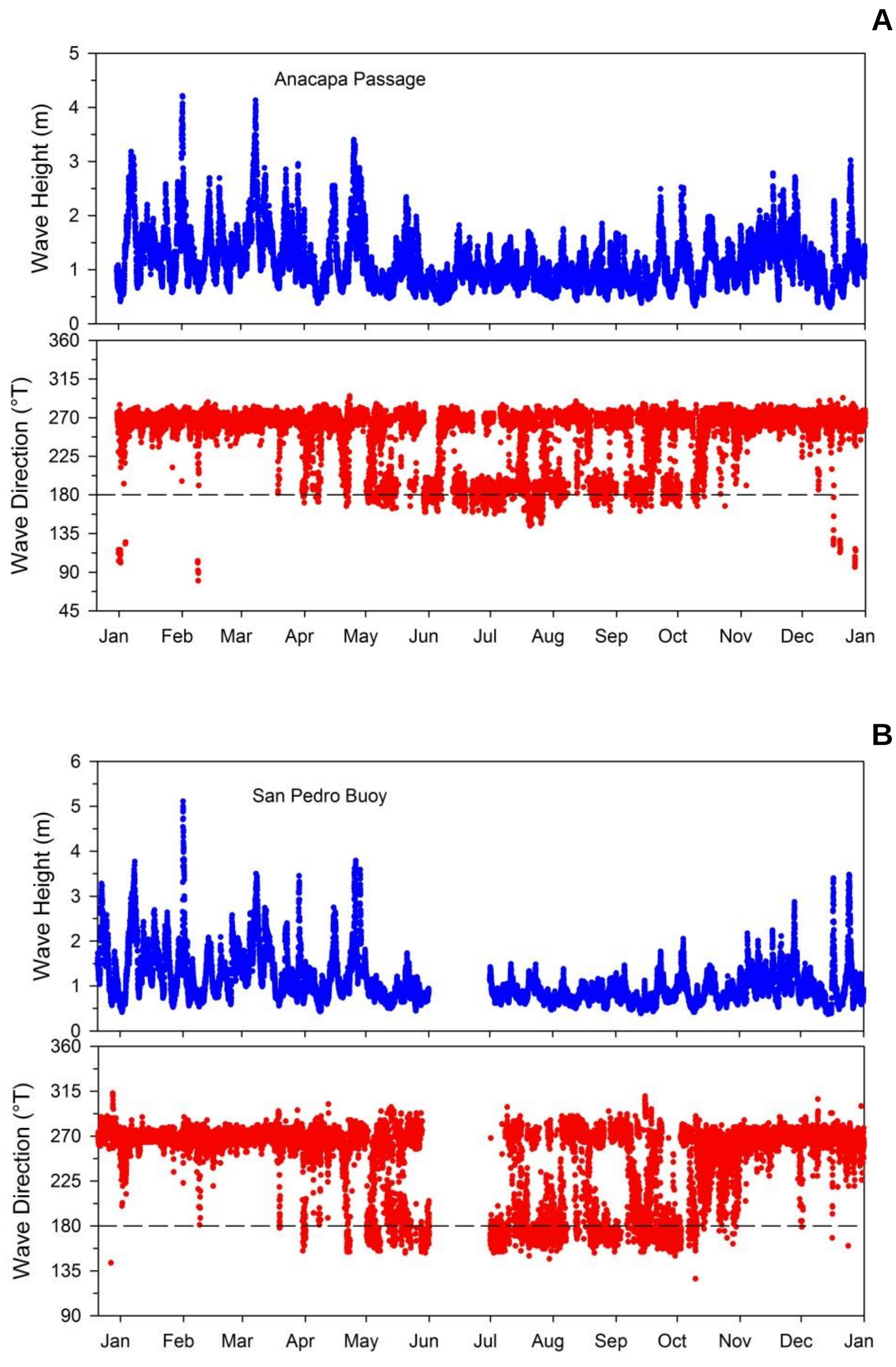


Figure 13. Wave height (blue) and direction (red) at (A) Anacapa Passage Buoy and (B) San Pedro Buoy from January 2016 through December 2016. Data from CDIP (2017).

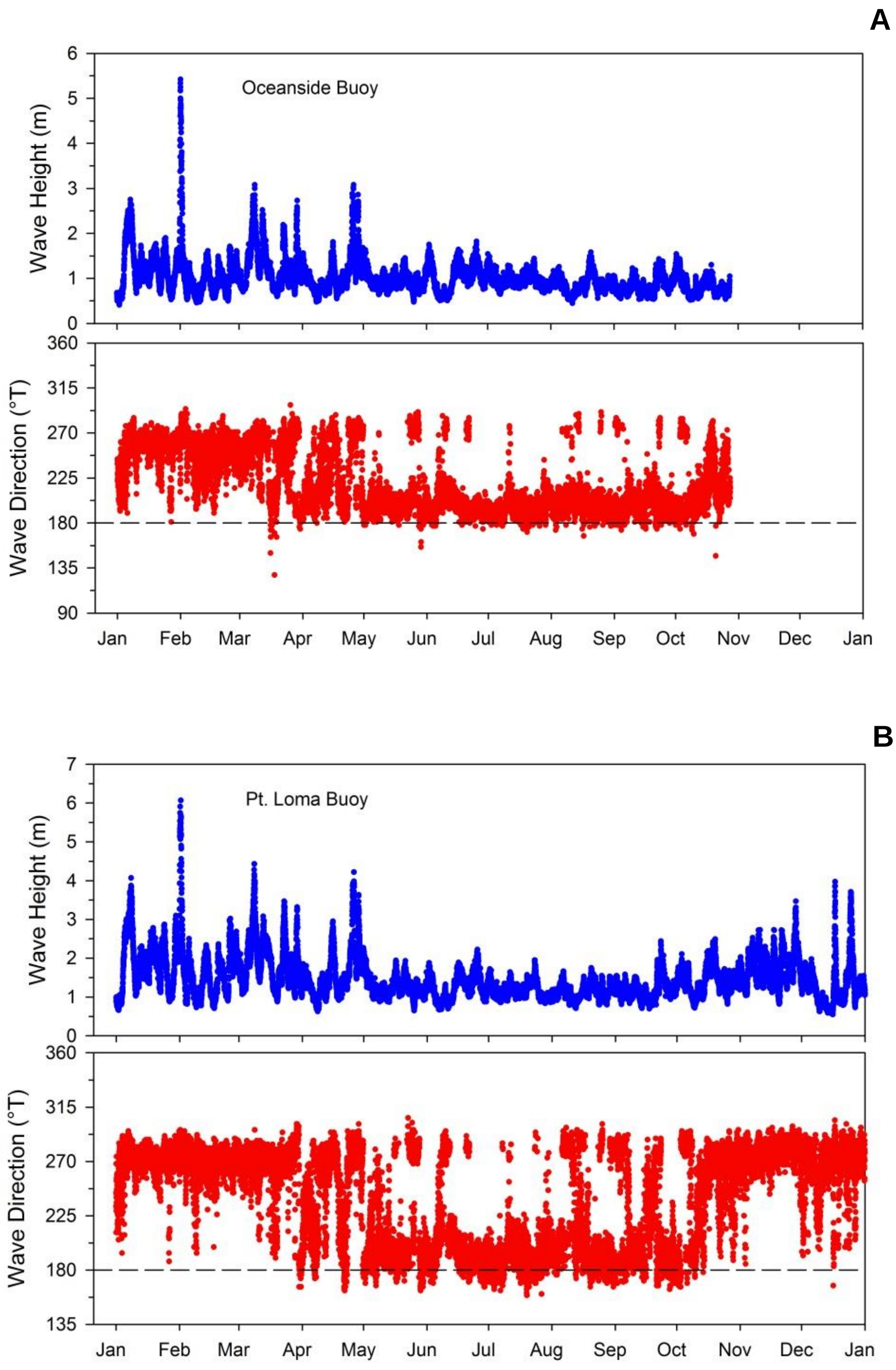


Figure 14. Wave height (blue) and direction (red) at (A) Oceanside Buoy and (B) Point Loma Buoy (bottom) from January 2016 through December 2016. Data from CDIP (2017).

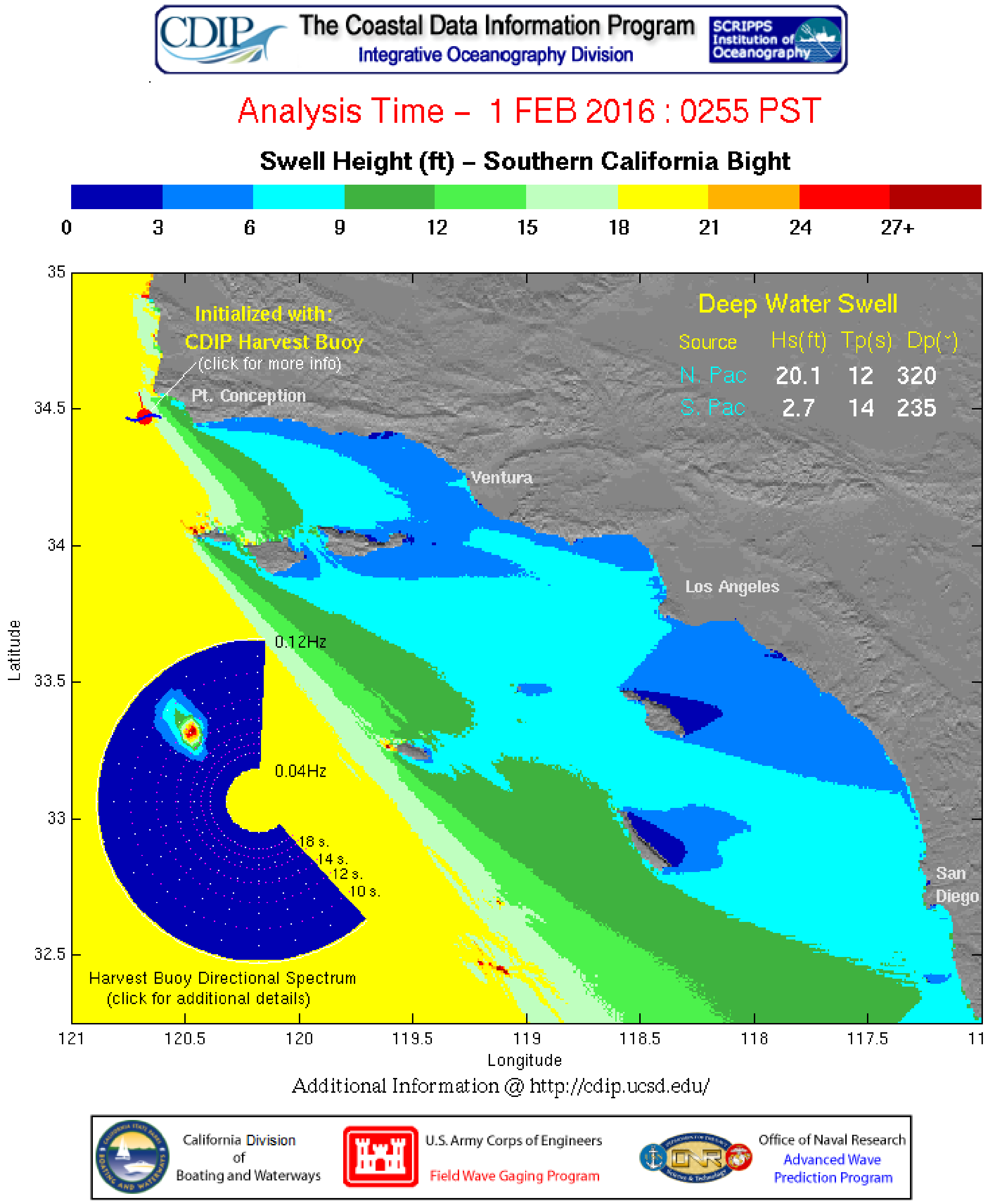


Figure 15. Swell height and direction in the SCB, 1 February 2016. Source: CDIP (2017).

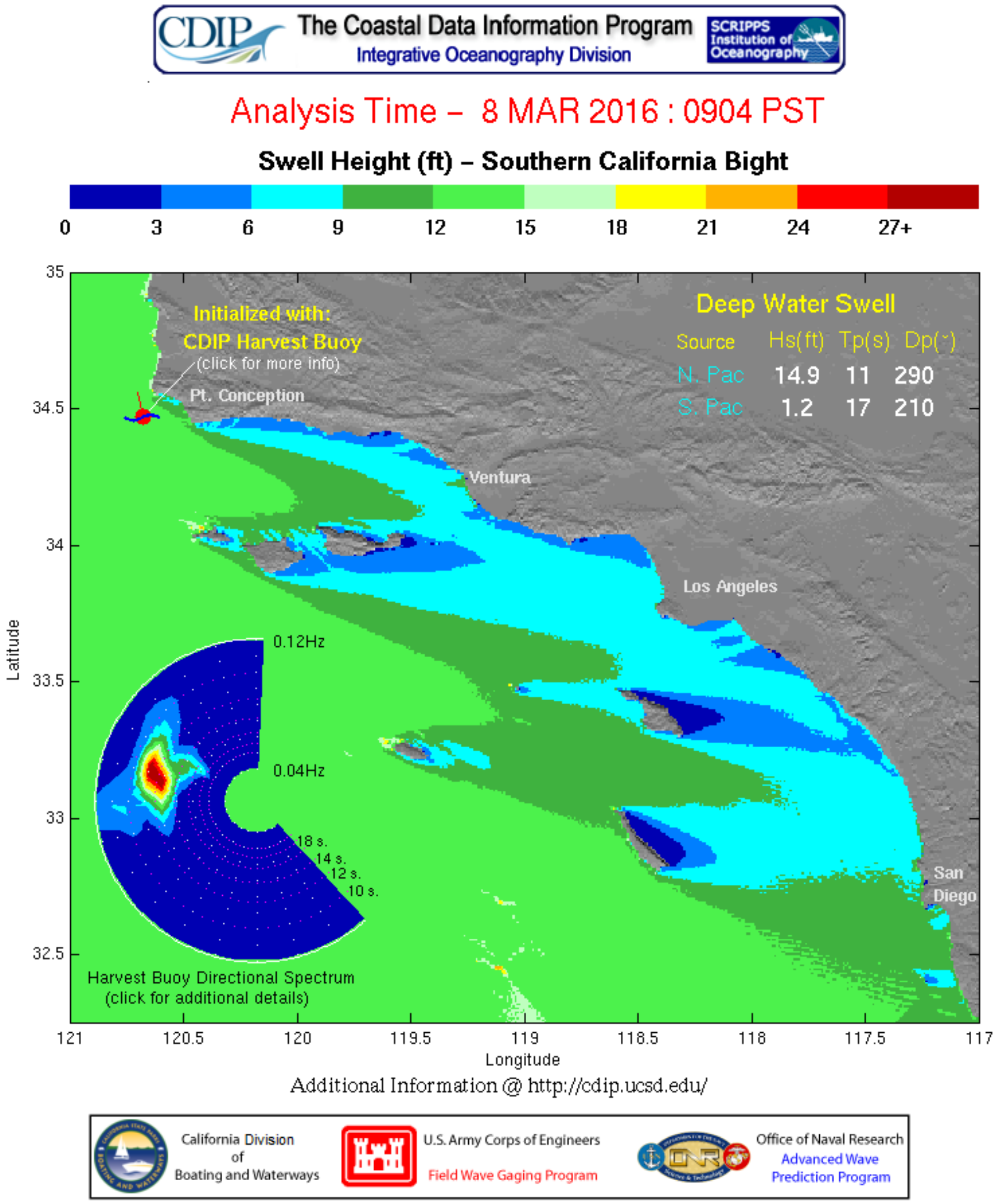


Figure 16. Swell height and direction in the SCB, 8 March 2016. Source: CDIP (2017).

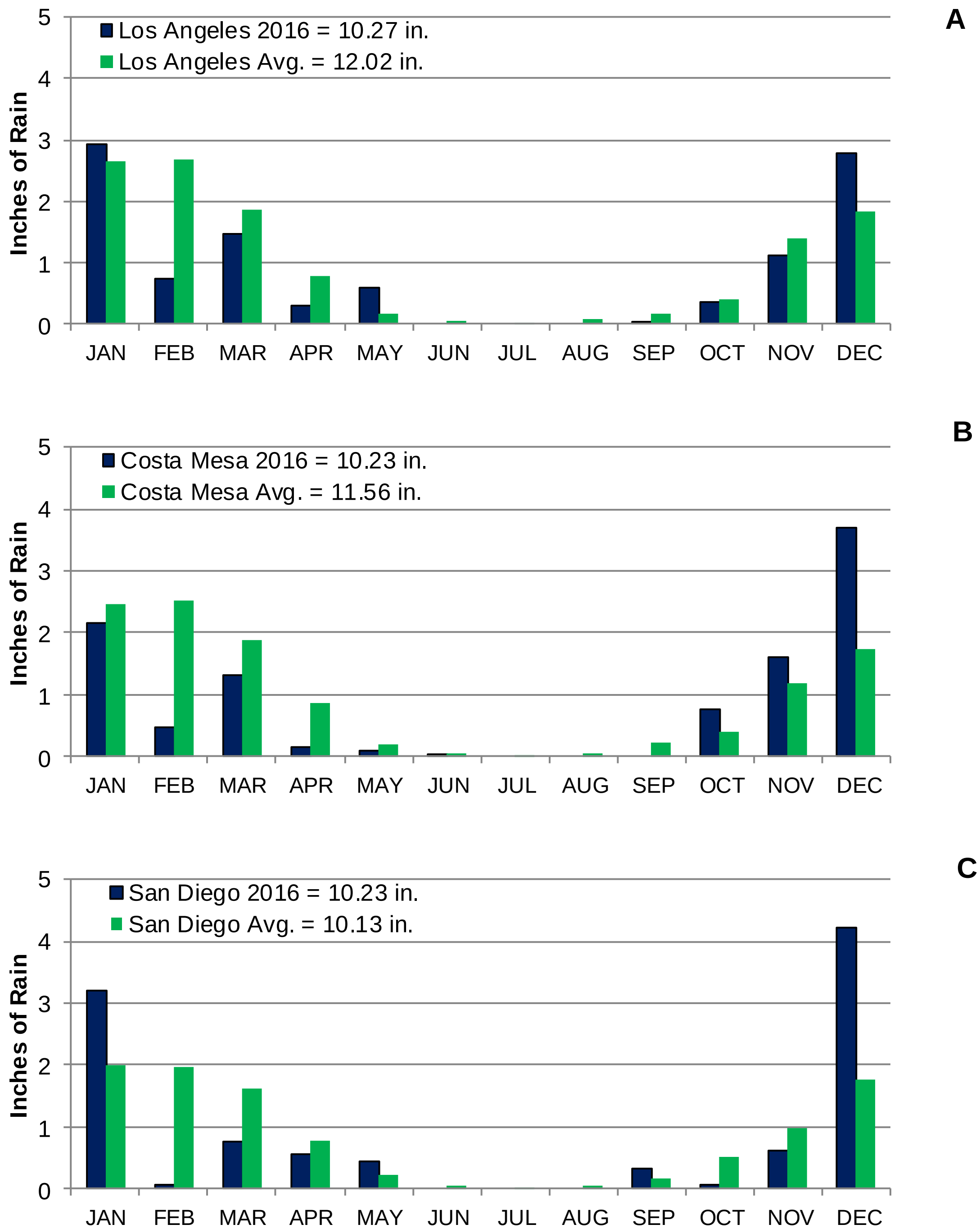
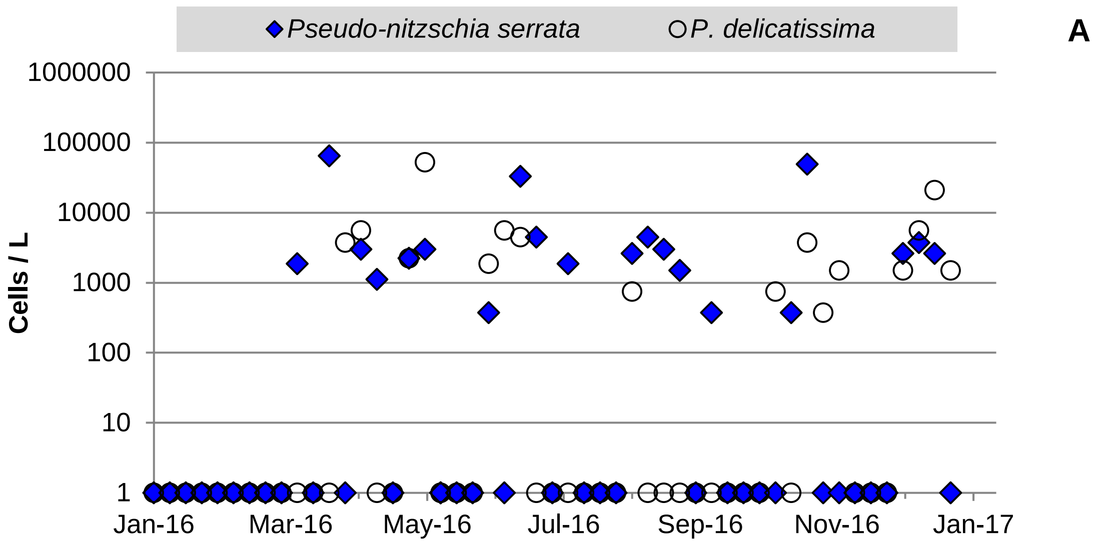


Figure 17. Monthly 2016 rainfall and average monthly rainfall recorded for (A) Los Angeles International Airport (Los Angeles), (B) Costa Mesa, and (C) Lindbergh Field (San Diego). Monthly averages include: LAX: 1936-2016; Costa Mesa: 1955-2016; and San Diego: 1939-2016. Sources: NOAA CNRFC (2017) and OCPW (2017).

Concentrations of the phytoplankton *Pseudo-nitzschia delicatissima* peaked in late-March at both Santa Monica Pier and Newport Pier (Figure 18). Concentrations of *P. seriata* (associated with harmful algal blooms) peaked in May and June, with higher levels reported at Santa Monica Pier.



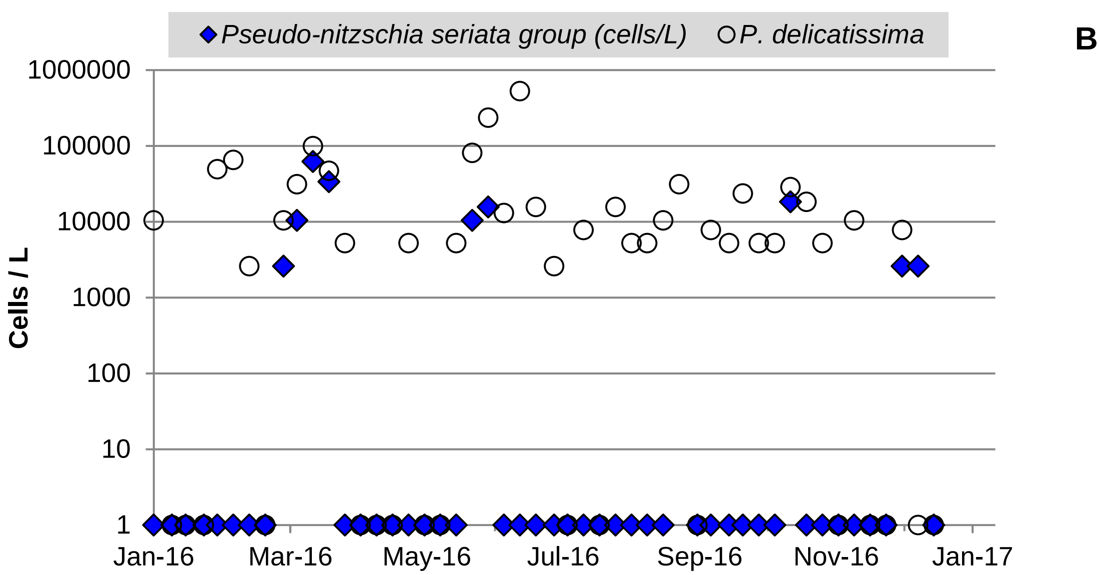


Figure 18. Concentrations of harmful algal bloom (HAB) species at (A) Santa Monica Pier and (B) Newport Pier in 2016. Source: SCCOOS (2017).

Periods of increased phytoplankton concentrations (exceeding 10^4 cells/liter) were recorded in Santa Monica Bay during five months, and at Newport Pier during nine months of 2016 (Figure 18). However, no widespread red tide (plankton bloom) was recorded during the year at either location. Concentrations at over 350,000 cells per liter (R. Shipe, pers. comm.) can effectively exclude light from all but the shallowest depths. This limits photosynthetic activity at depth and may have been responsible for a portion of the severe impacts on the kelp bed resources observed in 2005 and 2006 (Gallegos and Jordan 2002, Gallegos and Bergstrom 2005).

2016 QUARTERLY OVERFLIGHT SUMMARY

Aerial surveys were flown on April 18, June 20, September 24, and December 28, 2016. Reasonable attempts were made to conduct one aerial overflight within each of the four quarters in the year (Table 3, Appendix D). Many of the beds in the Central Region displayed maximum canopies during the April overflight, although some peaked in June or December (Table 4). Nearly all of the beds in Region Nine reached maximum extent in December (Table 5).

Table 3. Status of planned aerial overflights in 2016.

Target Date	Actual Date	Comments
1st Quarter - March 2016	April 18, 2016	Delayed for aircraft repair and coastal fog. Excellent conditions
2nd Quarter - June 2016	June 20, 2016	Excellent conditions
3rd Quarter – Sept. 2016	September 24, 2016	Excellent conditions
4th Quarter – Dec. 2016	December 28, 2016	Restricted airspace from the entrance to San Diego Bay and just north of Imperial Beach. Excellent conditions

2016 VESSEL SURVEY SUMMARY

Boat surveys were conducted periodically throughout the year from Newport Beach to Barn kelp (during ongoing physical and biological surveys for other projects). These surveys were conducted in early 2017 (instead of 2016) because of prevailing poor ocean conditions in late 2016 (Figure 14), but are considered to be part of the 2016 survey. A focused vessel survey of the kelp was conducted from San Onofre to Imperial Beach on March 13, 2017, and from Newport Beach to San Mateo Point on March 29, 2017. Results from these surveys are presented in the individual summaries of each kelp bed and in Appendix D.

Table 4. Rankings assigned to the 2016 aerial photograph surveys of the kelp beds between Ventura Harbor and Newport / Irvine Coast. The basis for a ranking was the status of a canopy during surveys from recent years, excluding periods of El Niño or La Niña conditions or following exceptional storms.

	2016 Surveys			
Kelp Beds	**18 April**	**20 June**	**24 September**	**28 December**
Ventura Harbor *	0.5	2.5	-	0.5
Channel Islands *	2.5	2.5	2.0	0.5
Port Hueneme *	2.5	1.0	3.0	1.5
Deer Creek	3.0	3.0	2.5	3.0
Leo Carillo	2.5	3.0	2.5	3.0
Nicolas Canyon	3.0	3.0	2.0	3.0
El Pescador/La Piedra	3.0	3.0	2.0	3.0
Lechuza Kelp	3.0	2.5	1.5	3.0
Point Dume	2.0	2.5	1.0	2.0
Paradise Cove	2.5	3.0	1.0	2.5
Escondido Wash	2.0	2.0	1.0	2.5
Latigo Canyon	2.5	2.5	-	2.0
Puerco/Amarillo	2.5	1.0	-	2.0
Malibu Pt.	2.5	-	-	-
La Costa	-	-	-	-
Las Flores	-	-	-	-
Big Rock	0.5	0.5	0.5	0.5
Las Tunas	-	-	-	-
Topanga	-	-	-	-
Sunset	3.0	0.5	0.5	0.5
Marina Del Rey *	1.5	0.5	0.5	1.0
Hyperion Pipeline *	-	-	-	-
Redondo Breakwater *	1.5	1.0	1.0	1.0
Malaga Cove - PV Point (IV)	3.0	2.0	3.0	3.0
PV Point - Point Vicente (III)	2.5	3.0	2.0	3.0
Point Vicente - Inspiration Point (II)	3.0	3.0	3.0	3.0
Inspiration Point - Point Fermin (I)	3.0	3.0	2.5	2.5
Cabrillo	4.0	3.0	2.0	2.5
LA/LB Harbor and Breakwaters	3.0	2.5	2.0	2.0
Horseshoe Kelp	-	-	-	-
Huntington Flats	-	-	-	-
Newport Harbor *	0.5	1.0	1.0	1.0
Corona Del Mar	0.5	2.0	1.0	2.0
North Laguna Beach	1.0	3.0	0.5	3.0

Notes:
Ranking values: 0.5 = trace or very small amount of kelp present; 1 = well below average; 2 = below average; 2.5 = average; 3 = above average; and 4 = well above average. Red indicates maximum canopy size for the year; " - " = no canopy present; * = not part of the monitored beds.

Table 5. Rankings assigned to the 2016 aerial photograph surveys of the kelp beds between Newport / Irvine Coast and Imperial Beach. The basis for a ranking was the status of a canopy during surveys from recent years, excluding periods of El Niño or La Niña conditions or following exceptional storms.

	2016 Surveys			
Kelp Bed	**18 April**	**20 June**	**24 September**	**28 December**
Newport Harbor *	0.5	1.0	1.0	1.0
Corona del Mar	0.5	2.0	1.0	2.0
No. Laguna Beach	1.0	3.0	0.5	3.0
So. Laguna Beach	0.5	0.5	-	1.5
South Laguna	0.5	0.5	-	2.0
Salt Creek-Dana Point	0.5	-	-	1.0
Dana Marina *	2.0	0.5	0.5	1.5
Capistrano Beach	1.0	-	-	2.0
San Clemente	0.5	0.5	0.5	3.0
San Mateo Point	1.0	1.0	0.5	2.0
San Onofre	0.5	0.5	0.5	2.0
Pendleton Reefs *	-	-	-	-
Horno Canyon	1.0	0.5	0.5	1.0
Barn Kelp	1.0	1.0	-	2.0
Santa Margarita	-	-	-	-
Oceanside Harbor *	-	-	-	-
North Carlsbad	-	-	-	-
Agua Hedionda	-	-	-	-
Encina Power Plant	-	-	-	1.0
Carlsbad State Beach	-	-	-	-
North Leucadia	1.0	0.5	0.5	2.0
Central Leucadia	-	-	-	2.0
South Leucadia	-	-	-	0.5
Encinitas	0.5	-	-	1.0
Cardiff	1.0	-	-	2.0
Solana Beach	-	-	-	2.0
Del Mar	-	-	-	-
Torrey Pines Park	-	-	-	-
La Jolla Upper	0.5	0.5	0.5	2.0
La Jolla Lower	0.5	0.5	0.5	2.0
Point Loma Upper	1.0	1.0	1.0	2.5
Point Loma Lower	1.0	1.0	1.0	2.5
Imperial Beach	2.0	-	-	-

Notes:
Ranking values: 0.5 = trace or very small amount of kelp present; 1 = well below average; 2 = below average; 2.5 = average; 3 = above average; and 4 = well above average. Red indicates maximum canopy size for the year; " - " = no canopy present; * = not part of the monitored beds.

2016 KELP CANOPY SUMMARY

Central Region. The following changes since 2015 were documented in the 26 CRKSC kelp beds in 2016:

- 6 kelp beds increased in size
- 14 kelp beds decreased in size (2 to zero)
- 2 kelp beds remained the same size
- 4 kelp beds still not visible (2 missing since 2015, 2 historically absent).

Overall, the maximum measured kelp canopy area in 2016 decreased by 9.5% from 2015 (from 5.255 km^2 to 4.757 km^2) (Table 1). Graphical depictions of each bed are presented in Appendix A, results of the vessel surveys are presented in Appendix D, and a mosaic of the kelp canopies along the coastline is presented in Appendix E.

Region Nine. The following changes since 2015 were documented in the 24 RNKSC kelp beds in 2016:

- 3 kelp beds increased in size
- 19 kelp beds decreased in size (4 to zero)
- 2 kelp beds still not visible (both missing since 2013).

Overall, the maximum measured kelp canopy area in 2016 decreased by 59% from 2015 (12.667 km^2 to 5.134 km^2) (Table 2). Graphical depictions of each bed are presented in Appendix A, results of the vessel surveys are presented in Appendix D, and a mosaic of the kelp canopies along the coastline is presented in Appendix E.

STATUS OF THE 50 KELP BEDS ALONG THE CENTRAL REGION AND REGION NINE THROUGH 2016

The following is a synopsis of the status of each individual bed during the 2016 survey year based upon the quarterly surveys. This section also includes a summary of canopy size variability over time. Maps of kelp coverage are provided in Appendix A, a historical summary is provided in Appendix B, and aerial photographs are included in Appendix E. The kelp bed areas are presented from upcoast to downcoast in Appendix D, which includes the aerial extent of the kelp beds in 2013 as a reference point. That year kelp coverage was relatively high in both regions, and smaller beds at La Costa, Santa Margarita, and Torrey Pines were visible.

CENTRAL REGION KELP SURVEYS

The combined kelp bed coverage of the Central Region has been above the long-term average (since 1967; 4.151 km^2) for 9 of the past 10 years (Figure 19). The ABAPY values by year for the Central Region (off north and central Los Angeles County, beds from Sunset Malibu, and off Orange County) are presented in Figure 20.

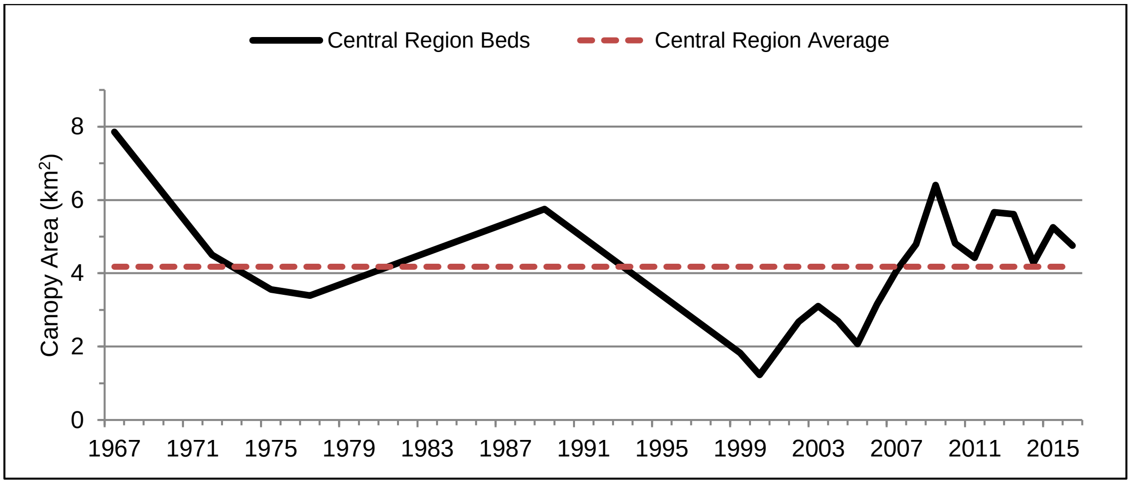


Figure 19. Combined canopy coverage of all kelp beds in the Central Region from Ventura to Newport Harbor/Irvine Coast.

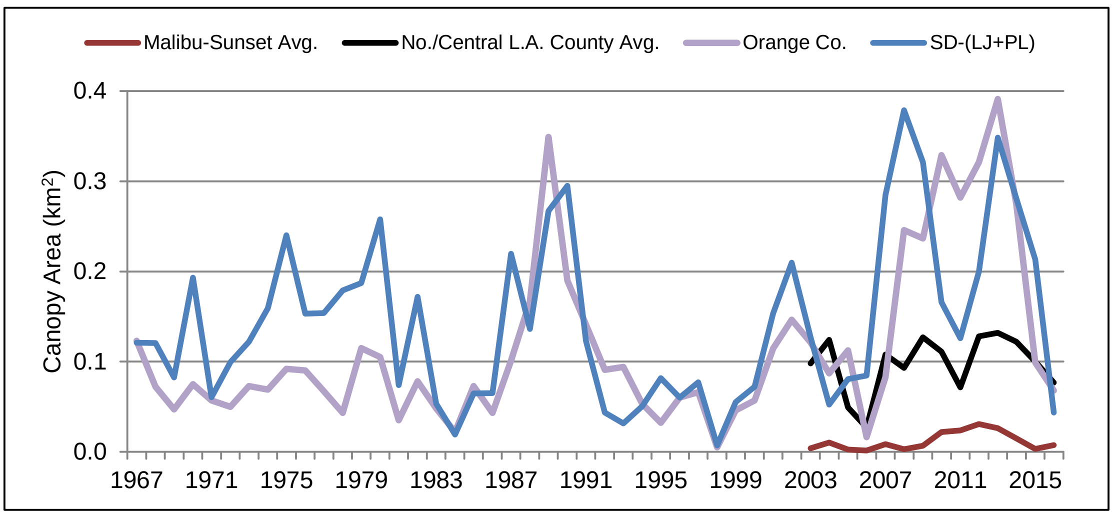


Figure 20. Average Bed Area Per Year (ABAPY) for four different areas: from 2003 through 2016 for (1) offshore north and central Los Angeles County, and (2) Malibu to Sunset; and from 1967 through 2016 for (1) offshore Orange County, and (2) offshore San Diego County (minus La Jolla and Point Loma).

Ventura Harbor to Point Mugu State Park

Kelp beds along this area of the coast remained about the same size between 2015 and 2016 (note: not considered to be one of the 26 designated kelp beds within the CRKSC).

There was a small amount of kelp growing along the breakwaters of Ventura Harbor (0.007 km^2), Channel Islands Harbor (0.007 km^2), and at Port Hueneme (0.011 km^2) in 2016 (Figure 1; Appendices A.1, A.4, A.5, D.1, and E.1). No kelp was noted offshore of the Mandalay and Ormond Beach Generating Stations (Appendices A.2, A.3, A.5, A.6, D.1 and E.1), and no kelp was visible between Port Hueneme and Deer Creek (Appendices A.5 through A.10, D.1, D.2, and E.1).

POINT MUGU TO POINT DUME

Deer Creek. This kelp bed decreased in size from 0.124 km^2 in 2015 to 0.087 km^2 in 2016 (a decrease of 30%).

The Deer Creek canopy was compared to the ABAPY of the northern and central portions of the Central Region to determine whether it was responding synoptically with the beds from the same area (Figures 1 and 21; Appendices A.10, D.2, and E.1). The decrease at Deer Creek (30%) was similar to the ABAPY decrease of 23% over the past year (Figure 21). The size of the Deer Creek kelp bed in 2015 was the highest ever recorded by the CRKSC surveys.

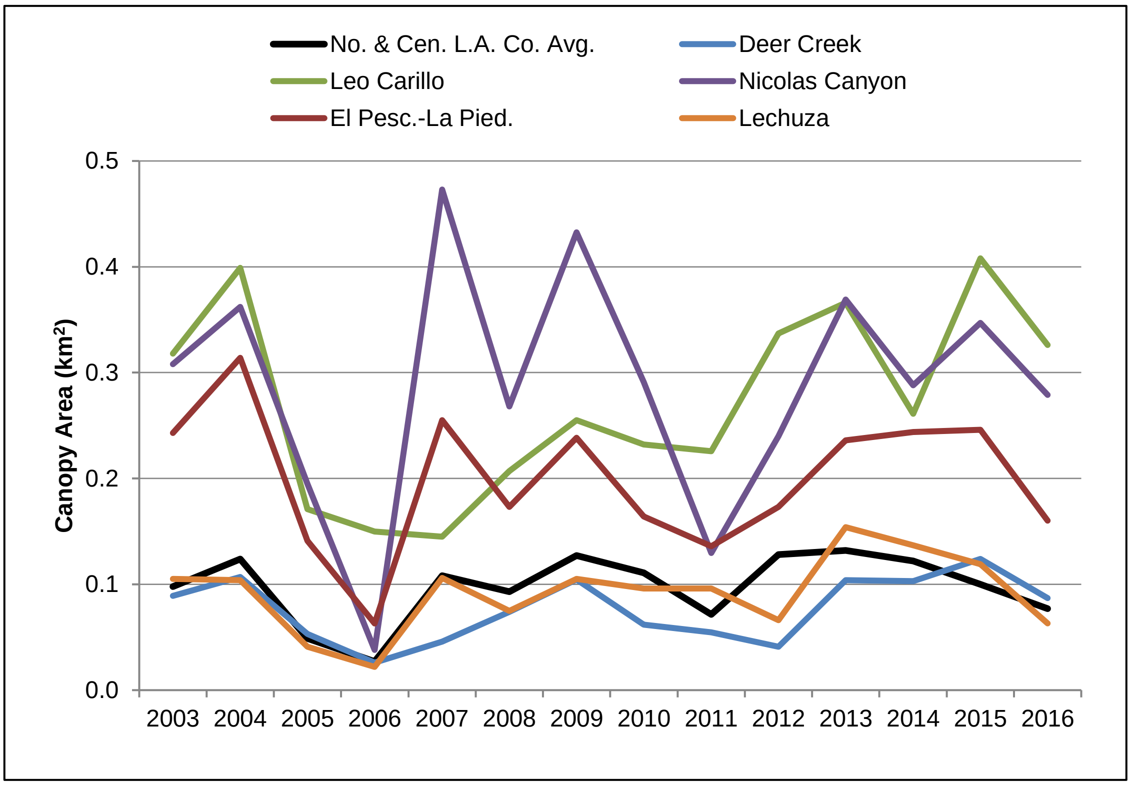


Figure 21. Comparisons between the average Northern and Central Los Angeles County ABAPY and the canopy coverage from Point Mugu through Point Dume from 2003 through 2016.

Leo Carillo. This kelp bed decreased in size from 0.408 km^2 in 2015 to 0.326 km^2 in 2016 (a decrease of 20%).

With the exception of 2007 and 2008, Leo Carillo kelp has reacted synoptically with the kelp beds in the region (Figures 1 and 21; Appendices A.11, D.2, and E.1). The decrease of the Leo Carillo kelp bed in 2016 (20%) was similar to the decrease of the ABAPY by 23%, but the kelp bed was still 20% larger than average since 2003. As with the Deer Creek kelp bed, the size of the Leo Carillo kelp bed in 2015 was the highest ever recorded by the CRKSC surveys.

Nicolas Canyon. This kelp bed decreased in size from 0.347 km^2 in 2015 to 0.279 km^2 in 2016 (a decrease of 20%).

The Nicolas Canyon and Leo Carillo kelp beds have usually been the two largest beds between Point Mugu and Point Dume (Figures 1 and 21; Appendices A.12, D.2, and E.1).

El Pescador/La Piedra. This kelp bed decreased in size from 0.246 km^2 in 2015 to 0.160 km^2 in 2016 (a decrease of 35%).

The changes in size at the El Pescador/La Piedra kelp bed have typically mirrored other beds within the Central Region, although the bed increased slightly in 2014 and 2015 while the ABAPY decreased (Figures 1 and 21; Appendices A.12, D.2, and E.1).

Lechuza. This kelp bed decreased in size from 0.119 km^2 in 2015 to 0.063 km^2 in 2016 (a decrease of 47%).

In 2013, the Lechuza kelp bed reached its largest extent (0.154 km^2), exceeding that of surveys recorded in the last century. However, it decreased in size each of the next three years. The patterns of change of the Lechuza kelp bed size were nearly identical to those of the average bed in the region until 2012, when the Lechuza kelp bed unexpectedly decreased while most beds in the region increased. Even though the ABAPY was similar in 2012 and 2013, the size of the Lechuza kelp bed more than doubled in 2013 (Figures 1 and 21; Appendices A.13, D.2, and E1). The Lechuza kelp bed was 32% smaller in 2016 than the long-term average.

POINT DUME TO MALIBU POINT

Point Dume. This kelp bed decreased in size from 0.169 km^2 in 2015 to 0.042 km^2 in 2016 (a decrease of 75%).

The canopy size of the Point Dume kelp bed typically fluctuated in synchrony with the ABAPY (Figures 1 and 22; Appendices A.14, D.3, D.4, and E.1). The size of the Point Dume kelp bed in 2015 was the highest ever recorded by the CRKSC surveys.

Paradise Cove. This kelp bed increased in size from 0.086 km^2 in 2015 to 0.127 km^2 in 2016 (an increase of 48%).

It was larger than average during most of the last decade, and has usually trended in relative concert with the ABAPY (Figures 1 and 22; Appendices A.14, D.3, and E.1). The bed reached its maximum size in 2012 (0.346 km^2), but decreased from 2013 through 2015. Paradise Cove kelp bed was 27% smaller in 2016 than its average size of 0.175 km^2.

Escondido Wash. This kelp bed decreased in size from 0.095 km^2 in 2015 to 0.084 km^2 in 2016 (a decrease of 12%).

This bed is typically larger than the ABAPY, and its fluctuations in size generally mirrored those of the ABAPY (Figures 1 and 22; Appendices A.14, A.15, D.3, and E.1).

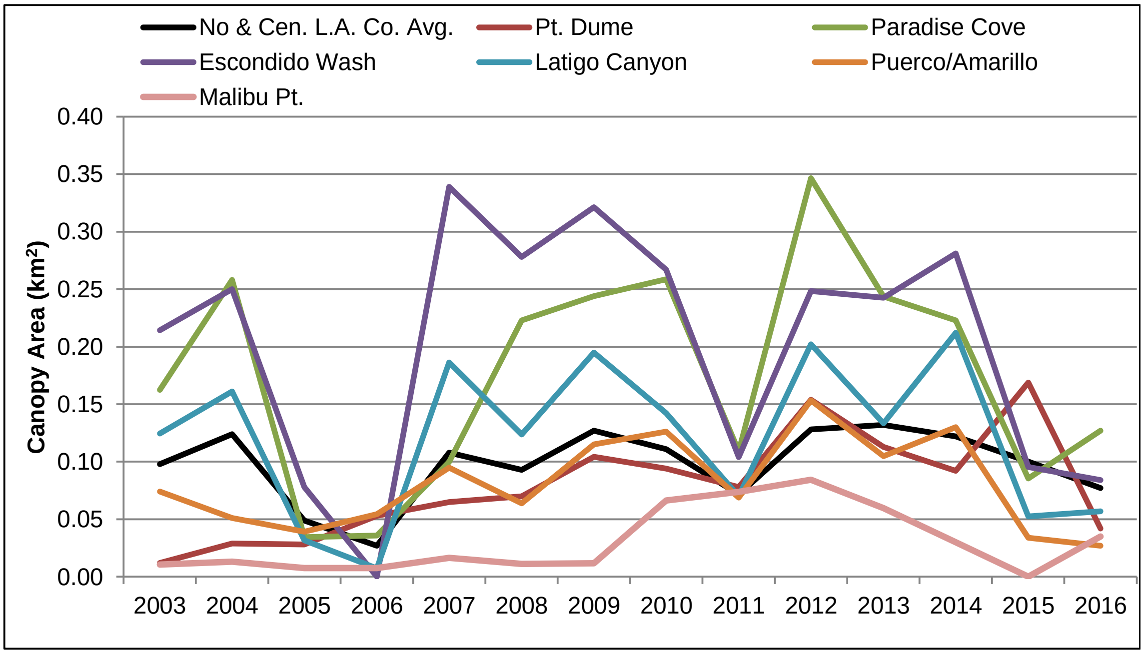


Figure 22. Comparisons between the average Northern and Central Los Angeles County ABAPY and the canopy coverage of the six kelp beds between Point Dume and Malibu Point from 2003 through 2016.

Latigo Canyon. This kelp bed increased in size from 0.052 km^2 in 2015 to 0.057 km^2 in 2016 (an increase of 10%).

In 2014, the Latigo Canyon kelp bed grew to its largest size on record (0.212 km^2) The Latigo Canyon kelp bed area is usually near the ABAPY for the region, and has tracked the ABAPY closely during 10 of the 14 years of monitoring since 2003, although it fell below he ABAPY in 2015 and 2016 (Figures 1 and 22).

Puerco/Amarillo. This kelp bed decreased in size from 0.034 km^2 in 2015 to 0.027 km^2 in 2016 (a decrease of 21%).

Like many other beds upcoast of Palos Verdes, the Puerco/Amarillo kelp bed was larger in December 2012 (0.153 km^2) than during any previous CRKSC survey. It decreased in size three of the last four years. This bed typically trended with the ABAPY from 2007 through 2014, but fell below the ABAPY in 2015 and 2016 (Figures 1 and 22; Appendices A.16, D.3, and E.1).

Malibu Point. This kelp bed disappeared in 2015, for the first time since the central region monitoring was initiated in 2003, but reappeared in 2016 with a size of 0.035 km^2.

The canopy size at Malibu Point was 0.084 km^2 in 2012, the largest extent of kelp since CRKSC surveys began. However, the Malibu Point kelp bed decreased in size the following two years, and it was not visible in 2015. It emerged in 2016 as a relatively small kelp bed off the mouth of Malibu Creek (Figures 1 and 22; Appendices A.17, D.3, and E.1). The size of this kelp bed was smaller than the ABAPY during most years, and it has not correlated well with the ABAPY.

MALIBU POINT TO SANTA MONICA PIER

The six kelp beds from La Costa to Sunset are usually among the smallest beds in the Central Region. Due to their small size (≤0.012 km^2 in 2016), the beds have not typically reacted in discernible patterns since 2003 (Figures 23 and 24). Exceptions to this include growth spikes at many beds in 2004 and 2012.

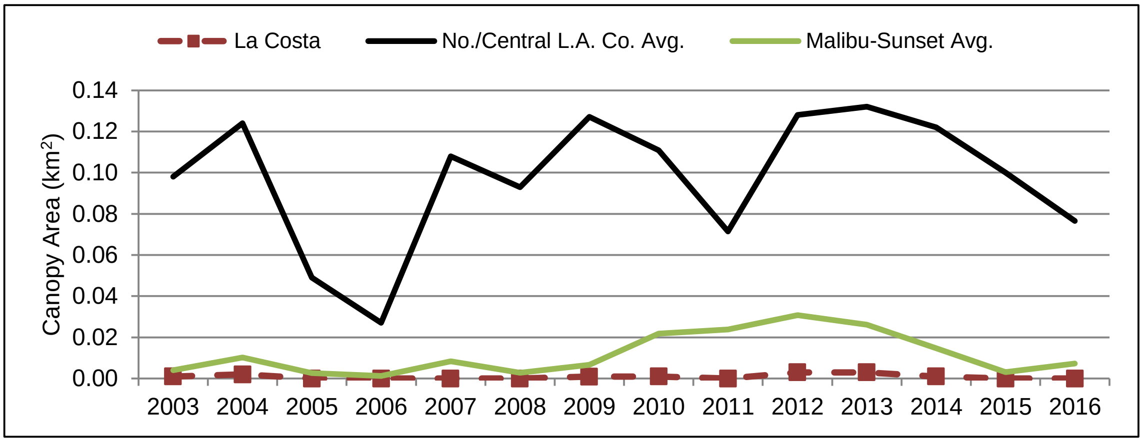


Figure 23. Comparisons between the average Northern and Central Los Angeles County ABAPY, the Malibu to Sunset ABAPY, and the canopy coverage of the kelp bed off La Costa from 2003 through 2016.

La Costa. This kelp bed was not observed in 2016, nor was it visible in 2015.

The La Costa kelp bed only has been present in half the years since 2003. In 2012, this kelp bed was not present in the June or October surveys, but it appeared as a very small bed (0.003 km^2) in December, the largest size recorded in 10 years of monitoring. It remained at that size in 2013, but decreased in size in 2014 and disappeared in 2015 (Figures 1 and 23; Appendices A.17, A.18, D.3, D.4, and E.2).

Las Flores. This kelp bed also was not observed in 2016, nor was it visible in 2015.

The Las Flores kelp bed reached its maximum size in December 2012, and at 0.025 km^2, it was slightly larger than in 2004. Canopy size decreased by 12% in 2013, and another 28% in 2014 (to 0.016 km^2), before disappearing in 2015 (Figures 1 and 24; Appendices A.19, D.3, D.4, and E.2).

Big Rock. This kelp bed decreased in size from 0.004 m^2 in 2015 to 0.001 km^2 in 2016 (a decrease of 75%).

In December 2012, the small kelp bed at Big Rock reached its largest size (0.018 km^2) since the inception of the CRKSC program. Canopy size decreased in 2013 and 2014, and in 2015 the bed size decreased from 0.011 km^2 to 0.004 m^2 (a 64% decrease). This kelp bed has generally not mirrored the ABAPY (due in part to its relatively small size), but the two have trended together since 2012 (Figures 1 and 24; Appendices A.18, A.19, D.4, and E.2).

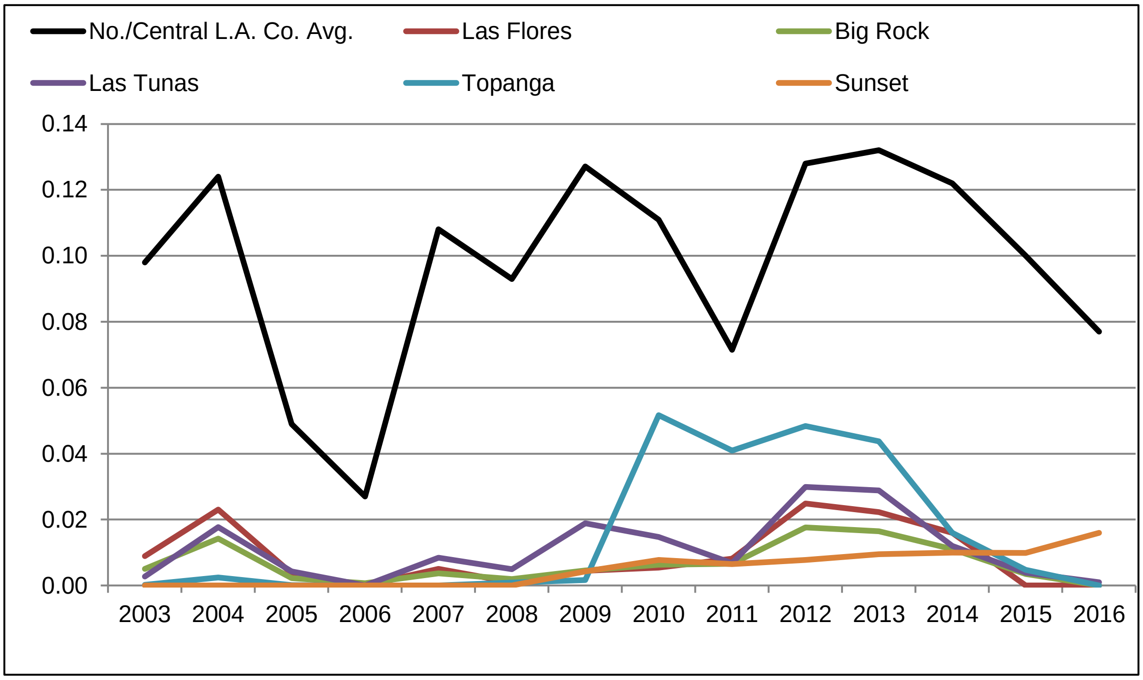


Figure 24. Comparisons between the average Northern and Central Los Angeles County ABAPY and the canopy coverage of the five kelp beds from Las Flores to Sunset from 2003 through 2016.

Las Tunas. This kelp bed was not visible in 2016, decreasing from 0.004 km^2 in 2015.

Las Tunas kelp bed canopy size reached 0.030 km^2 in December 2012. Canopy size decreased in 2013 and 2014, and in 2015 the bed size decreased by another two-thirds (from 0.012 km^2 to 0.004 m^2). Similar to Big Rock, Las Tunas is a very small bed, and well below the ABAPY for the region, but has usually responded in synchrony with the ABAPY (Figures 1 and 24; Appendices A.19, D.4, and E.2).

Topanga. This kelp bed also was not visible in 2016, decreasing from 0.005 km^2 in 2015.

Topanga kelp bed reached its maximum size in 2010 at 0.052 km^2. However, it decreased in size from 2012 until its disappearance in 2016 (from 0.048 km^2 to zero over four years). Topanga is a relatively small bed, and well below the ABAPY for the region, and its extent has generally not mirrored the ABAPY (Figures 1 and 24; Appendices A.20, D.4, and E.2).

Sunset. This kelp bed increased in size from 0.010 km^2 in 2015 to 0.015 km^2 in 2016 (an increase of 50%).

Sunset kelp bed—once a very large bed—was not observed in any of the CRKSC surveys through 2012, but a small amount of kelp was noted on the submerged breakwater offshore of Santa Monica at the southern end of the bed from 2009 through 2016 (Figures 1 and 24; Appendices A.20, A.21, D.4, and E.2). The bed size remained the same from 2013 through 2015 (0.010 km^2).

SANTA MONICA PIER TO REDONDO BEACH BREAKWATER

Santa Monica Pier to King Harbor. No kelp was seen between the two harbors along the Hyperion Treatment Plant outfall pipeline, offshore the Scattergood and El Segundo Generating Stations, Chevron Oil Refinery, Manhattan or Hermosa Beach, or the Redondo Beach Generating Station in 2016 (Figure 1; Appendices A.22 through A.27, D.4, D.5, and E.2) (note: not considered to be one of the 26 designated kelp beds within the CRKSC)..

Although no kelp was noted in 2003 or 2004 from the Santa Monica Pier to Marina del Rey Harbor, a small amount of kelp was noted along the breakwaters at Marina del Rey Harbor and King Harbor in April 2005 and at slightly higher concentrations in December 2006. Since at least 2005, kelp has been visible at both the Marina del Rey and King Harbor breakwaters during some portion of the year (Appendices A.23, A.27, D.5, and E.2).

Redondo Beach Breakwater to Malaga Cove, Torrance. In 2016, no kelp was seen between King Harbor and Malaga Cove at the Palos Verdes Peninsula (except for that observed at the King Harbor Breakwater) (Figure 1; Appendices A.27, A.28, D.6, E.2 and E.3) (note: not considered to be one of the 26 designated kelp beds within the CRKSC).

This stretch of coastline appears to have been unsuitable for kelp since the Crandall survey of 1911, implying that it continues to be sandy bottom with no substantial hard substrate.

MALAGA COVE TO POINT FERMIN

The Palos Verdes (PV) kelp beds are typically quite large and have been more accessible to researchers than other areas, resulting in many comprehensive surveys of this region (Table 6). The CRKSC divides the two beds that CDFW recognizes into four distinct kelp regions since they have at times responded differently to oceanographic conditions. Maps of the kelp beds at Palos Verdes Peninsula from 1890 (and possibly earlier) indicate that the kelp beds were large even then, but major fluctuations in extent of the Palos Verdes kelp beds have occurred at least since 1911, when 9.124 km^2 of kelp was reported (Table 6 and Appendix B.2).

Despite the region-wide decline of kelp beds since 1911, the extent of the decline in the Palos Verdes kelp forest over the first half of the 20th century was unusual. Appendix B presents representative survey results of 2.676 km^2 from February 21 2002 since that particular survey provided information on all four sections of the Palos Verdes Peninsula. The varying estimates probably reflect the time of year during which the surveys were conducted and suggest that the February 2002 survey did not represent the annual maximum canopy at Palos Verdes. The total of nearly 4.0 km^2 of kelp by June 2009 was the largest measurement of kelp at Palos Verdes in the 20 years since the 1989 survey total of about 4.5 km^2 of kelp. The beds off of Palos Verdes decreased in size by 6% between 2015 and 2016, but the decrease was not synoptic among the four beds (i.e., two of the bed sizes decreased, one bed increased, and one bed remained essentially the same size).

Table 6. Historical record of kelp canopy coverage of the Palos Verdes Peninsula.

Year	km^2	Acres	Hectares	Naut. Mi$^{2\ A}$ (N mi^2)	Sources
2016	3.060	756.14	306.00	0.892	CRKSC IR Survey (4 Surveys)
2015	3.149	778.13	314.90	0.918	CRKSC IR Survey (4 Surveys)
2014	1.647	406.98	164.70	0.480	CRKSC IR Survey (4 Surveys)
2013	2.600	642.47	260.00	0.758	CRKSC IR Survey (4 Surveys)
2012	2.599	642.22	259.90	0.758	CRKSC IR Survey (4 Surveys)
2011	2.396	592.06	239.60	0.699	CRKSC IR Survey (4 Surveys)
2010	2.494	616.41	249.45	0.727	CRKSC IR Survey (4 Surveys)
2009	3.998	987.92	399.80	1.17	CRKSC IR Survey (4 Surveys)
2008	2.916	720.56	291.60	0.85	CRKSC IR Survey (3 Surveys)
2007	2.062	509.53	206.20	0.60	CRKSC IR Survey (4 Surveys)
2006	2.187	540.49	218.73	0.64	CRKSC IR Survey (4 Surveys)
2005	1.099	271.57	109.90	0.32	CRKSC IR Survey (4 Surveys)
2004	0.589	145.54	58.90	0.17	CRKSC IR Survey (4 Surveys)
2003	1.425	352.12	142.50	0.42	CRKSC IR Survey (4 Surveys)
2002	2.837	701.00	283.68	0.83	CF&G/Ocean Imaging (2 Surveys)
2000	1.230	303.94	123.00	0.36	W.J. North IR Survey (1 Survey)
1999	1.267	313.00	126.67	0.37	CF&G IR Survey (1 Survey)
1998	0.498	123.00	49.78	0.15	CF&G IR Survey (3 Surveys)
1997	1.048	259.00	104.81	0.31	CF&G IR Survey (2 Surveys)
1996	1.356	335.00	135.57	0.40	CF&G IR Survey (2 Surveys)
1995	1.493	369.00	149.33	0.44	CF&G IR Survey (2 Surveys)
1994	2.703	668.00	270.33	0.79	CF&G IR Survey (2 Surveys)
1993	1.214	300.00	121.41	0.35	CF&G IR Survey (1 Survey)
1992	1.731	427.70	173.08	0.50	CF&G IR Survey (3 Surveys)
1991	2.964	732.50	296.43	0.86	CF&G IR Survey (4 Surveys)
1990	3.641	899.60	364.06	1.06	CF&G IR Survey (4 Surveys)
1989	4.549	1124.20	454.95	1.33	CF&G IR Survey (2 Surveys)
1988	3.379	835.00	337.91	0.99	CF&G IR Survey (4 Surveys)
1987	4.242	1048.30	424.23	1.24	CF&G IR Survey (4 Surveys)
1986	3.097	765.20	309.67	0.90	CF&G IR Survey (4 Surveys)
1985	2.627	649.20	262.72	0.77	CF&G IR Survey (4 Surveys)
1984	2.861	707.00	286.11	0.83	CF&G IR Survey (4 Surveys)
1983	1.963	485.00	196.27	0.57	CF&G IR Survey (4 Surveys)
1982	2.871	709.40	287.08	0.84	CF&G IR Survey (4 Surveys)
1981	2.424	598.90	242.37	0.71	CF&G IR Survey (4 Surveys)
1980	2.397	592.40	239.74	0.70	CF&G IR Survey (4 Surveys)
1979	1.842	455.25	184.23	0.54	CF&G IR Survey (4 Surveys)
1978	1.205	297.80	120.52	0.35	CF&G IR Survey (4 Surveys)
1977	0.365	90.30	36.54	0.11	CF&G IR Survey (4 Surveys)
1976	0.262	64.80	26.22	0.08	CF&G IR Survey (4 Surveys)
1975	0.095	23.50	9.51	0.03	CF&G IR Survey (3 Surveys)
1974	0.015	3.70	1.50	0.00	CF&G IR Survey (2 Surveys)
1967	1.062	262.4	106.2	0.31	SAI (1 Survey)
1959[B]	0.034	8.48	3.43	0.01	SWQCB 1964
1958	0.171	42.38	17.15	0.05	SWQCB 1964
1957	0.446	110.18	44.59	0.13	SWQCB 1964
1955	0.823	203.41	82.32	0.24	SWQCB 1964
1953	1.509	372.92	150.92	0.44	SWQCB 1964
1947	3.601	889.93	360.14	1.05	SWQCB 1964
1945	5.591	1381.51	559.08	1.63	SWQCB 1964
1928	9.912	2449.42	991.25	2.89	SWQCB 1964
1911	9.124	2254.58	912.40	2.66	Crandall 1912

A - Data in nautical mi^2 are from SWQCB (1964);B - 1959 value as reported by SWQCB (1964) is actually <0.01 N mi^2. This was changed to 0.01 N mi^2 (8.5 acres).2003-2016 data includes Cabrillo. Values after 1967 are maximum coverage for each year.

The Portuguese Bend landslide is an important local factor in limiting kelp forests on reefs along the southern face of Palos Verdes (Appendix A.29). It affects areas in the Palos Verdes (PV) I and PV II kelp beds. This slide, which has been active since 1956, has contributed as much as 9.4 million metric tons of sediment to the nearshore waters (Kayen et al. 2002). Besides increasing water column turbidity with attendant effects on sea floor light availability, sediment from the slide buried many low-lying reefs that would otherwise support kelp beds (LACSD 2003). Kayen et al. (2002) compared bathymetry in the region to assess the magnitude of the historic accretion of sediment on these reefs. Comparing 1933 and 1976 bathymetric surveys, they found shoaling of the seafloor of greater than one meter between the 3- and 15-m isobaths, within the depth range suitable for kelp bed formation.

The Bay Foundation mapped and recorded 0.615 km^2 of urchin barrens around the PV III and PV II kelp beds in 2010 (Ford et al. 2015). Subsequent SCUBA-based community monitoring further qualified these barrens as areas featuring low diversity and productivity relative to areas of the Palos Verdes Peninsula supporting temporally and spatially stable giant kelp forests. Additional study has shown that the urchin individuals inhabiting these barrens are in poor physical condition, with low gonadosomatic indices relative to urchins in neighboring kelp forests (Claisse et al. 2013).

To enable the recovery of historic kelp forests in Santa Monica Bay, the “Kelp Project” engaged in sea urchin suppression to reduce the density of urchins on shallow rocky reefs beginning in 1997; these early efforts (1997-2009) were supported by the Santa Monica Bay Baykeeper. The Kelp Project demonstrated that reducing urchin density from as high as 100 sea urchins per square meter to less than 2 sea urchins per square meter enabled the natural development of giant kelp and other macroalge at restoration areas in Malibu and Palos Verdes. Restoration areas off of Escondido Beach, Malibu, have proven resilient to disturbances for over 10 years. After reaching restoration targets of <2 sea urchins per square meter and >1 giant kelp holdfast per 10 square meters, the restoration measures were stopped in 2004 (Ford and Meux 2010). The kelp in this area has matured and recovered from many disturbances, including large-scale red tide events in 2005 and 2006 and a 200-year storm event in the same period. Surveys performed in the restoration areas off Escondido Beach in 2008 quantified large kelp plants in high densities (Pondella et al. 2011).

Kelp restoration efforts now are focused on 54 hectares of existing urchin barrens which have been identified along the Palos Verdes Peninsula. The purpose of the Palos Verdes Kelp Forest Restoration Project, initiated in 2013, is to reduce the density of purple sea urchins to 2 per square meter within the boundaries of sea urchin barrens off the Palos Verdes Peninsula. This should allow for the recruitment and development of giant kelp and other species of macroalgae in these areas by reducing sea urchin grazing pressure to restore biogenic habitat to rock reefs that historically supported kelp forests (Ford et al. 2017).

Restoration sites have been established at 5 sites off Palos Verdes: Honeymoon Cove, Marguerite, Underwater Arch Cove, Hawthorne and Point Fermin. Pre-restoration monitoring is conducted on all sites (according to CDFW standards) to estimate the density of purple urchins, red urchins, and giant kelp, and to characterize the substrate. Post-restoration monitoring is conducted within 1-2 weeks after urchin suppression by the restoration teams to verify that urchin densities have been reduced to <2 per square meter and restoration sites are re-surveyed periodically (monthly to quarterly) to verify that purple sea urchin densities remain at <2 per square meter. Response monitoring is conducted at a later time to determine the responses of the natural community to restoration activities. The assessment technique used for response monitoring is adapted from the Cooperative Research and Assessment of

Nearshore Ecosystems (CRANE) methodology and is performed by the Vantuna Research Group. In addition, an adaptation of the Core and Biodiversity protocols used on the west coast of North America as part of the MARINe network will be applied to the intertidal and shallow subtidal areas addressed by the project. Finally, a gonadosomatic index generated in 2011 for red and purple sea urchins, specific to the Palos Verdes Peninsula, will be applied to data gathered by the restoration project to evaluate the condition of urchins in restoration areas (Ford et al. 2017).

Restoration and monitoring activities have been conducted in restoration, control and reference sites since July 2013 and are ongoing. Restoration efforts are Honeymoon Cove and Underwater Arch Cove are considered complete: urchin suppression has resulted in urchin densities below the target of <2 per square meter in a total area of 8.33 acres for Honeymoon Cove and 8.37 acres for Underwater Arch Cove. Restoration efforts remain in progress at the other three restoration sites, but urchin suppression has resulted in urchin densities below the restoration target in a total area of 8.79 acres for Marguerite, 4.29 acres for Hawthorne and 3.93 acres for Point Fermin. An estimated 3,248,619 purple urchins have been suppressed over three years at these five restoration sites on the Palos Verdes Peninsula (Ford et al. 2017).

Analyses of gonadosomatic indices of urchins, species richness of fishes, and fish biomass, as well as increased density of giant kelp, indicate preliminary results from the restoration effort were positive (Ford et al. 2015). Kelp coverage within the restoration areas (identified in yellow in Appendix A.29) was sparse in 2016, but at Honeymoon Cove it appeared to be denser in 2016 than it was in 2009, previously the year with the highest canopy coverage in the last 25 years.

Palos Verdes IV. This kelp bed remained approximately the same size (less than 1% difference) in 2016 (1.420 km^2) as it was in 2015 (1.410 km^2).

The Palos Verdes IV (PV IV) kelp bed historically has been the largest of the beds on the Palos Verdes Peninsula. In 2015, the bed increased more than four-fold to its largest size since 2009. The PV IV kelp bed typically is much larger than the average kelp bed in the region. It is apparent from the ABAPY graph that 2003–2005 and 2014 were poor years for growth at Palos Verdes. It is equally clear from the ABAPY that the PV IV kelp bed responded similarly to other beds in the region, though generally with a sharper upward or downward trend (Figures 1 and 25; Appendices A.28, D.6, and E.3).

Palos Verdes III. This kelp bed decreased in size from 0.750 km^2 in 2015 to 0.430 km^2 in 2016 (a decrease of 43%).

Palos Verdes III (PV III) kelp bed includes the area from Palos Verdes Point to Point Vicente. Since PV III kelp bed is contiguous with PV IV kelp bed, its areal coverage has historically tracked that of PV IV kelp bed, with the exception of periods of area-wide kelp canopy decline when Palos Verdes III kelp bed declined to an even greater degree than PV IV. In 2015, the PV III kelp bed increased in size by 60% (to 0.750 km^2), the largest canopy coverage measured for this bed since 2003. Despite the reduction, PV III was still 30% larger than the 2003–2016

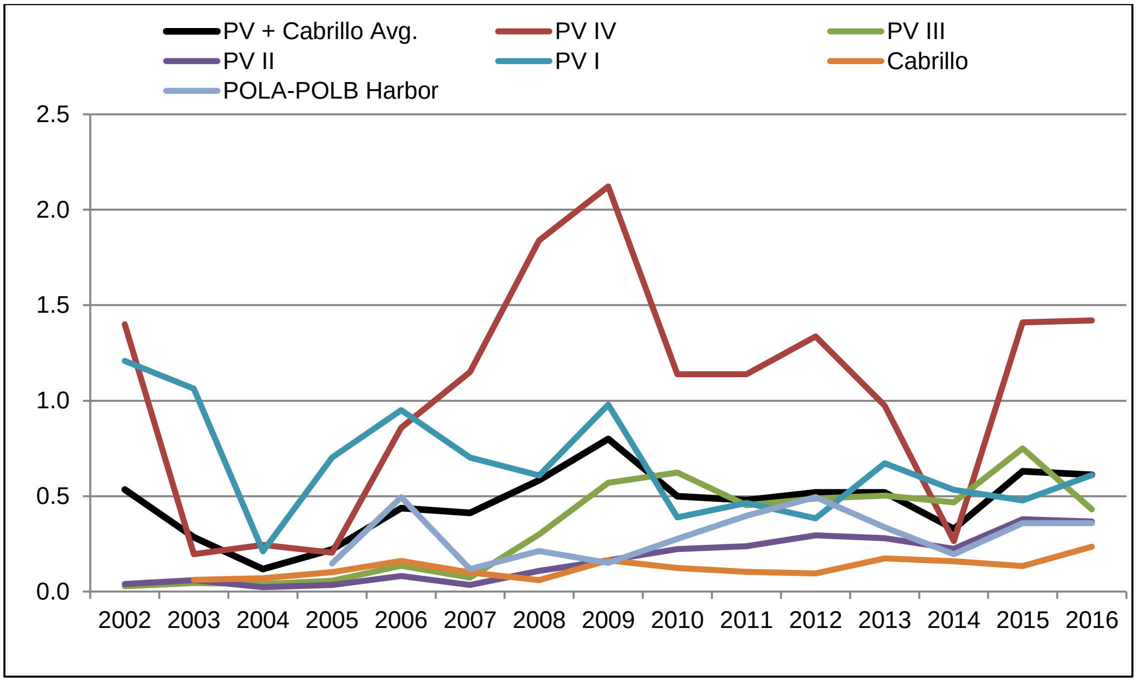


Figure 25. Comparisons between the average Palos Verdes and Cabrillo ABAPY and the canopy coverage of the kelp beds off Palos Verdes from 2002 through 2016.

average. Prior to 2010, PV III was well below the ABAPY, but in 2010, 2014, and 2015 the kelp bed outperformed the ABAPY (Figures 1 and 25; Appendices A.29, A.81, D.6, and E.3). It has generally corresponded to the ABAPY since 2010.

Palos Verdes II. This kelp bed decreased in size from 0.379 km^2 to 0.366 km^2 (a decrease of 3%).

Palos Verdes II (PV II) kelp bed includes the kelp from Point Vicente to Inspiration Point. Unlike the PV III and PV IV beds, canopy size at PV II increased for five consecutive years (2008 through 2012), and in December 2012 it covered 0.295 km^2, the largest total of any CRKSC survey. It reached its maximum size in 2015 (to PV II kelp bed is much smaller than the ABAPY, and patterns of bed size have been muted (Figures 1 and 25; Appendices A.29, A.81, D.6, and E.3). However, with the exception of continued growth from 2009 through 2010, the bed has generally corresponded with the ABAPY.

Palos Verdes I. This kelp bed increased in size from 0.478 km^2 in 2015 to 0.610 km^2 in 2016 (an increase of 28%).

Palos Verdes I (PV I) kelp bed includes the area from Inspiration Point to Point Fermin. Unlike the other Palos Verdes kelp beds, PV I increased substantially (75%) in 2013, and the canopy coverage was the highest recorded since 2009 (Figures 1 and 25; Appendix A.30). Canopy size decreased in 2014 and 2015, to PV I kelp bed was considerably larger than the ABAPY during some years, and its size and growth patterns have corresponded to the ABAPY during most years since 2008 (Figure 25). However, the two have been out of sync for the last two years. A turbid plume from the Portuguese Bend landslide area was visible during all four overflights, but prominent during the April and June overflights (Figure 38). Turbidity was relatively low during December 2016, the month when the PV I canopy was estimated to be at its peak during the year.

POINT FERMIN TO NEWPORT BEACH

Cabrillo. This kelp bed increased in size from 0.133 km^2 in 2015 to 0.235 km^2 in 2016 (an increase of 77%).

The Cabrillo kelp bed includes the area east of Point Fermin up to and including the western end of the San Pedro Breakwater. In 2013, Cabrillo kelp bed increased in size by 83%, and the measured area was the highest recorded since 2003. The canopy area decreased slightly in 2014 and 2015. The canopy area in 2016 (0.235 km^2) was the highest ever recorded by the CRKSC, surpassing the 2013 level. The bed is relatively small, but it has usually corresponded to the ABAPY.

Los Angeles and Long Beach Harbors (POLA-POLB). Kelp coverage was identical in 2016 to the size measured in 2015 (0.359 km^2).

Kelp grows along the POLA-POLB breakwaters, on the armored edges of the outer harbors, and extends into the inner harbors in some places (Figure1; Appendices A.31 through A.34, D.6, D.7, and E.4). This kelp was not adequately considered in CRKSC reports before 2005, but it has been measured on a yearly basis since. The existence of these beds was known for some time, but the extent was not thought to be great. In response to growing curiosity as to the extent of the kelp in the Port Complex, it was requested that the overflight photographs for the third quarterly survey in 2005 (28 September 2005) include the entire outer harbors. Analysis revealed a narrow band of dense kelp (0.147 km^2) on both the inside and outside of the riprap. Only a small portion of the berths in the southern part of the Port Complex was included in the photographs, and it was suggested that the outer harbor be included in future overflights. The more inclusive survey of the harbor complex in 2006 measured 0.494 km^2 of giant kelp on the inner and outer breakwaters (Table 1). Due to reports of kelp along a number of the inner breakwaters, the entire Port Complex was photographed and surveyed by biologists to determine whether the algae in the infrared photographs was giant kelp, feather boa kelp (*Egregia menziesii*), and/or *Sargassum* spp. The visual inspection of the growth along the breakwaters and within the confines of the Ports confirmed that the major portion was giant kelp. Diver surveys in the Ports in 2013 and 2014 confirmed that *Macrocystis* was estimated to comprise >95% of the kelp coverage, with *Egregia* comprising <5% (MBC and Merkel 2016).

The canopy area within the Ports peaked in 2012 at 0.495 km^2. With the exception of the three-year period of 2009–2011, the patterns of the POLA-POLB kelp have generally not corresponded to the ABAPY. The coverage of the kelp in the Port Complex was also smaller than the ABAPY during most years, but the two have been relatively similar in size during the last five years.

Although much of the area downcoast from the Ports of Los Angeles and Long Beach breakwaters to the Newport/Irvine Coast is along a broad, alluvial fan from the San Bernardino Mountains, the area once supported several kelp beds. Rocky habitat existed off of San Pedro in the Horseshoe kelp area, and offshore of Huntington Beach in an area known as Huntington Flats (Appendices A.31, A.35, A.36, D.7, D.8, and E.5).

Horseshoe Kelp. This bed was not observed in 2016, nor was it visible in 2015.

In fact, no giant kelp canopy has formed at the site of Horseshoe kelp in more than 60 years. Subsurface kelp has been observed at this location; in 2004, the kelp *Pterygophora californica* was photographed growing at depths of 20–30 m (Wong et al. 2012). *Pterygophora* is present in dense stands on a considerable portion of the hard substrate in the region. The approximate location of this site is 10 km south of the Angel's Gate, the entrance to the POLA (Appendices A.31, D.7, and E.4).

Huntington Flats. This bed was not observed in 2016, nor was it visible in 2015.

No kelp canopy has been observed in this area since the CRKSC surveys started in 2003 (Appendices A.35, A.36, D.8, and E.5).

Huntington Flats to Newport Harbor. No kelp was observed from Huntington Flats to Newport Harbor (which includes the area offshore of the Huntington Beach Generating Station and Orange County Sanitation District outfalls) in 2016 (Appendices A.36 through A.40, D.8, and E.5). However, narrow bands of kelp were visible on the Newport Harbor jetties during all four quarterly surveys in 2016 (Appendices A.40, A.41, D.8, and E.5) (note: not considered to be one of the 26 designated kelp beds within the CRKSC).

NEWPORT BEACH TO ABALONE POINT, LAGUNA BEACH

Newport/Irvine Coast. This kelp bed decreased in size from 0.045 km^2 to 0.036 km^2 in 2016 (a decrease of 20%).

Downcoast from Newport Harbor, giant kelp grows in a number of small beds (collectively called the Newport/Irvine Coast kelp bed, and referred to in some reports as the Corona del Mar kelp bed). Canopy coverage during December 2013 was the highest on record, and represented an 8% increase since 2012 (Figures 2 and 26; Appendices A.41, A.42, D.8, D.9, and E.5). Canopy size decreased in 2014 and 2015, and it decreased an additional 28% in 2016 (to 0.032 km^2). Kelp restoration efforts from 1986 through 2009 revived these beds from extirpation in the early 1980s (MBC 2010c). Kelp disappeared from this stretch of coast again in the 1990s, returned due to further restoration efforts in 2003. Low coverage or no canopy coverage was reported until 2005, and following that survey, the canopy area increased through 2014. However, in 2016 the canopy declined to its lowest coverage total since 2007.

During the vessel survey in February 2016, scattered canopy was visible from Corona del Mar to Crystal Cove and a dense canopy was observed at Whistlers reef off Corona del Mar. Only scattered kelp was observed off of Reef Point even though a fair amount was observed in the December 2015 overflight. Only scattered kelp was observed on the surface in locations where dense beds previously thrived. However, subsurface kelp was visible from the vessel. Kelp tissue color at Crystal Cove was medium yellow, indicating a recent lack of nutrients. During the vessel survey in March 2017, the kelp bad at Corona del Mar measured approximately 150 m by 100 m, fronds were three to four meters long, and tissue color was dark yellow. At Whistlers reef off Corona del Mar, kelp grew between depths of 10 m and 13 m, fronds were three to four meters long, and tissue color was dark yellow. A large canopy (600 m long by 200 m wide) was visible at Scotchman's Cove, fronds were two to four meters long, and tissue color on the bottom was dark yellow.

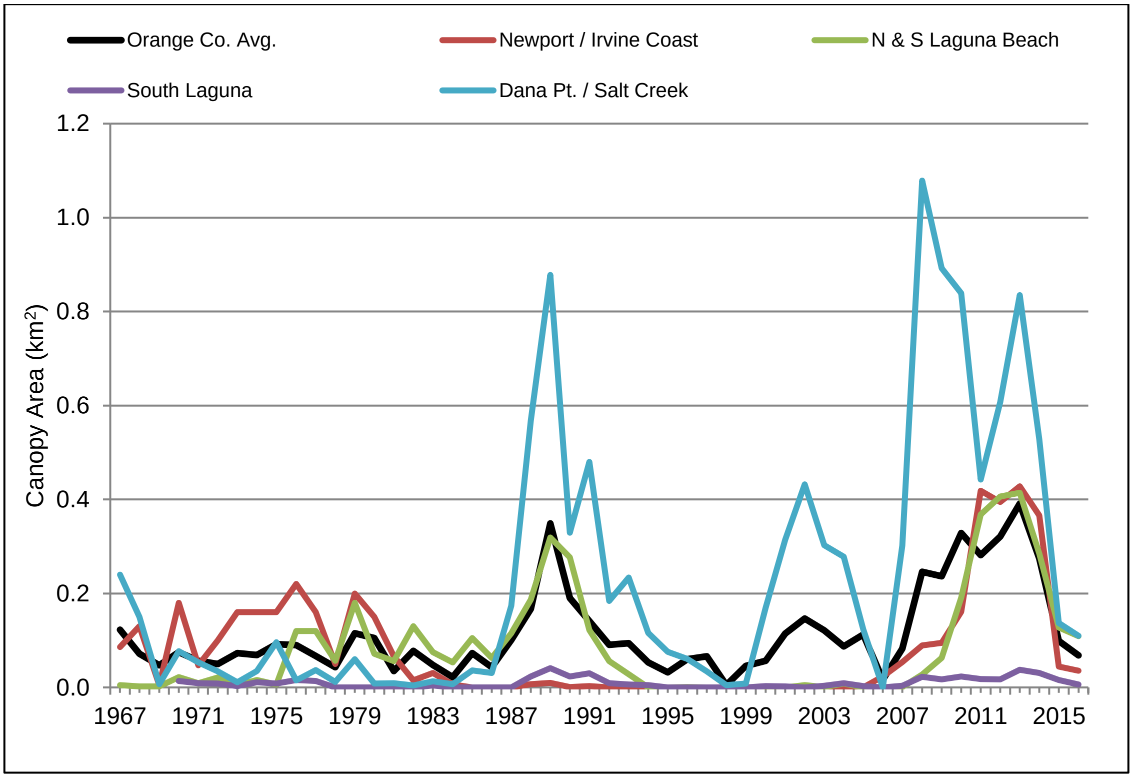


Figure 26. Comparisons between the average Orange County ABAPY and the canopy coverage of the kelp beds from Newport/Irvine Coast to Dana Point/Salt Creek from 1967 through 2016.

REGION NINE KELP SURVEYS

The Region Nine program identifies 24 individual kelp beds, although many are comprised of two or more distinct beds. As described previously, the boundary between the Central Region and Region Nine is Abalone Point in Laguna Beach. However, the Region Nine surveys have historically included the beds from Newport Harbor to Abalone Point (described above). The combined RNKSC kelp canopy coverage has been well above the long-term average during each of the last nine years through 2015 (Figure 27). Each bed is also compared to the average for the beds in both Orange and San Diego County, excluding the very large beds of La Jolla (LJ) and Point Loma (PL), because these two beds skew the data (Figures 2, 26, 27, and 28; Appendices A.41 through A.80, D.9 through D.15, and E.5 through E.9). The ABAPY values by year for Region Nine (beds offshore Orange County, and offshore San Diego County, minus Point Loma and La Jolla) are presented in Figure 20.

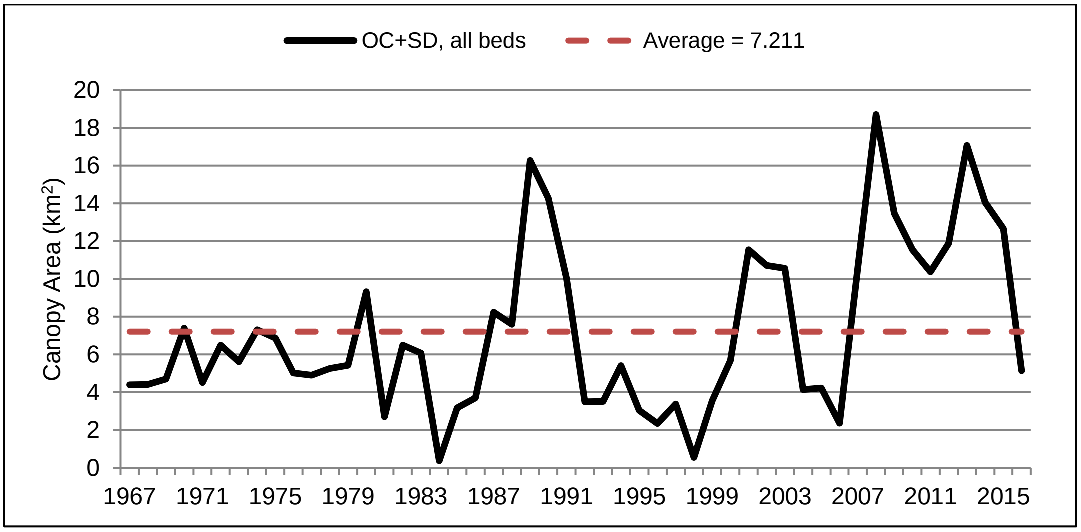


Figure 27. Combined canopy coverage of all kelp beds off Orange and San Diego Counties from 1967 through 2016.

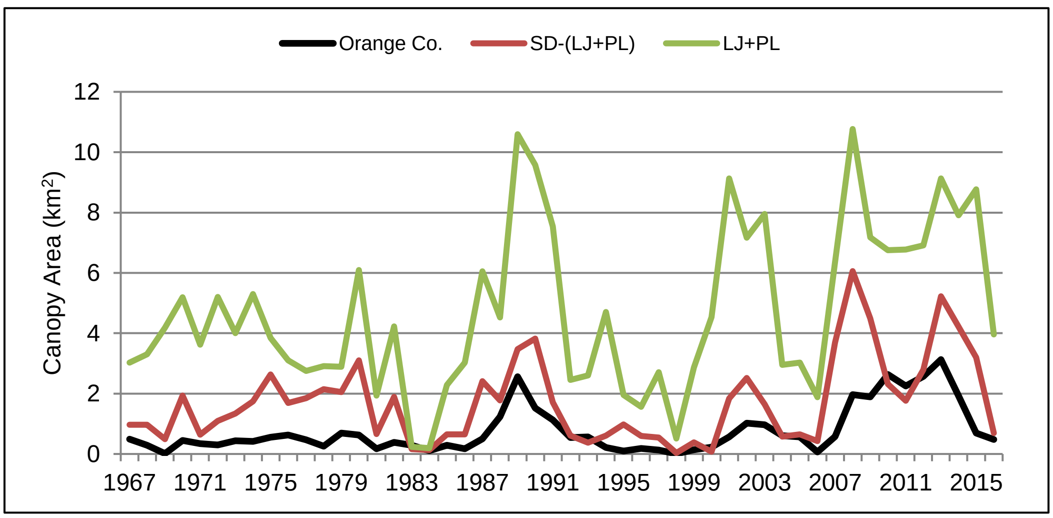


Figure 28. Diagram showing components of the Total Area graph partitioned into the kelp beds of: Orange County; San Diego County less La Jolla and Point Loma (SD-[LJ+PL]); and La Jolla plus Point Loma (LJ+PL) from 1967 through 2016.

ABALONE POINT TO CAPISTRANO BEACH

North Laguna Beach/South Laguna Beach. The North Laguna Beach kelp bed decreased in size from 0.080 km^2 in 2015 to 0.074 km^2 in 2016 (a decrease of 7.5%), while the South Laguna Beach kelp bed decreased in size from 0.048 km^2 in 2015 to 0.035 km^2 in 2016 (a decrease of 27%). Combined, the two kelp beds decreased from 0.128 km^2 in 2015 to 0.109 km^2 in 2016 (a decrease of 15%).

Based upon the combined annual total kelp canopy coverage, the total area calculated at these two areas in 2013 (0.415 km^2) was the largest on record. However, canopy declined each year thereafter. By 2016, combined canopy size was 22% lower than the long-term average of 0.085km^2 The two Laguna Beach beds followed the patterns of the ABAPY (when canopy was apparent), and survived the El Niño of 1982–1984, but were extirpated in 1994 (Figures 2 and

26; Appendices A.42, A.43, D.9, and E.5). The Laguna Beach beds were not visible until about 2006 when they reappeared as a result of restoration efforts, and have since followed the ABAPY. During the 2016 vessel survey, the existing canopy measured about 150 by 200 m, with scattered kelp on the surface throughout the area. Subsurface kelp was visible on the fathometer. Tissue color was dark yellow, and about 80% of the inspected fronds were mature. During the March 2017 vessel survey off Heisler Park, kelp was growing to depths of 11 to 18 m, and the bed was approximately 200 m by 200 m. Tissues were dark yellow, and fronds were two to three meters long. At one of the restoration sites, kelp was growing in two distinct patches, but was scattered throughout both areas. The total extent at that site was approximately 300 m long by 100 m wide. On the bottom, tissues were dark yellow, and there was no evidence of grazing, encrusting, or sedimentation.

South Laguna. This kelp bed decreased in size from 0.016 km^2 in 2015 to 0.006 km^2 in 2016 (a decrease of 63%).

In 2013, the South Laguna kelp bed more than doubled in size from 2012, and it reached its largest extent since 1989. The bed decreased in size by 65% in 2016 (to 0.006 km^2). The South Laguna kelp bed was much smaller than the ABAPY during most years, and canopy size at this site has not trended well with the ABAPY (Figures 2 and 26; Appendices A.45, D.9, and E.6). However, the bed responded to relatively large stimuli such as the 1989–1990 La Niña, and since 2007 has usually trended in the same direction as the ABAPY Its size in 2016 was 33% smaller than the long-term average of 0.009 km^2. During the February 2016 vessel survey there was no visible kelp on the surface, although kelp was observed on the fathometer throughout the area. During the March 2017 vessel survey, surface canopy was approximately 500 m long by 50 m wide, with scattered kelp and three- to four-meter-long fronds.

Dana Point/Salt Creek. This kelp bed decreased in size from 0.137 km^2 in 2015 to 0.110 km^2 in 2016 (a decrease of 20%).

The canopy at Dana Point/Salt Creek has fluctuated greatly over the last 49 years. Maximum canopy size was reported in 2008, but it decreased by more than half (59%) by 2011. Water conditions changed and the kelp bed increased by 22% through 2013, only to decrease in subsequent years. The beds at Dana Point/Salt Creek have been much larger than the ABAPY for much of the past decade (Figures 2 and 26; Appendices A.46, D.9, and E.6). Canopy growth/reduction has usually corresponded with the ABAPY, although canopy decreases in 2009 and 2010 were out of synchrony with the Orange County average. During the February 2016 vessel survey, no surface canopy was observed but a large amount of subsurface kelp was observed in scattered areas of the bed's footprint. The subsurface kelp was visible out to the 15-m isobath. During the March 2017 vessel survey, scattered kelp was visible on the surface (and just below the surface) at Salt Creek. Kelp was growing at depths of about 13 to 18 m, but plants were visible on the fathometer inshore to about 9 m. Fronds were three to four meters long, and tissues were dark yellow.

Capistrano Beach. This kelp bed increased in size from 0.007 km^2 in 2015 to 0.012 km^2 in 2016 (an increase of 71%).

In 2016, the Capistrano Beach kelp bed expanded), but it still only covered 5% of the historical maximum canopy area measured in 1989 (0.233 km^2). The Capistrano Beach bed (combined with San Clemente beds) have responded in synchrony with the ABAPY—increasing during good years and decreasing during stressful periods (Figures 2 and 29; Appendices A.47 A.48, D.10, and E.6).

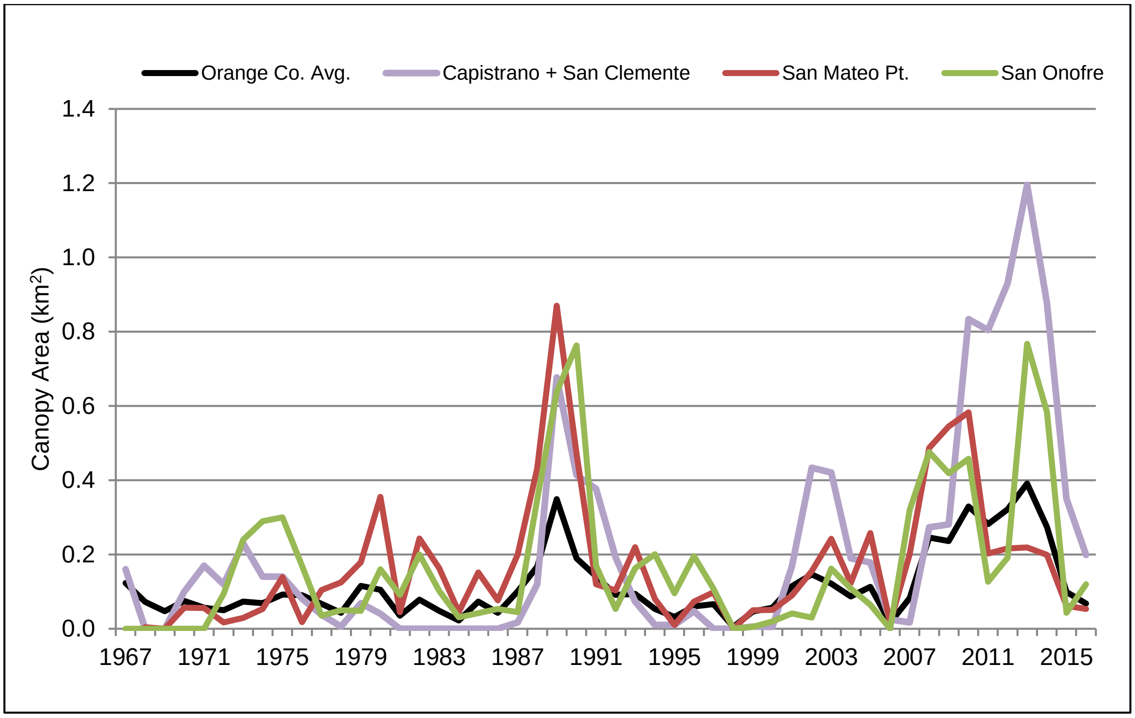


Figure 29. Comparisons between the average Orange County ABAPY and the canopy coverage from Capistrano Beach to San Onofre from 1967 through 2016. The Capistrano and San Clemente kelp bed areas are combined to facilitate visualization.

During the 2016 vessel survey, kelp was sparse and there was no coherent canopy at Capistrano Beach. However, some subsurface kelp was visible on the fathometer. The subsurface kelp was three to four meters tall. During the March 2017 vessel survey, there was no kelp on the sea surface. Subsurface kelp was visible at about the 14-m isobath, but the current was holding it down.

SAN CLEMENTE TO SAN ONOFRE

San Clemente. This kelp bed decreased in size from 0.343 km^2 in 2015 to 0.187 km^2 in 2016 (a decrease of 45%).

Beginning in 2002, the kelp beds at San Clemente were enhanced by the placement of approximately 50 small artificial reefs (each measuring 40 m x 40 m) on barren sand at depths of about 12 to 15 m. Kelp immediately recruited to these reefs, and canopies in the shape of small squares were visible during most of the aerial surveys of 2002 and 2003. In early 2008, Southern California Edison (SCE) added additional reef material (covering 0.712 km^2 in total) and kelp recruited to the new reefs in late 2008. After increasing in size for seven consecutive years (from 0.014 km^2 in 2006 to 1.097 km^2 in 2013, a 99% increase), the canopy coverage of this reef decreased by 83% from 2013 to 2016, with 46% canopy loss from 2015 to 2016 Despite this, observations by divers indicated good recruitment in 2015 (K. Anthony 2016, pers. comm.). The canopy area was still much larger than the long-term Orange County average in 2015, and San Clemente was the fourth largest bed in Region Nine. The San Clemente beds (combined with the Capistrano Beach beds) have responded synchronously with the ABAPY (Figure 29; Appendices A.49, A.50, D.10, and E.6). During the January 2015 vessel survey, there was a cohesive canopy more than 1.6 km long. However, during the

February 2016 vessel survey, only scattered plants were observed on the surface, and they consisted of an even mix of mature and young fronds. Kelp was observed on the bottom with the fathometer in widely scattered areas within the footprint of the reef. During the March 2017 vessel survey, surface kelp was visible in an area at the northwestern end of the kelp bed measuring approximately 150 m by 100 m. Kelp tissues were dark yellow, fronds were two to four meters long. In the central portion of the kelp bed at one of the artificial reef modules, fronds were two to three meters long.

San Mateo Point. This kelp bed decreased in size from 0.062 km^2 in 2015 to 0.053 km^2 in 2016 (a decrease of 15%).

The bed was much smaller than the maximum sizes measured in 1989 (0.870 km^2) and 2010 (0.583 km^2). The average change in canopy size in Region Nine between 2012 and 2013 was a 22% increase; however, the San Mateo bed remained about the same size (Figures 2 and 29; Appendices A.50, D.10, and E.6). Still, the San Mateo kelp bed has closely followed the patterns of the Orange County long-term average (Figure 29). There was a 200-m by 300-m canopy observed during the February 2016 vessel survey, with scattered individual kelp surfacing in the surrounding area. The canopy extended out to a depth of 17 m, and consisted of young, dark yellow fronds. Kelp was visible on the fathometer inshore to a depth of 11 m. Giant kelp >2 m tall were not observed during dive surveys at some of the stations within San Mateo kelp bed in December 2015, but density increased to 0.54 kelp/m^2 at one station by December 2016, the highest at that station since the 1980s (MBC unpubl. data, 2017). During the March 2017 vessel survey, kelp was growing to a depth of 18 m, and consisted of mature, dark yellow fronds that were two to four meters long. Tissues were dark yellow.

San Onofre. This kelp bed increased in size from 0.043 km^2 in 2015 to 0.120 km^2 in 2016 (an increase of 179%).

The San Onofre Nuclear Generating Station (SONGS) reactors were shut down in January 2012 due to safety concerns, and the decision was made in June 2013 to permanently retire the facility. Discharge flows from the ocean outfall have decreased substantially, since limited water flow is required to gradually cool down spent nuclear fuel (current flows are approximately 4% of the previous volumes discharged during normal plant operations).

Canopy size at San Onofre in 2013 (0.767 km^2) represented more than a four-fold increase from 2012, and that canopy size was the largest recorded by the RNKSC in this century (Figures 2 and 29; Appendices A.50, A.51, D.10, and E.6). In 2015, the San Onofre kelp bed decreased in size by 93%, and canopy area was the smallest measured since 2006. The kelp bed nearly tripled in size in 2016, and canopy size (0.120 km^2) was similar to that measured in 2011 Because of their location in a similar geographically area, San Mateo kelp bed has been used in several scientific studies as a control station for San Onofre kelp, and the two beds usually react similarly (Figure 30). The San Onofre kelp bed has usually followed the ABAPY for Orange County and San Diego County (Figure 29). In February 2016, no canopy was visible during the vessel survey, but scattered kelp was visible and observed on the fathometer. All of the fronds observed were young with good apical tips, and tissue color was medium yellow. Giant kelp >2 m tall were not observed during dive surveys at San Onofre kelp in 2015, but density increased to 0.02 kelp/m^2 in July and December 2016 (MBC unpubl. data, 2017). Densities were still below the long-term mean for San Onofre (0.10 kelp/m^2). During the March 2017 vessel survey, kelp was visible in two areas measuring approximately (1) 100 m by 150 m and (2) 300 m by 200 m. Fronds were four to five meters long, and the apical tips

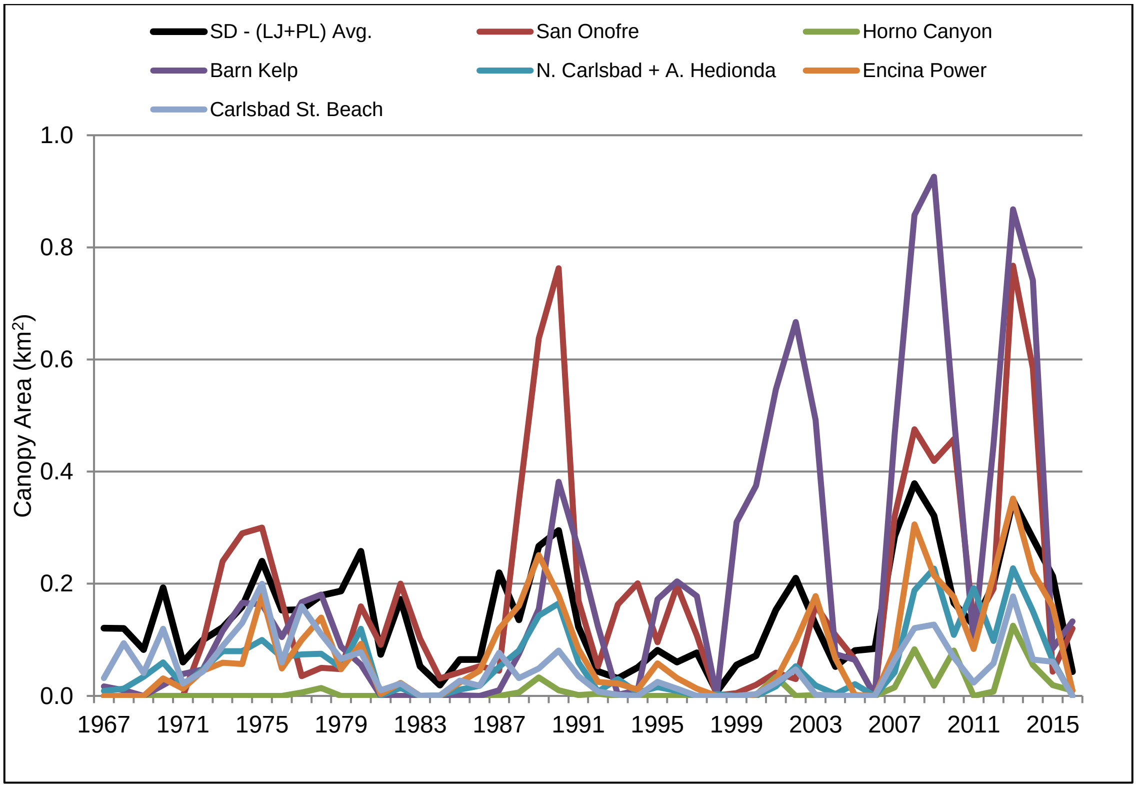


Figure 30. Comparisons between the average SD-(LJ+PL) ABAPY and canopy coverage from San Onofre to Carlsbad State Beach for the years shown.

were mostly tattered. Almost all (95%) of the fronds were encrusted in the smaller area examined, but not at the larger area. Tissues were dark yellow.

HORNO CANYON TO SANTA MARGARITA RIVER

Horno Canyon. This kelp bed decreased in size from 0.019 km^2 in 2015 to 0.010 km^2 in 2016 (a decrease of 47%).

The Horno Canyon kelp beds are small and have been viable only during very large stimuli—such as the La Niñas of 1989–1990, 2001, and 2007–2008—and during the last five years (Figures 2, 12 and 30; Appendices A.52, A.53, D.11, and E.7). In 2013, kelp coverage at Horno Canyon (0.125 km^2) was the highest on record since 1911. The canopy area decreased each of the last three years, including a 49% reduction in 2016 (Figure 30). Pendleton Artificial Reef (PAR) is just upcoast from Horno Canyon (Appendix A.52). During the February 2016 vessel survey, no kelp was observed growing at PAR, nor was any kelp visible below the surface. During the March 2017 vessel survey, no surface canopy was visible at PAR, but one kelp plant was visible on the fathometer. No other kelp was visible at Horno Canyon.

Barn Kelp. This kelp bed increased in size from 0.085 km^2 in 2015 to 0.133 km^2 in 2016 (an increase of 56%).

In 2013, Barn kelp was more than three times larger than average, and it was the fifth largest kelp bed in Region Nine. By 2015, it had decreased in size by 90%, and it was the eleventh largest bed of 24 beds (Figures 2 and 30; Appendices A.53, A.54, D.11, and E.7). No kelp was visible downcoast from Barn kelp offshore Camp Pendleton (Appendices A.55, D.11, and E.7). Other than the severe downturn from 1980 to 1987, and the increase in 2016, Barn kelp reacted similarly to the other beds in the San Diego region (Figure 30).

Because of the importance of this bed as a long-term control for San Onofre kelp bed, a dive survey was conducted here on two 50-m by 2-m transects in February 2016. A total of 104 adult, juvenile, and recruiting kelp were observed on one transect and 95 on the other transect. There were about 20 recruits counted on each transect, which could enhance recovery if environmental conditions become favorable. There was some sediment and encrusting bryozoans on the blades, and tissues were medium to dark yellow, which suggested recent nutrient availability. In March 2017, surface kelp was visible in several large areas measuring about 1,500 m by 100 m. Fronds were dark yellow and approximately two to three meters long.

Santa Margarita. This kelp bed was not observed during 2016, nor was it visible in 2015.

The Santa Margarita kelp bed is a small bed that occasionally forms a canopy off the Santa Margarita River mouth (Figure 2; Appendices A.56, D.11, and E.7). In 1911, Santa Margarita was the site of a substantial kelp bed that covered 0.858 km^2. Kelp disappeared here sometime before regular surveys began in 1967 by Dr. North. No kelp was seen during any of the vessel or aerial surveys until 1991, when a small bed covered an area of 0.049 km^2; it was much smaller in 1992, and disappeared in 1993. No canopy was observed at Santa Margarita for the next two decades, but a small kelp bed was visible during the December 2013 overflight. The size of the bed in 2013 (0.080 km^2) was 63% larger than in 1991. No canopy was observed at this site since 2013. During the vessel surveys in February 2016 and March 2017, no kelp was visible on or below the surface despite a thorough search of the area.

NORTH CARLSBAD TO CARLSBAD STATE BEACH

North Carlsbad. This kelp bed was not visible in 2016, decreasing from a size of 0.047 km^2 in 2015.

The North Carlsbad kelp bed is usually comprised of several small beds (Figures 2 and 30; Appendices A.59, A.60, D.12, and E.7). In 2016, however, the beds were not visible. The North Carlsbad and Agua Hedionda kelp beds disappeared or became very small during warm-water periods, but reacted strongly to stimuli such as large La Niña events (Figures 12 and 30). The two beds combined followed the ABAPY closely, but were out of synchrony during the 2011–2012 surveys (Figures 2 and 30; Appendix A.59). During the February 2016 vessel survey, one patch measuring 100 m by 30 m, and small patches of scattered kelp were observed in the area. Tissues were dark yellow, and apical meristems (scimitars) on growing tips were tattered, likely due to 4-m to 5-m swells the previous week. In March 2017, kelp was inspected in an area measuring 100 m by 100 m; fronds were two to three meters long and tissues were dark yellow.

Agua Hedionda. This kelp bed was not visible in 2016, decreasing from a size of 0.016 km^2 in 2015.

The North Carlsbad and Agua Hedionda kelp beds disappeared or became very small due to periods of below-average nutrient availability, but reacted strongly to stimuli such as large La Niña events. The two beds combined followed the ABAPY closely, but remained below the San Diego long-term average, and were out of synchrony during 2011–2012 ((Figures 2 and

30; Appendices A.59, D.12, and E.7). During the February 2016 vessel survey, the bed at Agua Hedionda was very patchy with only a few adult plants observed in the water column. Fronds were four to five meters long, and tissues were medium yellow and dark yellow. During the March 2017 vessel survey, no kelp was visible on or below the sea surface off Agua Hedionda.

Encina Power Plant. This kelp bed decreased in size from 0.159 km^2 in 2015 to 0.009 km^2 in 2016 (a decrease of 94%).

The Encina Power Plant kelp bed reached its maximum size in 2013 (0.352 km^2). The canopy decreased in size during each of the next three years (Figures 2 and 30; Appendices A.60, A.61, D.12, and E.8). The canopy in this area has oscillated above and below this mean since 1999 (Figure 30). In 2016, however, canopy area was only 11% of the historical average. The Encina Power Plant kelp bed mirrored the other beds in the San Diego region, and its changes in size over the years tend to follow the ABAPY (Figure 30).

Because this bed had been so vibrant during the December 2014 vessel survey, but appeared to be diminished at the surface during the February 2016 vessel survey, an in-water dive survey was conducted at this location in February 2016. On two 50-m by 2-m transects, adult, juvenile and recruiting kelp were observed on the bottom: 73 on one transect and 30 on the other. There was some sedimentation, and many of the adult kelp were lacking blades. Urchins were observed in holes and did not appear to be mobile, and there were several old holdfasts that may have been dislodged due to the heavy surge caused by the recent high surf. During the March 2017 vessel survey, the Encina Power Plant kelp bed was dense and extensive (~500 m long by 300 m wide). The bed consisted of mostly mature plants (60%), and subsurface kelp was visible on the fathometer.

Carlsbad State Beach. This kelp bed was not observed in 2016, decreasing from a size of 0.061 km^2 in 2015.

The Carlsbad State Beach (Carlsbad State Park) kelp bed made considerable gains in 2013, and increased three-fold to 0.178 km^2 (Figures 2 and 30; Appendices A.60, A.61, D.12, and E.7). However, it decreased in size thereafter, and was not visible in 2016. This bed grew or decreased in size similarly to the other beds in the San Diego region through about 1977. It acted in opposition to the ABAPY in 1978–1979, but while muted, acted in concert with the ABAPY during the last three decades (Figure 30). During the February 2016 vessel survey, the bed off Carlsbad State Beach consisted of only scattered kelp, and a few fronds reached the surface. Many of those fronds consisted of missing or tattered meristems. During the March 2017 vessel survey, no kelp was visible on the sea surface, but a few subsurface plants were visible on the fathometer.

LEUCADIA TO TORREY PINES

Leucadia. This kelp bed decreased in size from 0.414 km^2 in 2015 to 0.032 km^2 in 2016 (a decrease of 92%).

The Leucadia kelp bed is comprised of the North, Central, and South Leucadia kelp beds (surveyed as three separate beds because of distinct breaks in the beds; see Figure 2; Appendices A.62, A.63, D.12, and E.7). In 2013, Leucadia kelp bed increased to its highest coverage in the last 30 years (0.541 km^2), but the bed size in 2016 represented only 6% of the 2013 maximum (Figure 31). In 2015, the North bed (off Batiquitos Lagoon) grew by 37%, the Central bed grew by 68%, and the South bed grew by 104% since 2014. In 2016, each of the three beds shrank by 90–93%. The Leucadia kelp beds have usually mirrored the other beds in the San Diego region (Figure 31). During the February 2016 vessel survey, the canopy at North Leucadia was extensive but sparse. Fronds were three to five meters long, with about 40% having encrustations. The canopy in the Central bed was also extensive but scattered, and about 40% of the blades inspected had encrustations. Fronds were about two meters long, and tissues were dark yellow. At the southern bed, tissues were dark yellow and fronds were tattered. During the March 2017 vessel survey, the Central bed was dense and consisted of three- and four-meter-long fronds, but the apical tips were mostly tattered. The southern bed was large (250 m by 250 m) and dense.

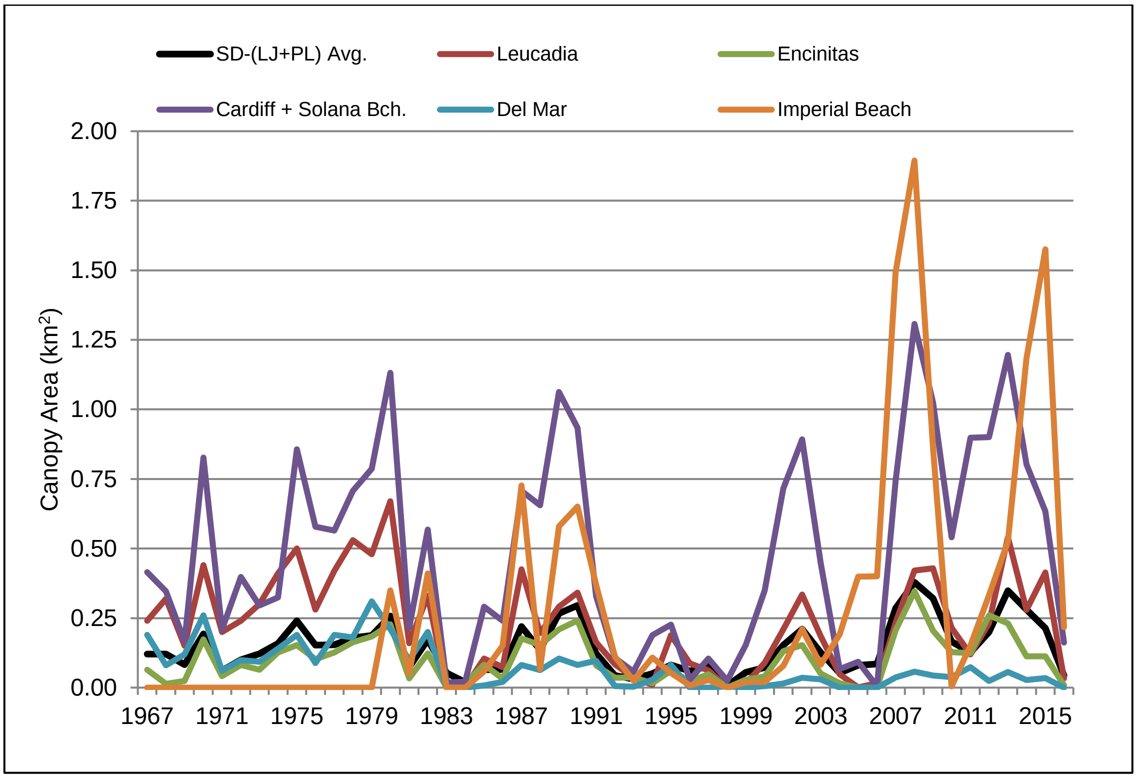


Figure 31. Comparisons between the average SD-(LJ+PL) ABAPY and canopy coverage from Leucadia to Del Mar (and Imperial Beach) for the years shown.

Encinitas. This kelp bed decreased in size from 0.113 km^2 in 2015 to 0.009 km^2 in 2016 (a decrease of 92%).

The size of this bed has mirrored the other beds in the San Diego region (Figure 31). The decrease in size from 2015 to 2016 was consistent with the other beds between Carlsbad and Imperial Beach (Figure 2; Appendices A.63, A.64, D.12, D.13, and E.7). During the vessel survey in February 2016, a thin kelp canopy covered an area measuring 300 m by 100 m; however, most of the growing apical scimitars were missing or tattered. In March 2017, kelp at Encinitas covered an area of about 400 m by 400 m. Most (60%) of the plants were mature, and most of the apical tips were tattered. The inshore extent of the bed was at a depth of 15 m.

Cardiff. This kelp bed decreased in size from 0.318 km^2 in 2015 to 0.024 km^2 in 2016 (a decrease of 92%).

This bed reached a peak of 0.590 km^2 in 2013, but has declined over the past few years (Table 2).

Solana Beach. This kelp bed decreased in size from 0.316 km^2 in 2015 to 0.138 km^2 in 2016 (a decrease of 56%).

In 2016, the Cardiff and Solana Beach kelp beds decreased in size by 92% and 56%, respectively (Figures 2 and 31; Appendices A.64, A.65, D.13, E.7, and E.8). Combined, these two beds are more than three times larger than the ABAPY in the San Diego region. Changes in Cardiff/Solana Beach kelp bed sizes have usually mirrored the other beds in the San Diego region, although the magnitude of the changes was generally greater because of the relatively large size of these two beds. By 2016, canopy sizes were only 4% (Cardiff) and 17% (Solana Beach) of historic maximum areas (Figure 31).

During the 2016 vessel survey, there was a thin canopy measuring about 50 m by 100 m off Cardiff, and a larger area measuring 200 m by 400 m off Solana Beach. Scattered kelp was present in both beds, and extensive subsurface kelp was metered at Cardiff. Most of the visible growing tips were tattered. Frond lengths were four to five meters off Solana Beach, and three to five meters off Cardiff. Tissues were medium yellow at both locations. In March 2017, scattered kelp was visible at Cardiff in an area of about 800 m by 400 m. Fronds were three to four meters long, and tissues were medium yellow in color. At Solana Beach, kelp was visible in two areas that extended for at least one kilometer alongshore and 400 m cross-shore. Kelp was growing at depths between 12 and 14 m.

Del Mar. This kelp bed was not observed in 2016, decreasing from a size of 0.034 km^2 in 2015.

The Del Mar kelp bed is typically one of the smallest beds in Region Nine, and in 2015 its canopy area (0.034 km^2) was the fourth smallest among beds displaying canopy (Figures 2 and 31; Appendices A.66, D.13, and E.8). This bed has remained below the San Diego long-term mean since 1983 (Figure 31). This kelp bed typically has mirrored the other beds in the San Diego region, although it reacted opposite the ABAPY during 2011–2012 and 2015. Its size has usually been much smaller than that of the ABAPY since 1983 (Figure 31). No surface canopy was observed during the February 2016 vessel survey, nor was any subsurface kelp seen on the fathometer. No surface canopy was visible during the March 2017 vessel survey; however, a few subsurface kelp plants were visible during a fathometer search at a depth of about 12 m.

Torrey Pines. This kelp bed was not observed in 2016, nor was it visible in 2015.

Torrey Pines kelp bed appeared as a small trace of kelp during La Niña conditions in 1988 and 1989. It reappeared in 2006 as a measurable canopy (0.010 km^2) with scattered giant kelp about 1.5 km north of Scripps Pier, another concentration about 3.5 km north, and a third concentration of scattered giant kelp was found about 1.5 km north of that position (5 km north of the pier) (Figures 2 and 31; Appendices A.67, A.68, D.13, and E.8). The canopy disappeared in 2007, but from 2008–2013 small canopies were observed in various locations in the area. In 2013, Torrey Pines kelp bed was measured at its largest extent (0.081 km^2), but no canopy was visible during the quarterly surveys of 2014–2016. Only a few giant kelp fronds were observed at the surface during the February 2016 vessel survey; no surface canopy was observed at Torrey Pines. During the March 2017 vessel survey, no kelp was visible on or below the sea surface.

LA JOLLA

La Jolla. This kelp bed decreased in size from 2.968 km^2 in 2015 to 0.927 km^2 in 2016 (a decrease of 69%).

La Jolla kelp bed is composed of two canopies: northern La Jolla and southern La Jolla (Figures 2 and 31; Appendices A.69, A.70, D.13, D.14, and E.8). Between southern La Jolla and Upper Point Loma (offshore Mission Bay), nearshore habitat is mostly sandy and kelp does not grow in this area (Appendices A.70, A.71, D.14, and E.8). In 2016, La Jolla kelp canopy coverage decreased by 69% and covered 0.927 km^2 (Figure 32). La Jolla kelp bed was the second largest bed in Region Nine. Changes in bed size at La Jolla have usually mirrored those at Point Loma, but in 2014 La Jolla decreased while Point Loma maintained most of its size (Figure 32). This suggests that, overall, they are usually affected by the same oceanographic regime, but that small differences in bathymetry and currents can still make profound differences in the availability of nutrients to kelp beds that otherwise appear very closely related.

During the February 2016 vessel survey, there was no coherent canopy along the entire northern or central La Jolla kelp bed footprint, nor was any canopy observed at southern La Jolla. There were, however, scattered individual kelp plants, as well as plentiful kelp observed on the fathometer throughout the area. Frond length was about one meter, and apical blades were tattered. Tissues were medium yellow. During the March 2017 vessel survey, kelp was extensive but density was low at northern La Jolla. Fronds were three to four meters long, and tissues were dark yellow. At southern La Jolla, kelp was growing in a continuous bed approximately six kilometers long. The offshore extent of the bed was on the 18-m isobath. Fronds were three to four meters long, and tissues were dark yellow.

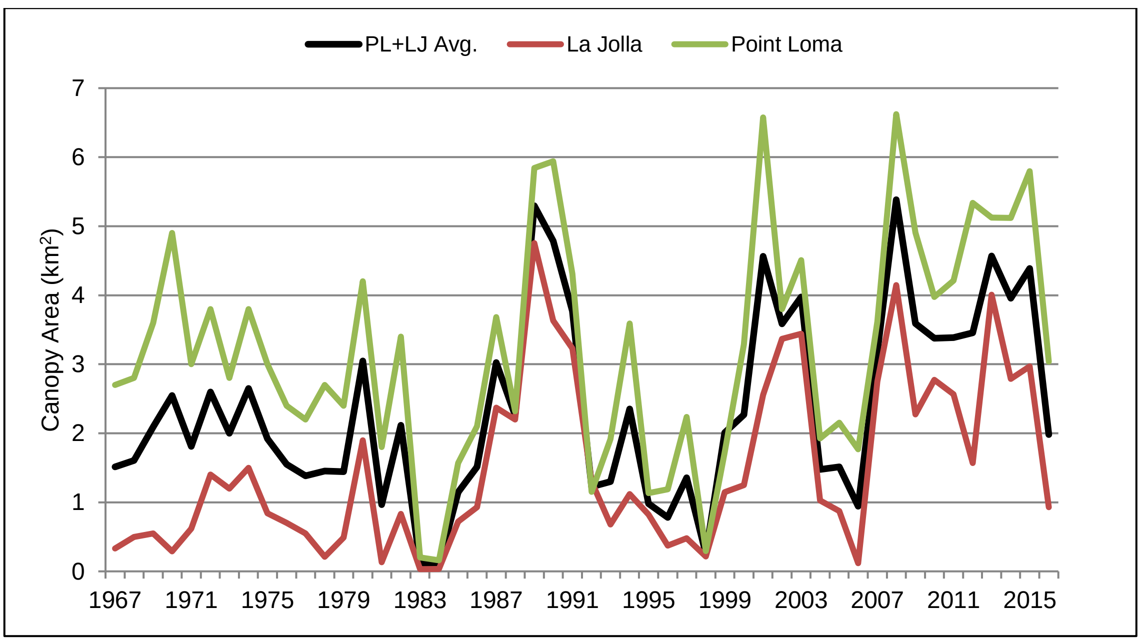


Figure 32. Comparisons between the (LJ+PL)/2 ABAPY and canopy coverage of the La Jolla and Point Loma kelp beds for the years shown.

POINT LOMA TO IMPERIAL BEACH

Point Loma. This kelp bed decreased in size from 5.806 km^2 in 2015 to 3.037 km^2 in 2016 (a decrease of 48%).

The Point Loma kelp bed is composed of many, usually contiguous, kelp canopies ranging from depths of 5 m to >30 m during years with sufficient nutrients (Figures 2 and 32; Appendices A.71 through A.74, D.14, D.15, and E.9). *Pelagophycus* is prevalent beyond about 30 m at Point Loma (Turner et al. 1968). Similar to La Jolla, the Point Loma kelp bed was divided into upper and lower sections. It is the largest bed in Region Nine. The canopy at Point Loma maintained a relatively large size (>5 km^2) from 2013–2015. However, in 2016, the canopy cover decreased 48% to a canopy area of 3.037 km^2, which was the lowest measured since 2006. The reduction in canopy coverage from 2015 to 2016 (2.759 km^2) was the largest annual decrease since 2001–2002 (2.775 km^2), although similar decreases were observed from 2008 to 2009 and from 2003 to 2004 (Figures 2 and 32; Appendices A.71 through A.74).

During the February 2016 vessel survey, kelp was scattered throughout the upper and lower sections of the bed, but no coherent canopy was observed. Subsurface kelp was visible on the fathometer. On the surface, fronds were two to eight meters long, and tissues were dark yellow. At Upper Point Loma (Appendix A.71), apical blades were tattered, and sedimentation was apparent on the fronds. At Lower Point Loma, apical blades were also tattered, but there was no indication of sedimentation.

During the March 2017 vessel survey, medium-density kelp was scattered throughout the Upper and Lower Point Loma kelp beds. Fronds were three to five meters long, and tissues were dark yellow. The offshore extent of kelp growth was at -17 m at Upper Point Loma, and -15 m at Lower Point Loma. There was extensive subsurface kelp visible on the fathometer at both locations.

IMPERIAL BEACH TO U.S./MEXICO BORDER

Imperial Beach. This kelp bed decreased in size from 1.576 km^2 in 2015 to 0.217 km^2 in 2016 (a decrease of 86%).

The canopy coverage at Imperial Beach has oscillated above and below the San Diego long-term mean since 1969 (Figures 2 and 31; Appendices A.78 through A.80, D.15, and E.9). In 2015, it was the third largest bed in Region Nine, and even though it did not match its size from 2008, it was still nearly five times larger than average. Except for the period from 1967 to 1979 (when it was missing) and 2015, the Imperial Beach kelp bed generally followed the ABAPY. The Imperial Beach kelp bed only was visible during the April survey, unlike most of the Region Nine kelp beds, which were found to have their maximum canopies at the end of the year.

The Imperial Beach kelp bed canopies have been observed in different locations during years when they were apparent. Svejkovsky (2015) noted "*major bed locations shifts and coverage area variability give the appearance in the persistence analysis that this kelp bed rarely persists longer than one year. In actuality the same bed appears to change in location slightly from year to year with some years (1999 and 2003) showing very sparse coverage and others (2008 and 2009) exhibiting much larger canopy area*."

In the vessel survey of February 2016, the Imperial Beach kelp bed was scattered but a fairly coherent canopy was estimated to cover 800 m by 800 m. Fronds were two to four meters long on the surface, and tissues were dark yellow. In addition to the surface canopy, subsurface kelp was visible on the fathometer in several locations. During the March 2017 vessel survey, there was no visible canopy at Imperial Beach. During a targeted fathometer search at two locations with dense kelp in 2016, no kelp was found.

UPDATE TO THE PRESENT

The first aerial survey for 2017 was conducted on March 29th. Based on a preliminary review of the data, the following is a summary of the canopy coverage through March 29, 2017, based on a review of the quarterly photographs.

- As of March 29, 2017, most of the kelp beds in both regions decreased in size (from canopy sizes observed in December 2016);
- Barn kelp was noticeably larger in March 2017 than three months earlier;
- There were turbid nearshore areas from Ventura Harbor to Port Hueneme, and at PV I; and
- There was substantial turbidity along several nearshore areas in Region Nine, including Capistrano Beach, Oceanside Harbor, Point Loma, and Imperial Beach. The turbidity at Imperial Beach prevented visibility of surface kelp canopy.

Sea surface temperatures in the Central Region and Region Nine were generally cooler from January–March 2017 than during the first quarter of 2016 (Figure 33), which could result in a higher nutrient quotient and better nutrient availability than during 2016 should that trend continue. El Niño-Southern Oscillation (ENSO)-neutral conditions were apparent at the equator from February through May 2017 (NOAA CPC 2017). ENSO-neutral and El Niño are equally favored during summer and fall 2017 in the Northern Hemisphere.

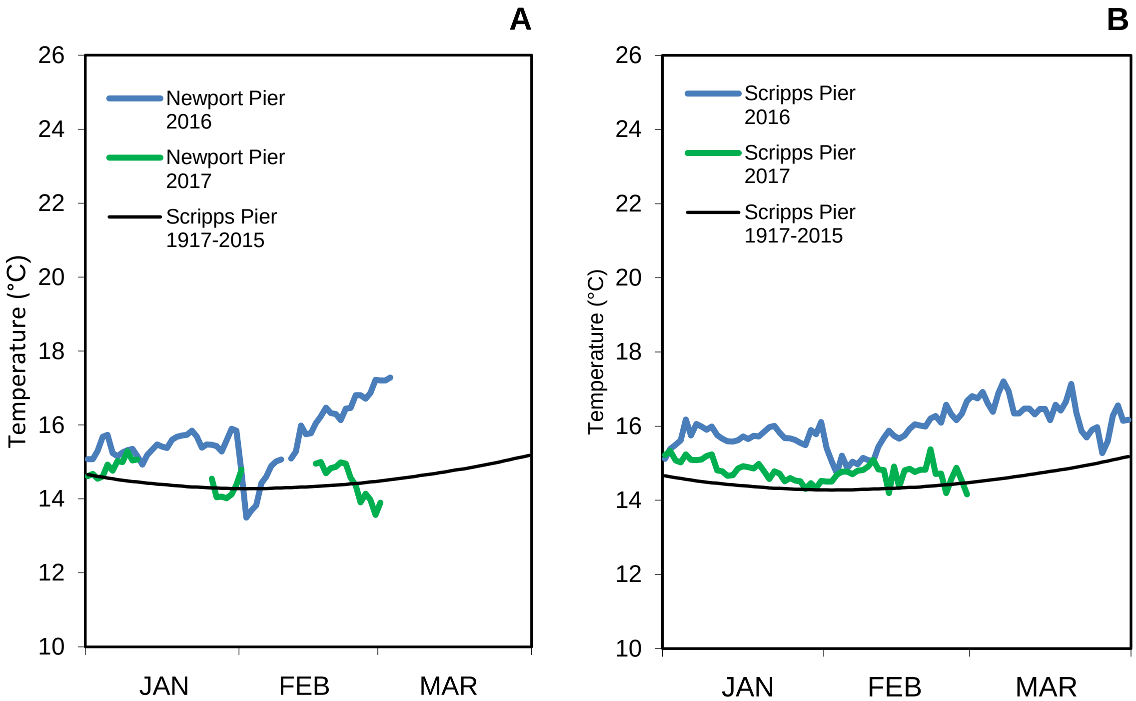


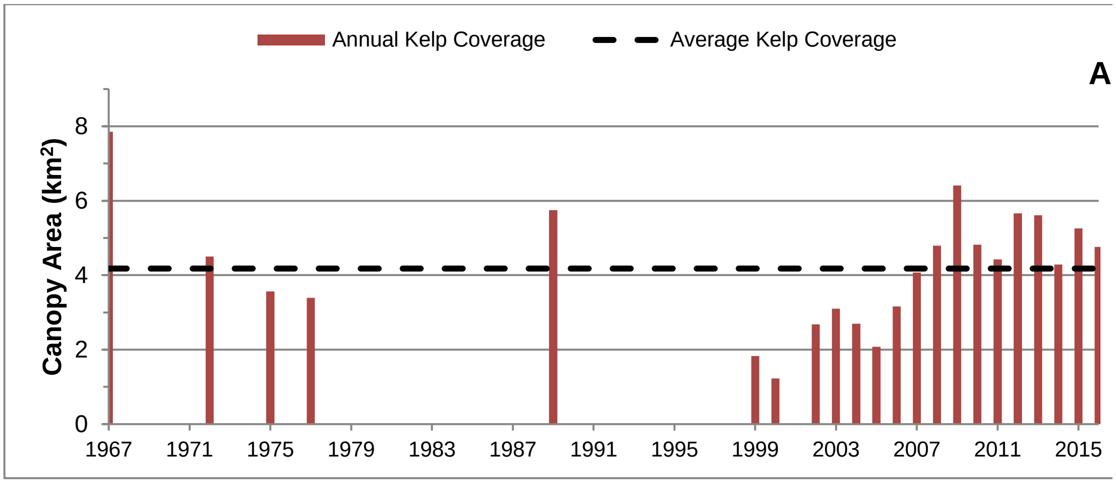
Figure 33. SSTs from January–April 2016 and 2017 at (A) Newport Pier and (B) Scripps Pier. 60-day harmonic mean from Scripps Pier (1917-2015) is presented for comparison.

It is unknown how the Central Region and Region Nine kelp beds will fare in 2017. By June 2017, El Niño conditions had dissipated at the equator, and water temperatures in southern California were near average (CDIP 2017; SCCOOS 2017). Equatorial El Niño and ENSO-neutral conditions are equally favored in summer and fall in the northern hemisphere (NOAA CPC 2017).

DISCUSSION

The CRKSC and RNKSC programs pose several monitoring questions that both surveys attempt to answer each year. These questions are:

1. What is the maximum areal extent of the coastal kelp bed canopies each year?
2. What is the variability of the coastal kelp bed canopy over time?
3. Are coastal kelp beds disappearing? If yes, what are the factors that could contribute to the disappearance.
4. Are new kelp beds forming?



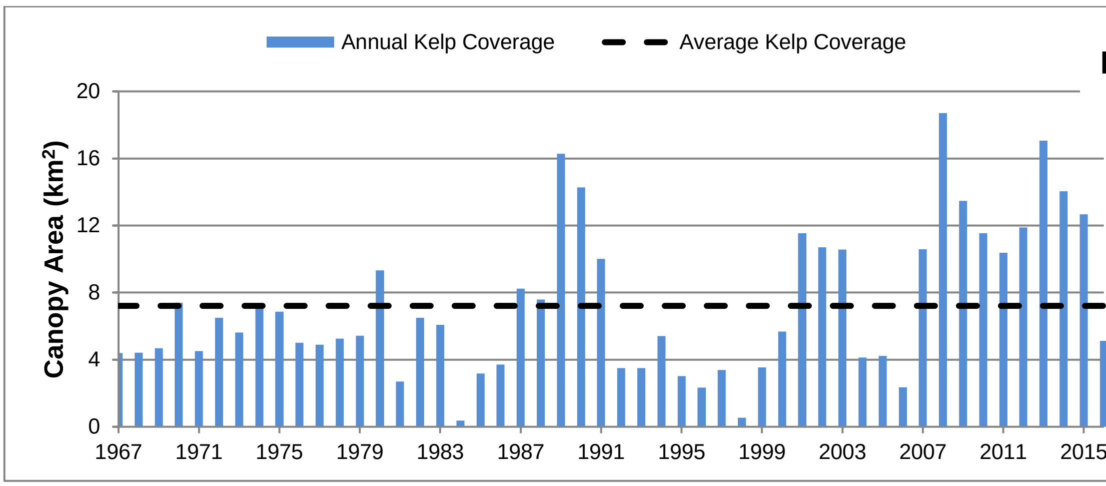


Figure 34. Annual and average kelp coverage in (A) the Central Region and (B) Region Nine.

Total canopy size within the 26 kelp beds monitored as part of the CRKSC program was above the historical averages in 2016 (Figure 34). However, the total canopy size of the 24 kelp beds in the RNKSC was below average. Together, the combined area of both study regions decreased 45% from 2015.

Kelp coverage in the CRKSC decreased by about 9.5%, and coverage in Region Nine decreased by about 59%. Within each region, there were major spatial differences in gains/losses. The six beds at the upcoast extent of the Central Region and the twelve beds at the downcoast extent of Region Nine all shrank in 2016, but between these areas 10 of the 32 kelp beds increased in size in 2016. Overall, two-thirds of the beds in the Central Region lost canopy in 2016 (including Las Tunas and Topanga, which disappeared), and nearly all of the Region Nine beds shrank last year (including North Carlsbad, Agua Hedionda, Carlsbad State Beach and Del Mar, which all disappeared). The Central Region kelp beds that increased in size last year included four beds between Paradise Cove and Sunset, two of the four Palos Verdes beds, and the Cabrillo kelp bed. The angle of the coastline from Point Dume to Santa Monica Bay is slightly different from that in other areas of Region Nine, and this affects the exposure to waves and upwelling, which is crucial in distributing nutrients. The PV I, PV IV, and the Cabrillo beds increased in size (by 1, 28, and 77%, respectively), while PV II and PV III decreased in size by 43% and 3%, respectively. Most of the kelp beds waned during the last half of 2016; however, the beds at Palos Verdes still displayed considerable canopy in the December survey.In 2015, three of the four beds at Palos Verdes increased in size, with the increase at PV IV the greatest among those three. This year, two of the beds increased in size, while two decreased in size. The five kelp beds at Palos Verdes (PV I through PV IV and Cabrillo) have only trended in the same direction as a group (in the same year) twice in the last 14 years.

Within Region Nine, the beds from North Carlsbad to Imperial Beach (excluding Torrey Pines, which only appears sporadically) lost an average of 86% of canopy size in 2016. The beds from Newport Beach to Barn Kelp (excluding Santa Margarita, which only appears sporadically) grew by an average of 27% in the last year. The two larger beds immediately upcoast from Imperial Beach (Point Loma and La Jolla) decreased in size since 2015. La Jolla lost 69% of canopy coverage, and Point Loma lost 48%. The Imperial Beach kelp bed, which expanded by 33% in 2016, shrank by 86%.

The reason for these uneven growth patterns at Palos Verdes and the three southernmost kelp beds is not known, but likely it is related to the angle of the coastline. This change in angle affects the exposure to wind, resulting waves, and upwelling (which is crucial for nutrient supply). Currents and water quality characteristics can interact with local geography and bottom topography and change on short time scales. Currents can bathe an area in nutrient-rich water in one portion of the tidal cycle and be completely absent in the next. From Salt Creek to Imperial Beach, most of the kelp was growing on the outer edges of the reefs when kelp coverage in 2016 was compared to canopies in 2008, the year with the largest coverage in Region Nine. This pattern is common, particularly in summer and fall. When thermoclines develop and shallow waters warm, surface kelp is usually limited to the outer margins of reef where deeper waters are cooler (MBC 1994–2016).

Konotchick et al. (2012) found that the discrepancies in the persistence of giant kelp in the northern and southern portions of the La Jolla kelp bed were caused by differential, alongshore vertical variations in temperature (and thereby nutrients) and topographically induced internal wave dynamics; instrumentation to elicit these parameters are not typically available in the scale of a regional study. Parnell (2015) analyzed algal patch structure and the importance of seascapes at La Jolla and Point Loma kelp beds. Understory algae grows within the La Jolla kelp forest, and offshore of the kelp forest (in association with *Pelagophycus*, which grows in waters as deep as 35 m). This highlights the importance of small-scale differences between/among kelp beds, and even within kelp beds, in affecting the distribution and growth of kelp.

From Ventura to Redondo Beach, kelp beds were at their greatest size during the 18 April or 20 June 2016 overflights. Sea surface temperatures in the Central Region were mostly above average from January through March, but there were marked periods of cool-water influx (potentially upwelled) beginning in February in both regions. Temperatures oscillated around the long-term harmonic mean from Scripps Pier from April through December. Most of the kelp beds from Malaga Cove (PV IV) to Imperial Beach attained maximum size during the 28 December 2016 overflight. The coolest temperatures of the year were recorded in June 2016 at Scripps Pier and in February 2016 at Newport Pier. Data from off Point Loma indicated that the water column was well mixed (i.e., no thermocline) from January through May, and surface waters warmed in June. Most of the kelp beds in southern California waned in size through the September survey. Note that there was above-average upwelling during five of the last six months of 2016.

Temperatures during the first three to four months of 2016 were mostly above average, but there were several cold-water influxes from mid-April through September. Seventy-four percent of the daily SST values at Scripps Pier in 2016 were above the long-term daily means and 84% were above the mean in 2015. The upwelling index (from offshore Solana Beach) indicated above-average upwelling during six months compared to the average since 1946. Strongest upwelling occurred in March, although the strongest upwelling events evident in the SSTs at the buoy/pier sites appeared to occur in summer and fall (Figures 7 through 9). The SSTs throughout the region increased in summer, but upwelling persisted through September. Highest SSTs occurred in July and August.

The warmer-than-average temperatures from late-2013 through most of 2015 coincided with “The Blob,” a large mass of warm water that formed off the Pacific Coast and affected coastal waters from the Bering Sea to Baja California (Bond et al. 2015). In November 2015, “The Blob” dissipated, but higher-than-normal temperatures remained along the southern California coast (NOAA SWFSC 2015). Typical atmospheric patterns over the northeast Pacific were replaced by a persistent ridge of high pressure that greatly affected the surface structure of the ocean (Leising et al. 2015). The Southern California Warm Anomaly (SCWA) was first evident in spring 2014 as a band of warm surface water along the shelf break. The temperature anomalies at a depth of 10 m in 2014 and 2015 were as large as those measured during the El Niño events in 1957–1958, 1982–1984, and 1997–1998.

El Niño conditions persisted into 2016, but transitioned to ENSO-neutral conditions in the spring (Figure 35). Despite predictions that El Niño rains would be strong in southern California in 2016, they failed to materialize. Instead, the heavy rains tracked north from the Bay Area to Washington (Serna 2016). This was due in part to warm waters off the Pacific Coast, which diverted incoming storms northward.

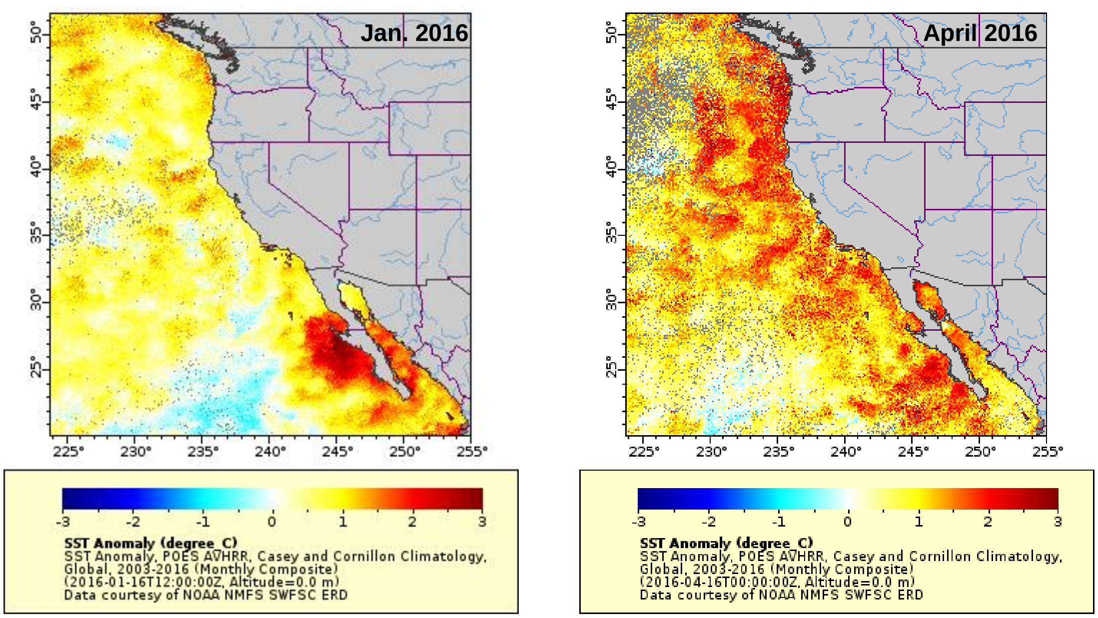


Figure 35. SST anomalies (+/- °C) off the West Coast of North America in January and April, 2016. Source: NOAA SWFSC ERD (2017).

The calculated NQ values in both regions were much lower than the long-term averages since 2013. Productivity—assessed here using chlorophyll a—was fairly unremarkable in southern California in 2016 compared to the rest of the West Coast (Figure 36), a typical pattern (MBC 2015). In July and August 2016, there was a disparity of 3–5°C between SSTs offshore Point Dume and Newport Beach, highlighting the difference in temperatures that can affect the southern California coast. Chlorophyll a values from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area off southern California were among the lowest on record from July 2014 through July 2016 (McClatchie et al. 2016).

Three major, basin-scale indicators all changed phase at some point during the winter of 2013/2014: the PDO changed to positive (indicating warmer temperatures in the North Pacific), the NPGO changed to negative (indicating lower productivity along the coast), and the MEI changed to positive, signaling the pending arrival of an equatorial El Niño. Based on peak MEI value in August–September 2015, the 2015–2016 El Niño was the third largest since 1950 (NOAA-ESRL 2017).

McClatchie et al. (2016) reported above-average SSTs, below average upwelling, and lower-than-average chlorophyll a values in southern California in 2015. Similar conditions persisted into 2016, but upwelling was about average (McClatchie et al. 2017). Even though the PDO is still positive in June 2017, the MEI values were negative since September 2016, but turned positive in April 2017 (Mantua 2017; NOAA-ESRL 2017).

While the temperature patterns were similar across southern California, and NQ values were regionally low, some distinct SST patterns have developed over the last few years. At Point Dume, the number of days with SSTs >16–20°C increased above the 20-year mean since 2011 (Figure 37).

Likewise, the number of days <14°C has declined substantially (to zero days in 2015 and two days in 2016). From 2012 through 2015, the number of days >16–18°C at Newport Beach increased substantially from the long-term mean, and the number of days <14°C decreased considerably in 2014–2015. Lastly, at Scripps Pier, the number of days with SSTs <14°C from 2011–2013 was well above the long-term mean, which could explain the protracted kelp growth during those periods. However, the number of days below 13–14°C decreased substantially from 2014 through 2016. Conversely, the number of days with SSTs >16–18°C was higher than average the last three years.

The pattern in mean SST has also differed along the coast. During the last five years, annual mean SSTs at Point Dume exceeded the 20-year mean each year, and they were substantially higher (by 1.7°C) during 2016 (Table 7; MBC 2012–2016; NOAA NDBC 2017). Mean temperature was 1.3°C higher than the long-term mean at Newport Beach Pier, but identical to the long-term mean at Scripps Pier in 2016 (MBC 2012–2016; CDIP 2017; NOAA NDBC 2017).

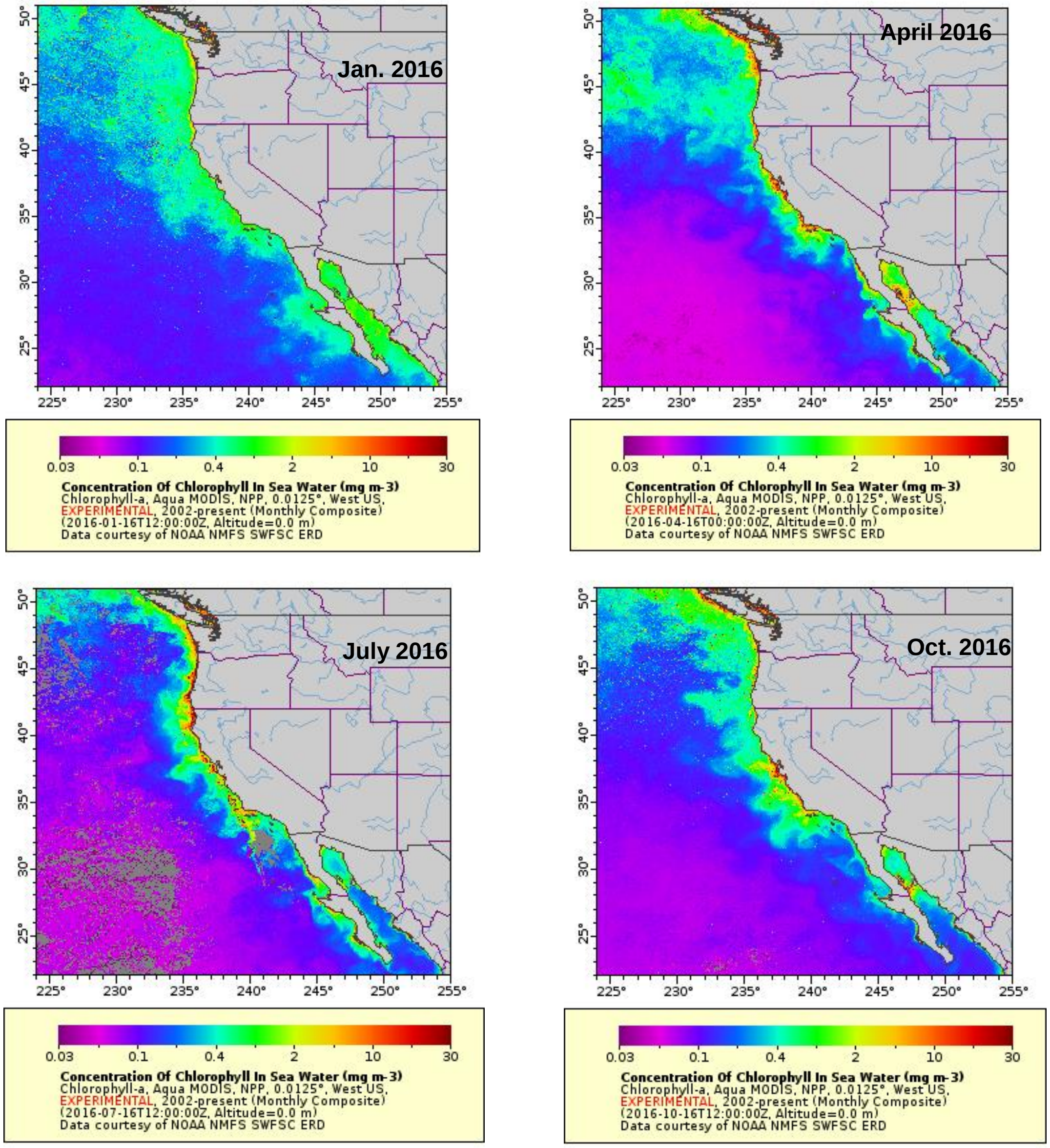


Figure 36. Chlorophyll-*a* concentration off the West Coast of North America in January, April, July, and October, 2016. Source: NASA (2017).

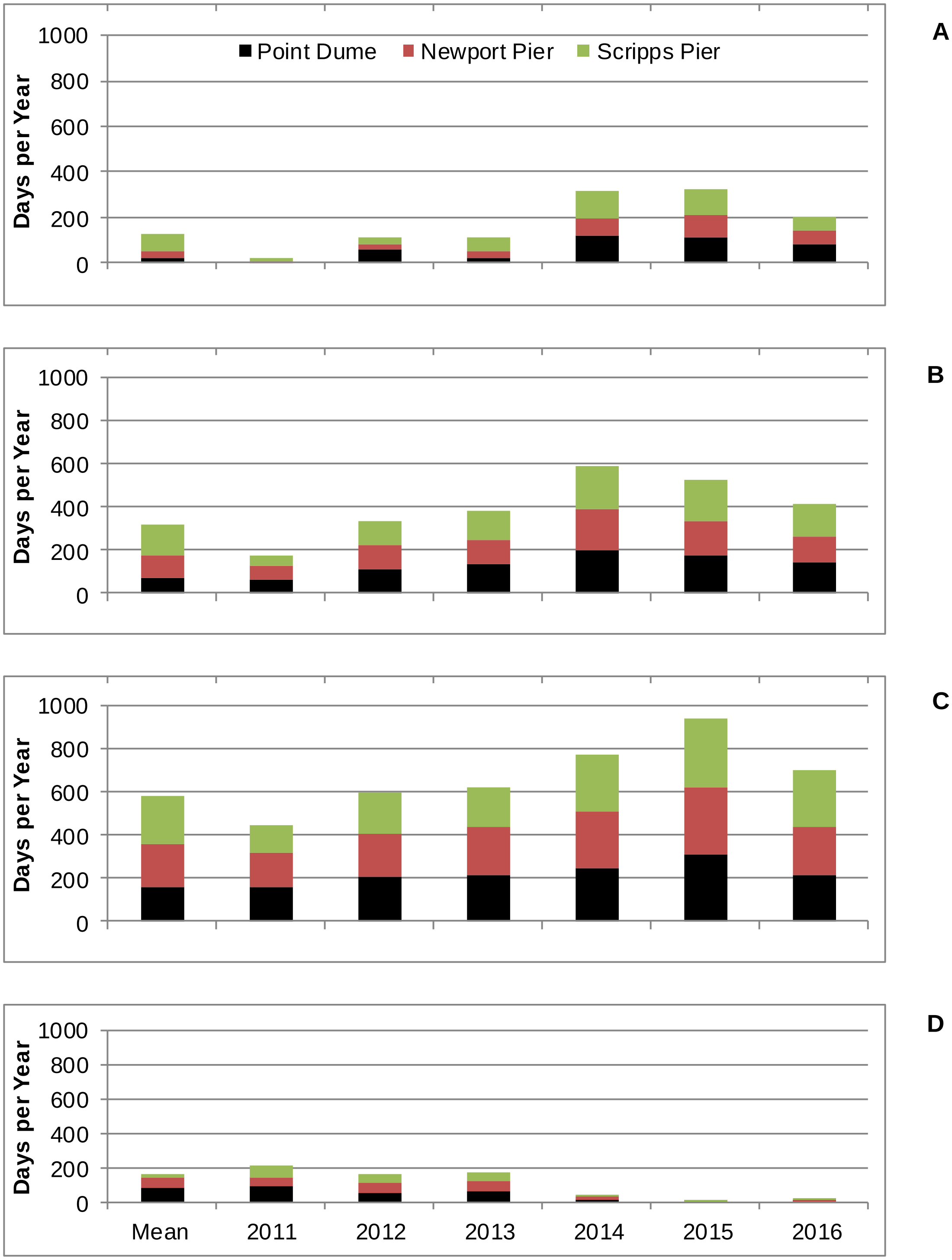


Figure 37. Number of days with SSTs (A) >20°C, (B) >18°C, (C) >16°, and (D) <14°C at three locations in southern California: 2011–2016, and the mean from 1994–2015.

Table 7. Comparison of (1) mean temperature from 1994–2015, and (2) annual mean temperature during 2011–2016 at three location in southern California. Red cells indicate years above the long-term mean (16–20°C), white cells are equivalent to the mean, and blue cells below the long-term mean (13–14°C).

		Annual Mean SST (°C)					
	Mean SST (°C) (1994–2015)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Point Dume	**15.9**	15.7	16.8	16.8	18.2	18.6	17.6
Newport Pier	**16.5**	15.9	16.6	16.7	18.0	18.4	17.8
Scripps Pier	**17.7**	15.7	16.6	17.0	18.8	18.9	17.7

La Niña conditions persisted in the Pacific Ocean through half of 2010 and most of 2011, and dissipated in early 2012 (Figure 12). During this period, most of the kelp beds in the region achieved larger-than-average canopies. Despite a return to ENSO neutral conditions in 2012 and 2013, kelp coverage was higher than average, particularly in Region Nine. In light of recent studies suggesting that all of southern California has been subjected to a marine environment relatively depleted of nutrients since 1977, that respite from El Niño conditions benefited the kelp beds. Seawater density values in the SCB in 2015 were almost all <25.0 (0.5% of the densities calculated for Newport Pier exceeded $\delta_t = 25$). Parnell et al. (2010) determined the relationship between density and nitrate at Point Loma was non-linear, with an inflection point near $\delta_t = 25$. Therefore, available density data indicate nitrate concentrations at Newport Pier were not conducive to kelp growth.

The MEI transitioned from neutral conditions in 2013 to positive values in April 2014, signaling the onset of El Niño. This coincided with higher-than-average SSTs in the SCB for most of 2014 and 2015, and the first three to six months of 2016. During a year when waters were warmer than average in both regions for most of the year, kelp canopy coverage only decreased by 2% since 2014. At the end of the El Niño events in 1982-1984 and 1997-1998, canopy area in Region Nine was <4 km^2; there was >12 km^2 of canopy cover in Region Nine in 2015, and ~5 km^2 in 2016. Kelp beds off northern California were reduced to record low coverages in 2015 (Catton 2016), and kelp beds between San Francisco Bay and the California/Oregon border shrank by 90% between 2008 and 2017 (Wirtschafter 2017). The CDFW has conducted kelp overflight surveys of the entire California mainland coastline and Channel Islands on an annual basis since 2002 (except no mainland survey was conducted in 2007) (CDFW 2017). Results are not directly comparable with those of the CRKSC and RNKSC due to differences in data collection and analysis methods. The CDFW imagery includes subsurface kelp, and includes the kelp canopy from only one survey, not necessarily the largest canopy extent of the given year. The CDFW survey of southern California was flown in September 2016, and recorded 2–3 km^2 of kelp canopy between Point Conception and the U.S./Mexico border, and represented a roughly 50% reduction in canopy from 2015.

While the canopy area is relatively low, the survey was flown during the quarter when most of the kelp beds were at their minimum size during the year.

Other environmental factors appeared from the data to have had minimal effects on the kelp beds of both regions during 2016. From 2012–2015, the state of California experienced the worst drought in its historical record (Swain 2015). Annual rainfall was below average (for the sixth year in a row) and effects from runoff (turbidity) were likely negligible. In the Central Region, flows from the Santa Clara and San Gabriel Rivers were about one third of average (USGS 2017). In Region Nine, flows from San Juan and San Mateo Creeks were <2% of average, but the flow rate from San Diego Creek (San Diego County) was 56% of average. A turbid plume emanating from the Portuguese Bend landslide was visible during all four overflights, but prominent during the April and June 2016 overflights (Figure 38). This nearshore source of sediment likely affects the growth dynamics of adjacent beds, but to what annual extent is unknown. Persistent turbidity at Palos Verdes could have affected surrounding beds (i.e., PV I and PV II at a minimum). Nearshore turbidity was also prevalent around Point Loma during the September and December 2016 overflights (Figure 39). Significant wave heights at Point Loma were ≤2.1 m in the six hours prior to survey completion in September and ≤1.2 m in December. About 12% of the waves measured at Point Loma in 2016 were >2.1 m, and it is possible such wave heights could have resulted in visible nearshore turbidity. However, average H_s at Point Loma in 2016 was about 1.5 m, so it is unlikely wave heights of 1.2 m would cause widespread turbidity.

Kelp was not harvested from the Point Loma kelp bed in 2016. The wave climate was relatively mild for most of 2015, although there were periods with waves that exceeded four meters, where one would expect to see damage from breaking waves. Wave height exceeded four meters at Point Loma during four separate events from January through April 2016. The largest waves (five to six meters) were measured on 1 February 2016. Canopy sizes at most of the Central Region kelp beds, and all of the Region Nine kelp beds, were below average in April 2016, despite above-average upwelling, suggesting the large waves could have affected the kelp beds. La Jolla kelp grows in shallower water than Point Loma kelp, and is more exposed to extreme wave stress (Parnell 2015). However, La Jolla kelp bed decreased in size by 2.0 acres compared to 2.8 acres at Point Loma.

Figure 38. Nearshore turbidity near the Portuguese Bend Landslide area, PV I kelp bed, on April 18, 2016.

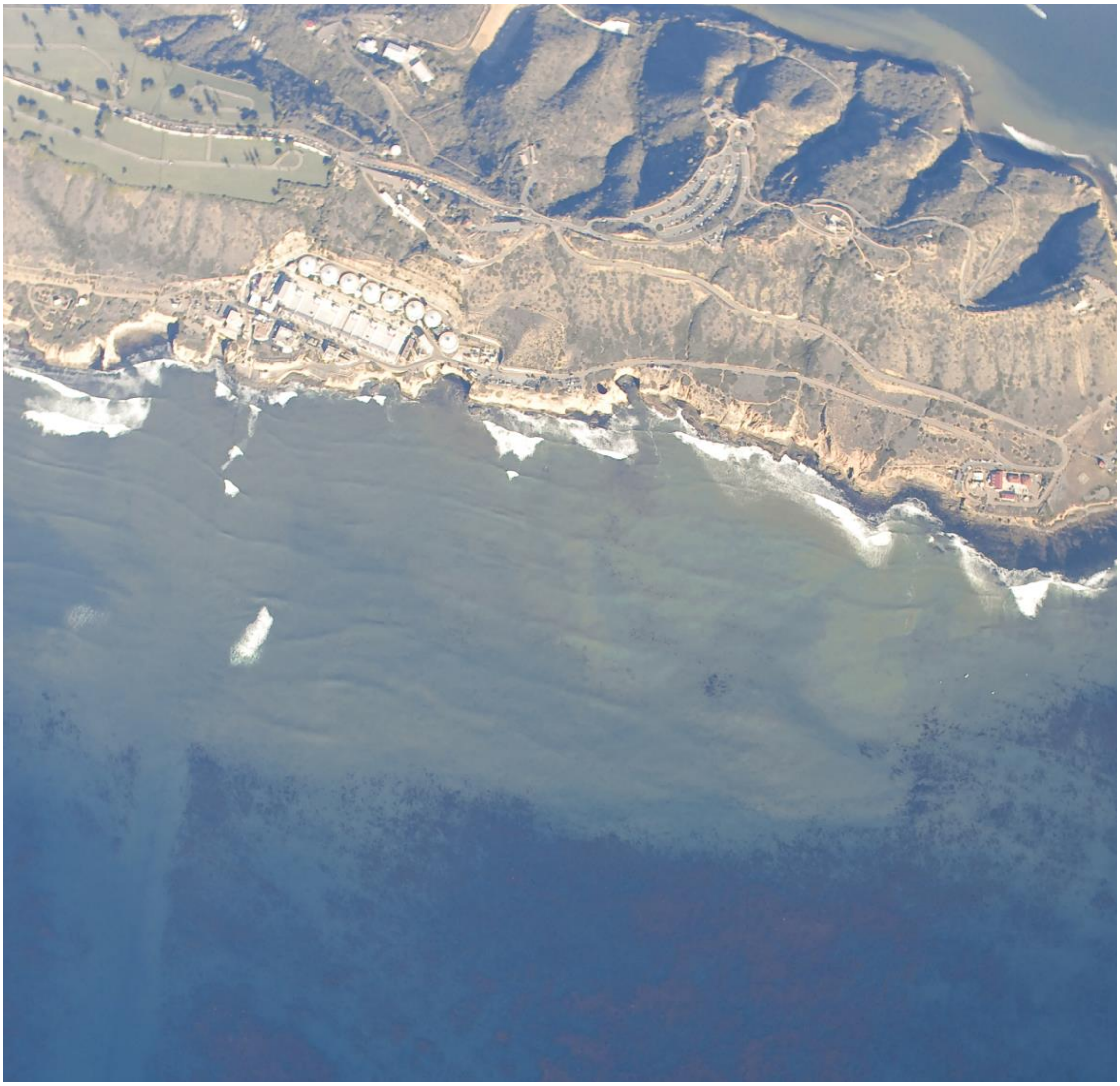


Figure 39. Nearshore turbidity near Point Loma on December 28, 2016.

The entire coast was exposed to large waves at some point during the year. Most of the beds were at their smallest size during the September overflight, but beds usually decrease in summer and fall. There were no large southerly swell events in 2016, and there were no large-wave events from May through December, so high water temperatures and seasonally low nutrient availability (and not large waves) were likely the primary factors in the canopy reduction. There were also no widespread algal blooms that persisted long enough to reduce canopy sizes even though concentrations of *Pseudo-nitzchia* exceeded concentrations that could affect photosynthesis throughout most of the year.

Most of the kelp beds in southern California decreased in size from 2015 through 2016, but there were three stretches of coastline with notable expansion of kelp beds: (1) Paradise Cove to Malibu Point, (2) Palos Verdes/Cabrillo, and (3) Capistrano Beach to Barn Kelp. All three areas were exposed to large waves from January through March (Figures 15 and 16), but the kelp beds east of Point Dume and along the Orange County coastline were afforded some protection from the island shadow effect. The average loss in canopy size at the beds outside of the three areas was 47%.

Available physical data (temperature, seawater density, and nutrient concentrations) for most of 2016 suggest oceanographic conditions were not conducive to kelp growth. However, variable patterns in canopy increases/decreases in adjacent beds (e.g., PV III and PV IV, Capistrano Beach and San Clemente, etc.) suggests physical and/or biological factor(s) at the individual bed scale (or finer) affected southern California's kelp beds in 2016, and allowed some kelp beds to expand even though most beds decreased in size.

CONCLUSION

Kelp bed canopy coverage varied by region in 2016. Two-thirds of the kelp beds in the Central Region decreased in size compared to the previous year, and nearly all of the Region Nine kelp beds shrank last year. The kelp beds that increased in size included: four kelp beds between Paradise Cove and Sunset, two of the four Palos Verdes kelp, and Cabrillo kelp bed. However, the other kelp beds in the Central Region decreased in size, highlighting what slight variations in geographic location and underwater topography can have on nutrient availability and kelp dynamics. Despite the region-wide declines, the total canopy coverage in 2016 remained above the long-term mean in the Central Region. In Region Nine, only 3 of the 26 beds increased in size, and the annual coverage was below average for the first year since 2006.

Most areas of offshore southern California were subjected to similarly large temperature fluctuations, but responses by kelp beds differed among areas. Sea surface temperatures have been above average during the last four years, and periods of cold-water intrusions have been shorter than average.

Results from 2016 were consistent with those from past kelp consortium surveys, and oceanographic conditions controlled the fate of the Central Region and Region Nine kelp beds. Variations in bed growth (or decline), sometimes within relatively small distances, were likely related to variations in bathymetry, current flow, nutrient availability, etc. There was no apparent correlation between kelp bed growth, or lack thereof, with the various discharges in the region, and there was no evidence to suggest any perceptible influence of the various dischargers on the persistence of the region's giant kelp beds.

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PERSONAL COMMUNICATIONS

Anthony, K. 2016. Kim Anthony, Southern California Edison. Comments transmitted by email to S. Beck (MBC) on 11 July 2016.

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