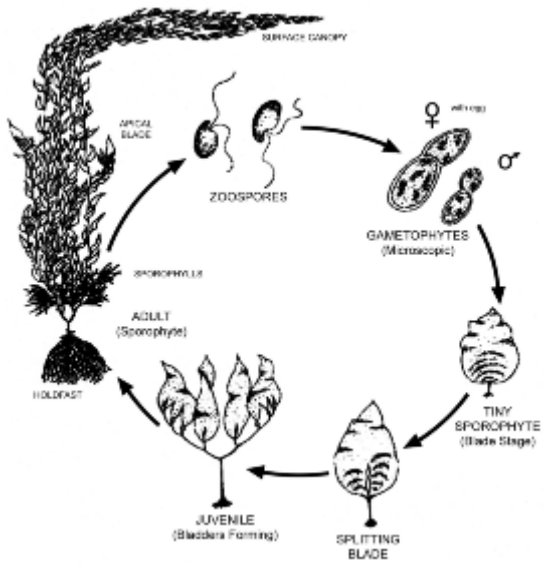
APPENDIX B

Life History of Giant Kelp
Historical Kelp Surveys
Crandall's Maps

LIFE HISTORY OF GIANT KELP

Kelp consists of a number of species of brown algae, of which 10 are typically found from Point Conception to the Mexican Border (the Southern California Bight [SCB]). Compared to most other algae, kelp species can attain remarkable size and long life span (Kain 1979; Dayton 1985; Reed et al. 2006). Along the central and southern California coast, giant kelp *Macrocystis pyrifera* is the largest species colonizing rocky (and in some cases sandy) subtidal habitats, and is the dominant canopy-forming kelp. Giant kelp is a very important component of coastal and island communities in southern California, providing food and habitat for numerous animals (North 1971; Patton and Harmon 1983; Dayton 1985; Foster and Schiel 1985). Darwin (1860) noted the resemblance of the three-dimensional structure of giant kelp stands to that of terrestrial forests. Because of its imposing physical presence, giant kelp biology and ecology have been the focus of considerable research since the early 1900s. Much effort was expended in the early years deciphering its enigmatic life history (Neushul 1963; North 1971; Dayton 1985; Schiel and Foster 1986; Witman and Dayton 2001; Reed et al. 2006). Giant kelp commonly attains lengths of 15 to 25 m and can be found at depths of 30 m. In conditions of unusually good water clarity, giant kelp may even thrive to depths of 45 m (Dayton et al. 1984).

Giant kelp may form beds wherever suitable substrate occurs, typically on rocky, subtidal reefs (North 1971). Such substrate must be free of continuous sediment intrusion. Giant kelp beds can form in sandy-bottom habitats protected from direct swells where individuals will attach to worm tubes; this occurs along portions of the Santa Barbara coastline (Bedford 2001). Like terrestrial plants, algae undergo photosynthesis and therefore require light energy to generate sugars. For this reason, light availability at depth is an important limiting factor to giant kelp growth. Greater water clarity normally occurs at the offshore islands, and as a result, giant kelp is commonly found growing there in depths exceeding 30 m. Along the mainland coast, high biological productivity, terrestrial inputs and nearshore mixing result in greater turbidity and hence lower light levels. Consequently, giant kelp generally does not commonly grow deeper than 20 m along the coastal shelf, although exceptional conditions off San Diego produce impressively large beds that can grow vigorously beyond 30 m.



Appendix B.1 Life cycle for giant kelp.

Giant kelp has a complex life cycle and undergoes a heteromorphic alternation of generations, where the phenotypic expression of each generation does not resemble the generation before or after it (Appendix B.1). The stage of giant kelp that is most familiar is the adult canopy-forming diploid sporophyte generation. Sporophyll blades at the base of an adult giant kelp release zoospores, especially in the presence of cold, nutrient-rich waters. These zoospores disperse into the water column and generally settle a short distance from the parent sporophyte (Reed et al. 1988). Within three weeks, the zoospores mature into microscopic male and female gametophytes that in turn produce sperm and eggs. This second generation does not resemble the sporophyte. The life cycle is completed when fertilization of the gametophyte egg develops into the adult sporophyte

stage. Successful completion of the life cycle relies on the persistence of favorable conditions throughout the process.

Giant kelp grows in groups called forests because erect bundles of fronds (stipes and blades) resemble tree trunks, and spreading canopies at the sea surface represent the stems and leaves (Dawson and Foster 1982). *Macrocystis* anchors to rocks (or occasionally in sand) by a holdfast, and new fronds, comprised of stipes and attached blades, grow up to the sea surface at rapid rates. Giant kelp is known as a biological facilitator (Bruno and Bertness 2001), where its three-dimensional structure and the complexity of its holdfast provides substrate, refuge, reduction of physical stress, and a food source for many fishes (Carr 1989) and invertebrates (Duggins et al. 1990). Stands of giant kelp can also affect flow characteristics in the nearshore zone, and enhance recruitment (Duggins et al. 1990), thus increasing animal biomass. For these reasons, giant kelp is also of great importance to sport and commercial fisheries.

HISTORICAL KELP SURVEYS

Giant kelp bed size and health are known to be highly variable but there has been a downward trend in canopy coverage since the inception of surveying in 1911 (Crandall 1912). In 1911, a mapping expedition of canopy-forming kelps along most of the Pacific coast was conducted to determine the amount of potash (potassium carbonate, an essential ingredient in explosives at the time) potentially available from the kelp. Using rowboats, compass, and sextants to triangulate positions, U.S. Army Captain William Crandall produced one of the most complete surface density kelp maps of the west coast of North America. Using this methodology, all of the existing kelp beds in the Central Region and Region Nine areas were mapped and these measurements have been used to define a baseline for southern California kelp beds (Appendix B.2) (Crandall Maps).

Despite the value of Crandall's maps, the accuracy of his measurements was questioned (Hodder and Mel 1978 [SAI 1978], Neushul 1981). These authors contended that measurement errors might have resulted from using a rowboat and triangulations from shore to compute the bed perimeters, particularly on very large beds such as Palos Verdes, Point Loma, and La Jolla. Although Crandall's ability to accurately triangulate a position was adequate, his measurements of large beds resulted from fewer fixed points and estimation of the area between points. Modern aerial surveys reveal numerous holes and a fair degree of patchiness in such beds. Crandall's estimates did not account for these natural gaps and therefore the 1911 survey probably overestimated the size of these larger beds. Given this ambiguity, Crandall's measurements should be viewed qualitatively rather than as quantitative estimates comparable to aerial survey data taken since the 1920s. However, the data are a very good approximation to use as a baseline. Anecdotal reports from area stakeholders reported by Cameron (1915) indicate kelp beds in 1911 were in fairly poor condition compared to previous years.

Although the historical El Niño Southern Oscillation (ENSO) index suggests that the five years prior to 1911 were favorable to the kelp, the Pacific Decadal Oscillation (PDO) (another environmental metric that has historical data extending back to that period) is in agreement with Cameron's 1915 statement. While the PDO is a poor predictor of oceanographic conditions in the Southern California Bight (Di Lorenzo et al. 2008), it does correlate with sea surface temperature (SST). Therefore, it provides some insight into the local hydrographic conditions at the time. The annual mean PDO was slightly negative between 1909 and 1911, before transitioning to a warm phase from 1912 through 1915. This is suggestive, but not conclusive, of lower nutrient concentrations in 1912–1915 that would result in poor kelp growth. To add further credibility to the premise that beds were larger than current trends would indicate, aerial photos of Palos Verdes kelp beds taken in 1928 (measured by North in 1964) found the area to be more than 10% larger than Crandall reported in 1911.

In 1964, Dr. Wheeler North, working for the State Water Quality Control Board (1964), re-measured Crandall's Palos Verdes charts and found the 2.66 square nautical miles (Nm^2 [9.12 km^2]) Crandall reported to be very similar to his measurement of 2.42 Nm^2, but North's measurement did not include much of Malaga Cove (that added an additional 0.130 Nm^2 of kelp to the Palos Verdes beds), resulting in North's measurement of about 2.55 Nm^2 (Crandall Maps).

Due to the large sizes reported by Crandall, Neushul (1981) assumed there was a scaling error, re-measured the maps, and calculated a value that was 10% less than Crandall's original measurement. However, Neushul (1981) wrote that his measurements resulted in

Appendix B.2 Kelp beds of the California coast as described by Crandall in 1911.

Crandall Sheet (Map in report) No.	Kelp Bed No.	Density	Bed Name 2013	Area Square Nautical Miles	Area Square Statute Miles	Area Square Kilometers
Sheet 52		Medium	Imperial Beach	0.287	0.3801	0.9844
Sheet 18	1	Very Heavy.	Point Loma	5.400	7.1516	18.5226
	2	Very Heavy.	La Jolla	2.300	3.0461	7.8893
Sheet 17	3	Medium	Del Mar	0.240	0.3178	0.8232
		N. Present	No Solana Beach	0.000	0.0000	0.0000
		N. Present	No Cardiff	0.000	0.0000	0.0000
	4	Medium	Encinitas 30% (0.970)	0.291	0.3854	0.9982
	4	Medium	Leucadia 50% (0.970)	0.485	0.6423	1.6636
	4	Medium	Carlsbad St Bch 20%	0.194	0.2569	0.6654
	5	Medium	Encina Power	0.125	0.1655	0.4288
	5	Medium	Agua Hedionda	0.125	0.1655	0.4288
	6	Medium	Carlsbad	0.140	0.1854	0.4802
	7	Medium	Santa Margarita	0.250	0.3311	0.8575
	8	Thin	Barn Kelp	0.370	0.4900	1.2691
	9	Thin	Barn Kelp	0.080	0.1059	0.2744
	10	Thin	Barn Kelp	0.260	0.3443	0.8918
	11	Thin	Horno Canyon	0.050	0.0662	0.1715
	12	Thin	San Onofre	0.110	0.1457	0.3773
	13	Thin	San Onofre	0.130	0.1722	0.4459
	14	Thin	San Onofre	0.060	0.0795	0.2058
	15	Thin	San Mateo	0.360	0.4768	1.2348
Sheet 14, 15, and 16	16	Thin	San Clemente	0.060	0.0795	0.2058
	17	Medium	Capistrano	0.240	0.3178	0.8232
	18	Medium	Doheny	0.220	0.2914	0.7546
	19	Medium	Dana Point/Salt Creek	0.340	0.4503	1.1662
		N. Present	Laguna Beach	0.000	0.0000	0.0000
	20	Medium	Corona Del Mar	0.220	0.2914	0.7546
	21	Medium	Cabrillo to Port Bend	0.760	1.0065	2.6069
	22	Thin	Portuguese Bend	0.100	0.1324	0.3430
	23	Thin	Point Vicente, PV	0.070	0.0927	0.2401
	24	Medium	PV Pt to Flat Rk, PV	1.600	2.1190	5.4882
	25	Medium	Malaga Cove, PV	0.130	0.1722	0.4459
Chart 13	1	Thin	Sunset Beach	0.280	0.3708	0.9604
	2	Thin	Topanga (50%)	0.005	0.0066	0.0172
	2	Thin	Las Tunas (50%)	0.005	0.0066	0.0172
	3	Thin	Big Rock	0.005	0.0066	0.0172
	4	Thin	Las Flores	0.004	0.0053	0.0137
	5	Thin	La Costa	0.006	0.0079	0.0206
		N. Present	Malibu Point	0.000	0.0000	0.0000
	6	Thin	Puerco/Amarillo (10%)	0.100	0.1324	0.3430
	6	Thin	Latigo Canyon (13%)	0.130	0.1722	0.4459
	6	Thin	Escondido Wash (17%)	0.170	0.2251	0.5831
	6	Thin	Paradise Cove (40%)	0.400	0.5297	1.3720
Chart 13	6	Thin	Point Dume (20%)	0.200	0.2649	0.6860
	7	Thin	Lechuza (33%)	0.037	0.0485	0.1255
	7	Thin	Pescador/Piedra (67%)	0.073	0.0971	0.2515
	8	Medium	Nicolas Canyon (33%)	0.367	0.4855	1.2575
	8	Medium	Leo Carillo (67%)	0.733	0.9712	2.5153
		N. Present	Deer Crk	0.000	0.0000	0.0000
Totals				17.512	23.192	60.068

only slight improvements from what Crandall measured: "*The smaller areas obtained by measurements from more recent maps of southern California kelp beds probably reflect both a slight increase in mapping precision over Crandall's methods, and an actual decrease in size."* In 2004, Crandall's original maps of Palos Verdes were re-measured by MBC Applied Environmental Sciences (MBC) using computer-aided spatial estimation software (including Malaga Cove), and the resulting area (2.57 Nm^2) was about 3% smaller but very similar to that reported by Crandall (2.66 Nm^2). Therefore, the actual sizes of the beds that Crandall

reported were probably relatively accurate because the areal survey extent and configuration he reported was subsequently confirmed from contemporary charts (Hodder and Mel 1978, Neushul 1981).

Thus, Crandall's kelp bed areas are retained as the baseline estimate, and the total regional area was probably larger from 1928–1934 than the area Crandall measured in 1911 (Appendix B.3 and B.4). Based on the sizes of the Palos Verdes beds in 1928 (9.912 km^2) and La Jolla kelp beds in 1934 (8.161 km^2) from aerial photos that North measured in 1964 (SWQCB 1964), the bed sizes were well above Crandall's measurements of 9.124 km^2 (2.66 Nm^2) for Palos Verdes (including the bed at Malaga Cove) and 7.889 km^2 (2.3 Nm^2) for La Jolla. This lends credence to Cameron's comment that kelp harvesters reported that the beds were at minimal levels at the time of Crandall's survey, and suggests even larger losses have occurred over time (Cameron 1915).

The next complete kelp survey of the southern California region was not undertaken until 1955. By that time, the beds in the Central Region had decreased greatly (to 6.750 km^2), and were only 36% of that recorded in 1911 (18.815 km^2). Beds in Region Nine were similarly reduced to 40% (16.310 km^2) of the 1911 total of 41.563 km^2. The most significant loss during this period was that of Sunset Kelp (offshore of Santa Monica); Sunset Kelp covered almost 1.0 km^2 in 1911, but was very small by 1955. The Sunset kelp bed remained small or completely missing through the intervening years, and the Palos Verdes beds were also small, having decreased sometime after 1945. By 1947, the Palos Verdes beds were only 3.6 km^2, and further to 1.5 km^2 by 1953. During an aerial survey conducted in 1963, kelp canopies were in very poor condition, with Palos Verdes covering only 0.180 km^2 and the La Jolla and Point Loma beds covering only 0.9 km^2. Exceptionally good conditions in 1967 resulted in a total of 7.856 km^2 of kelp canopy coverage in the Central Region, but this was only about 42% of the estimate from 1911. Palos Verdes kelp beds south of Point Vicente were missing, but north of Point Vicente, they totaled almost 1.0 km^2. In Region Nine, similar results were observed in 1967 with the La Jolla/Point Loma kelp beds covering 3.03 km^2 and the total for the region only 4.4 km^2. La Jolla kelp bed was only about 0.330 km^2 in 1967, and it stayed small until after 1975, when it became a consistently large kelp bed (over 1 km^2) through most of the next four decades.

Restoration activities began in 1974 by the Kelp Habitat Improvement Project. At that time, the Palos Verdes beds were only 0.015 km^2. In 1975, after restoration, those beds began increasing and covered 4.6 km^2 during the exceptionally favorable conditions in 1989 (North and Jones 1991). The impetus provided by the 1989 La Niña resulted in almost 6 km^2 of kelp canopy in the Central Region and more than 16 km^2 in Region Nine, but kelp coverage decreased to less than one-third of these totals during the subsequent two decades. In 2009 (Central) and 2008 (Region Nine), favorable conditions again increased canopy totals to about 6.5 km^2 in the Central Region and 18.7 km^2 in Region Nine, larger than they had been since 1967 and 1955, respectively (Appendix B.3 and B.4; Text Tables 1 and 2).

Appendix B.3 Historical canopy coverage in km² of Ventura, Los Angeles, and Orange County kelp beds to Newport-Irvine Coast, from 1911 to 2002. Values represent an estimate of coverage utilizing varying methods over the years.

	Canopy Area (km²)														
Kelp Bed	1911	1928	1945	1955	1963	1967	1972	1975	1977	1980	1984	1989	1999	2000	2002
Deer Creek	ND	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Leo Carillo	2.515	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Nicolas Canyon	1.258	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
El Pesc/La Piedra	0.252	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Lechuza	0.126	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Total F&W 17	4.151a	ND	ND	3.010	ND	4.144	2.589	1.606	1.579	ND	ND	0.914	0.530	ND	ND
Pt. Dume	0.686	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Paradise Cove	1.372	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Escondido Wash	0.583	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Latigo Canyon	0.446	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Puerco/Amarillo	0.343	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Malibu Pt.	ND	ND	ND	p	p	p	p	p	p	ND	ND	p	p	ND	ND
Total F&W 16	3.43a	ND	ND	2.140	1.780	2.538	1.813	1.502	1.528	ND	ND	0.220	0.033	ND	ND
La Costa	0.021	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Las Flores	0.014	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Big Rock	0.017	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Las Tunas	0.017	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Topanga	0.017	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Sunset	0.960	ND	ND	p	p	p	ND	p	p	ND	ND	p	p	ND	ND
Total F&W 15	1.355a	ND	ND	0.020	0.000	0.026	ND	0.026	0.000	ND	ND	0.045	0.000	ND	ND
Malaga Cove-PV Pt. (IV)	5.934	ND	ND	p	p	p	ND	p	p	0.940	0.655	p	p	p	1.400
PV Pt-PT. Vic (III)	0.240	ND	ND	p	p	p	ND	p	p	0.215	0.692	p	p	p	0.028
Total F&W 14	6.174	ND	ND	0.820	0.030	1.062	ND	0.009	0.026	1.155	1.347	3.312	0.737	0.648	1.429
Pt Vic to Pt Insp (II)	p	ND	ND	p	p	p	ND	p	p	0.190	0.171	p	p	p	0.039
Pt Insp to Cabr (I)	p	ND	ND	p	p	p	ND	p	p	1.052	1.342	p	p	p	1.208
Cabrillo	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0001	0.0001	ND	ND
Total F&W 13	2.950	ND	ND	0.080	0.150	0.000	ND	0.259	0.104	1.342	1.513	1.248	0.530	0.582	1.247
Total PV	9.124a	9.912a	5.591a	0.900	0.180	1.062	ND	0.268	0.130	2.497	2.860	4.560c	1.267	1.230	2.676a
POLA-POLB Harbor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Horseshoe	ND	1.94b	ND	ND	ND	ND	ND	ND	ND	ND	ND	tr	0.0001	tr	0.0001
Huntington Flats	ND	ND	ND	ND	ND	-	-	-	-	-	-	tr	-	-	-
Newport-Irvine Coast	0.755	ND	ND	0.680	0.000	0.086	0.100	0.160	0.160	0.148	0.008	0.010	-	-	tr
Total F&W 10	0.755	-	-	0.680	0.000	0.086	0.100	0.160	0.160	0.148	0.008	0.010	0.0001	-	0.000
TOTAL	18.815d	11.852d	5.591	6.750	1.960	7.856	4.502d	3.562	3.397	2.681d	2.893d	5.748	1.829	1.230	2.676d

ND = No Data; p = this bed included in the total below; tr = trace of kelp; "-" = 0
red = warm year El Nino; **blue** = cold year La Nina; **no color** = neutral year

a = Earlier measurement in naut mi^2 converted to km^2
b = Estimate in mid-1920s
c = Ecoscan (1990) indicates 2.003 km^2 from a July 1989 survey.
Used Wilson (1989) results for PV showing the kelp beds at greatest extent.
d = Total is not inclusive of all beds in region

Sources: Crandall (1912); 1928, 1945, 1955 from SWQCB (1964); 1955, 1963 from Neushul (1981); 1967, 1972, 1975, 1977 from Hodder and Mel (1978); Ecoscan (1990) and Wilson (1989), North (2000); TMLandsat 7 (2002).

Appendix B.4 Historical canopy coverage of the kelp beds from Laguna Beach to Imperial Beach from 1911 to 1987. Values represent an estimate of coverage utilizing varying methods over the years. Red denotes warm-water years, blue denotes cold-water years, and neutral years are in black.

	Canopy Area (km²)														
Kelp Bed	1911	1934	1941	1955*	1959*	1963*	1967	1970	1975	1980	1983	1984	1985	1986	1987
North Laguna Beach	Tr	ND	ND	p	0.160	ND	0.001	0.011	0.003	0.036	0.035	0.025	0.028	0.022	0.028
South Laguna Beach	Tr	ND	ND	p	ND	ND	0.001	0.011	0.003	0.036	0.040	0.028	0.077	0.041	0.087
South Laguna	Tr	ND	ND	p	0.180	0.020	-	0.014	0.008	-	0.004	-	-	-	-
Dana Point-Salt Creek	1.166	ND	ND	p	p	p	0.240	0.077	0.096	0.008	0.013	0.007	0.036	0.031	0.174
Capistrano Beach	1.578	ND	ND	p	p	p	0.080	0.050	0.070	0.020	-	-	-	-	-
Total F&W 9	2.744	-	-	2.020	0.340	0.020	0.322	0.163	0.180	0.100	0.092	0.060	0.141	0.094	0.289
San Clemente	0.206	ND	ND	6.310	3.710	0.010	0.080	0.050	0.070	0.020	-	-	-	-	0.017
San Mateo Point	1.235	ND	ND	p	p	p	-	0.057	0.140	0.360	0.163	0.045	0.152	0.077	0.200
San Onofre	1.029	ND	ND	p	p	p	-	-	0.300	0.160	0.102	0.031	0.042	0.053	0.045
Total F&W 8	2.470	-	-	6.310	3.710	0.010	0.080	0.107	0.510	0.540	0.265	0.076	0.194	0.130	0.262
Horno Canyon	0.172	ND	ND	ND	ND	ND	-	-	-	-	-	-	-	-	-
Barn Kelp	2.435	ND	ND	1.370	ND	0.130	0.017	0.019	0.160	0.056	-	-	-	-	-
Santa Margarita	0.858	ND	ND	ND	ND	ND	-	-	-	-	-	-	-	-	-
Total F&W 7	3.465	-	-	1.370	-	0.130	0.017	0.019	0.160	0.056	-	-	-	-	-
North Carlsbad	0.480	ND	ND	2.620	2.520	1.180	0.009	0.060	0.100	0.120	-	-	-	-	0.031
Agua Hedionda	0.429	ND	ND	p	p	p	-	0.006	0.036	0.019	-	0.001	0.011	0.018	0.021
Encina Power Plant	0.429	ND	ND	p	p	p	-	0.025	0.144	0.074	-	0.002	0.024	0.045	0.120
Carlsbad State Beach	0.499	ND	ND	p	p	p	0.032	0.120	0.200	0.078	-	-	0.027	0.018	0.077
Total F&W 6	1.837	-	-	2.620	2.520	1.180	0.041	0.211	0.480	0.291	-	0.003	0.062	0.081	0.249
Leucadia	1.996	ND	ND	p	p	p	0.240	0.440	0.500	0.670	0.001	0.002	0.104	0.074	0.426
Encinitas	0.832	ND	ND	p	p	p	0.065	0.173	0.153	0.228	-	0.016	0.083	0.032	0.177
Cardiff	ND	ND	ND	0.340	0.400	0.160	0.125	0.337	0.297	0.442	0.018	0.021	0.176	0.120	0.340
Solana Beach	ND	ND	ND	p	p	p	0.290	0.490	0.560	0.690	-	0.001	0.115	0.120	0.367
Del Mar	0.823	ND	ND	p	p	p	0.190	0.260	0.190	0.210	-	-	0.008	0.021	0.081
Torrey Pines	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total F&W 5	3.651	-	-	0.340	0.400	0.160	0.910	1.700	1.700	2.240	0.019	0.040	0.486	0.367	1.391
La Jolla F&W 4	7.889	8.161	7.847	1.660	6.490	0.640	0.330	0.290	0.840	1.900	0.032	0.034	0.720	0.930	2.369
Point Loma F&W 3&2	18.523	11.465	8.286	1.990	0.610	0.240	2.700	4.900	3.000	4.200	0.200	0.160	1.570	2.100	3.682
Imperial Beach F&W 1	0.984	ND	ND	ND	ND	ND	-	-	-	0.350	-	-	0.058	0.150	0.727
TOTAL	41.563	19.626	16.133	16.310	14.070	2.380	4.400	7.390	6.870	9.327	0.608	0.373	3.173	3.702	8.242

NOTE: p = part of above value; * = Incomplete data; ND - No Data; "-" = 0; Tr = Trace <100 m²

Sources: 1934, 1941 from SWQCB(1964); 1955, 1959, 1963 from Neushul (1981).

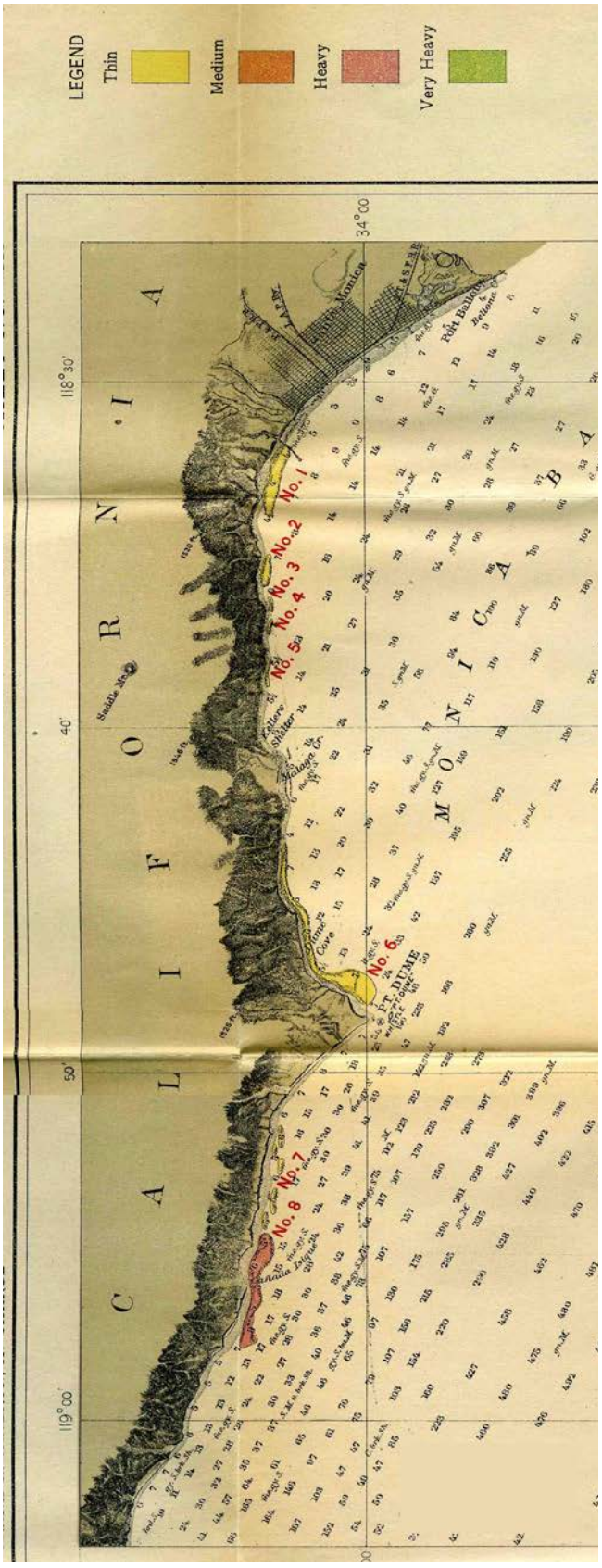
Appendix B.4 (Cont.). Historical canopy coverage of the kelp beds from Laguna Beach to Imperial Beach from 1988 to 2002. Values represent an estimate of coverage utilizing varying methods over the years. Red denotes warm-water years, blue denotes cold-water years, and neutral years are in black.

	Canopy Area (km²)														
Kelp Bed	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
North Laguna Beach	0.042	0.055	0.034	0.029	-	-	-	-	0.001	-	-	-	-	-	-
South Laguna Beach	0.145	0.264	0.243	0.093	0.056	0.028	-	-	-	-	-	-	-	-	0.005
South Laguna	0.023	0.041	0.023	0.030	0.009	0.006	0.005	-	-	-	-	-	0.003	0.002	<0.001
Dana Point-Salt Creek	0.568	0.878	0.329	0.480	0.184	0.234	0.116	0.076	0.061	0.034	0.005	0.080	0.170	0.314	0.432
Capistrano Beach	0.032	0.233	0.110	0.134	0.148	0.022	-	-	-	-	-	<0.001	<0.001	0.044	0.118
Total F&W 9	0.810	1.471	0.739	0.766	0.397	0.290	0.121	0.076	0.062	0.034	0.005	0.080	0.173	0.359	0.555
San Clemente	0.124	0.444	0.304	0.243	0.044	0.051	0.010	0.010	0.047	-	-	0.006	0.005	0.124	0.316
San Mateo Point	0.432	0.870	0.472	0.120	0.103	0.220	0.080	0.010	0.073	0.098	-	0.051	0.050	0.090	0.155
San Onofre	0.348	0.638	0.763	0.170	0.053	0.163	0.201	0.096	0.196	0.108	<0.001	0.005	0.020	0.041	0.030
Total F&W 8	0.904	1.952	1.539	0.533	0.200	0.434	0.291	0.116	0.316	0.206	-	0.062	0.075	0.255	0.501
Horno Canyon	0.006	0.033	0.010	0.018	0.040	-	-	-	-	-	-	-	0.002	0.034	-
Barn Kelp	0.008	0.116	0.382	0.262	0.124	0.002	0.010	0.172	0.204	0.178	-	0.310	0.375	0.547	0.667
Santa Margarita	-	-	-	0.049	0.009	-	-	-	-	-	-	-	-	-	-
Total F&W 7	0.014	0.149	0.392	0.329	0.173	0.002	0.010	0.172	0.204	0.178	-	0.310	0.377	0.581	0.667
North Carlsbad	0.049	0.096	0.119	0.044	0.004	0.018	0.020	0.008	-	-	0.003	-	-	0.017	0.053
Agua Hedionda	0.032	0.047	0.046	0.016	0.004	0.012	0.004	0.008	0.009	-	-	-	-	-	<0.001
Encina Power Plant	0.161	0.251	0.179	0.083	0.025	0.022	0.011	0.058	0.032	0.013	-	-	0.002	0.029	0.097
Carlsbad State Beach	0.032	0.049	0.081	0.035	0.008	0.002	0.011	0.025	0.013	-	-	-	0.003	0.023	0.047
Total F&W 6	0.274	0.443	0.425	0.178	0.041	0.054	0.046	0.099	0.054	0.013	0.003	-	0.005	0.069	0.197
Leucadia	0.197	0.291	0.341	0.163	0.084	0.035	0.010	0.189	0.087	0.062	-	0.015	0.090	0.209	0.334
Encinitas	0.153	0.209	0.241	0.080	0.036	0.037	0.016	0.061	0.023	0.048	-	0.029	0.040	0.131	0.153
Cardiff	0.229	0.575	0.468	0.072	0.054	0.034	0.080	0.092	0.026	0.031	0.016	0.063	0.150	0.309	0.405
Solana Beach	0.427	0.488	0.466	0.257	0.053	0.023	0.108	0.134	0.003	0.073	0.009	0.091	0.200	0.407	0.488
Del Mar	0.063	0.104	0.082	0.097	0.006	0.003	0.029	0.082	-	*Tr	0.004	-	0.006	0.015	0.035
Torrey Pines	Tr	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-
Total F&W 5	1.069	1.667	1.598	0.669	0.233	0.132	0.243	0.558	0.139	0.214	0.029	0.198	0.486	1.071	1.415
La Jolla F&W 4	2.200	4.755	3.632	3.230	1.301	0.681	1.119	0.824	0.371	0.478	0.215	1.146	1.250	2.555	3.366
Point Loma F&W 3&2	2.322	5.842	5.943	4.310	1.153	1.917	3.589	1.134	1.187	2.235	0.295	1.725	3.290	6.574	3.799
Imperial Beach F&W 1	0.067	0.579	0.651	0.370	0.111	0.025	0.108	0.053	0.008	0.027	-	0.019	0.020	0.078	0.210
TOTAL	7.593	16.279	14.268	10.015	3.498	3.510	5.419	3.032	2.341	3.385	0.547	3.540	5.676	11.542	10.710

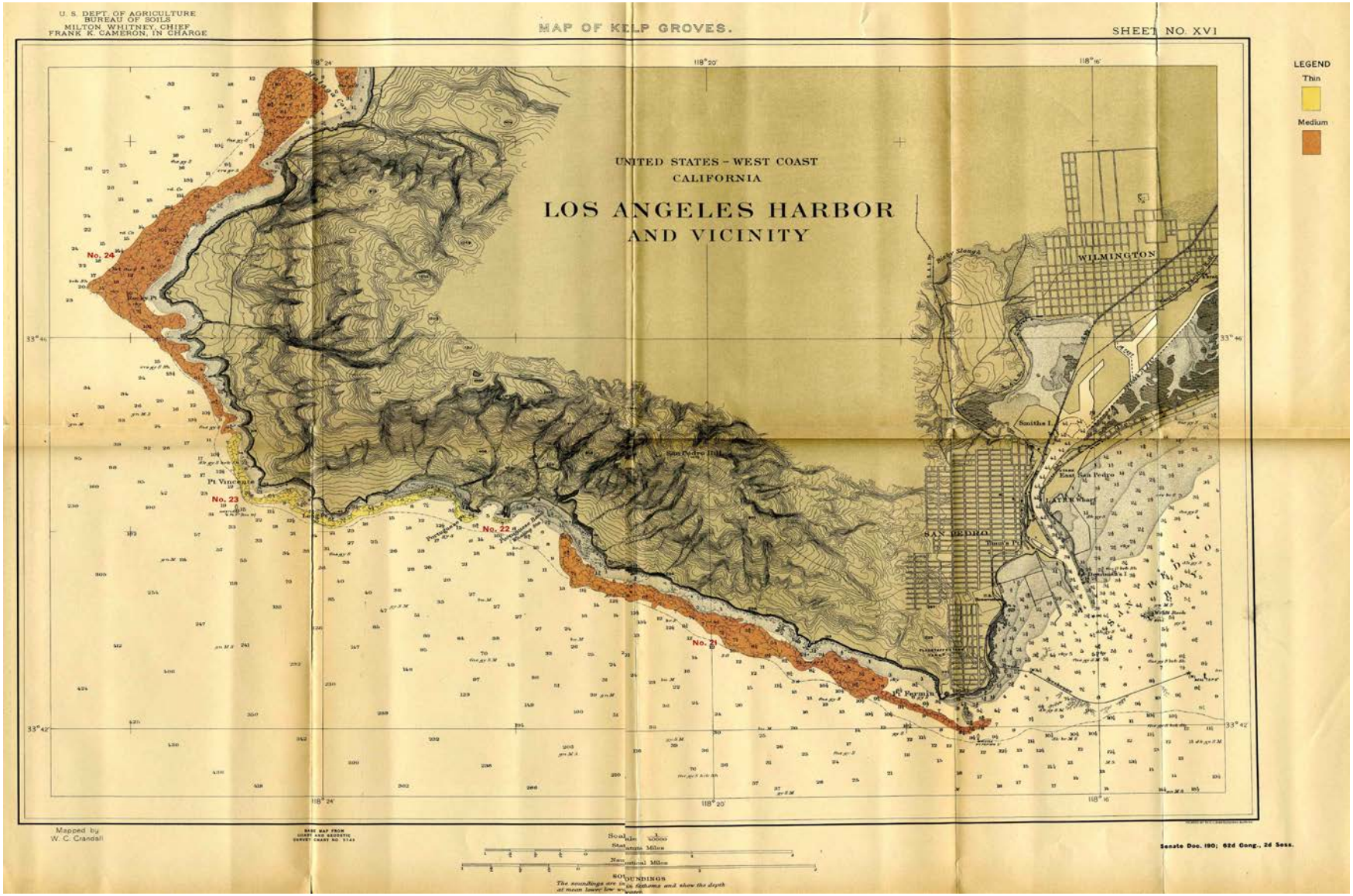
NOTE: p = part of above value; * = Incomplete data; ND - No Data; "-" = 0; Tr = Trace <100 m²

The Imperial Beach kelp bed south of San Diego measured 0.984 km^2 in 1911, and was never again measured to be larger than about 0.727 km^2 for the rest of the century (occurring in 1987, Appendix B.4). However, by the end of 2007, Imperial Beach kelp bed measured 1.493 km^2 (Text Table 2, MBC 2011b), almost 50% greater than what Crandall measured, lending further credence to Cameron's (1915) statement that beds were in poor condition in 1911 compared to earlier years. It therefore follows that the Palos Verdes, La Jolla, and Point Loma kelp beds of Central and Region Nine prior to 1911 were likely much larger than they are today.

As these measurements indicate, most of the beds remain smaller than those of a century ago. Ongoing surveys attempt to determine what environmental factors have changed in the intervening years to cause such large declines.

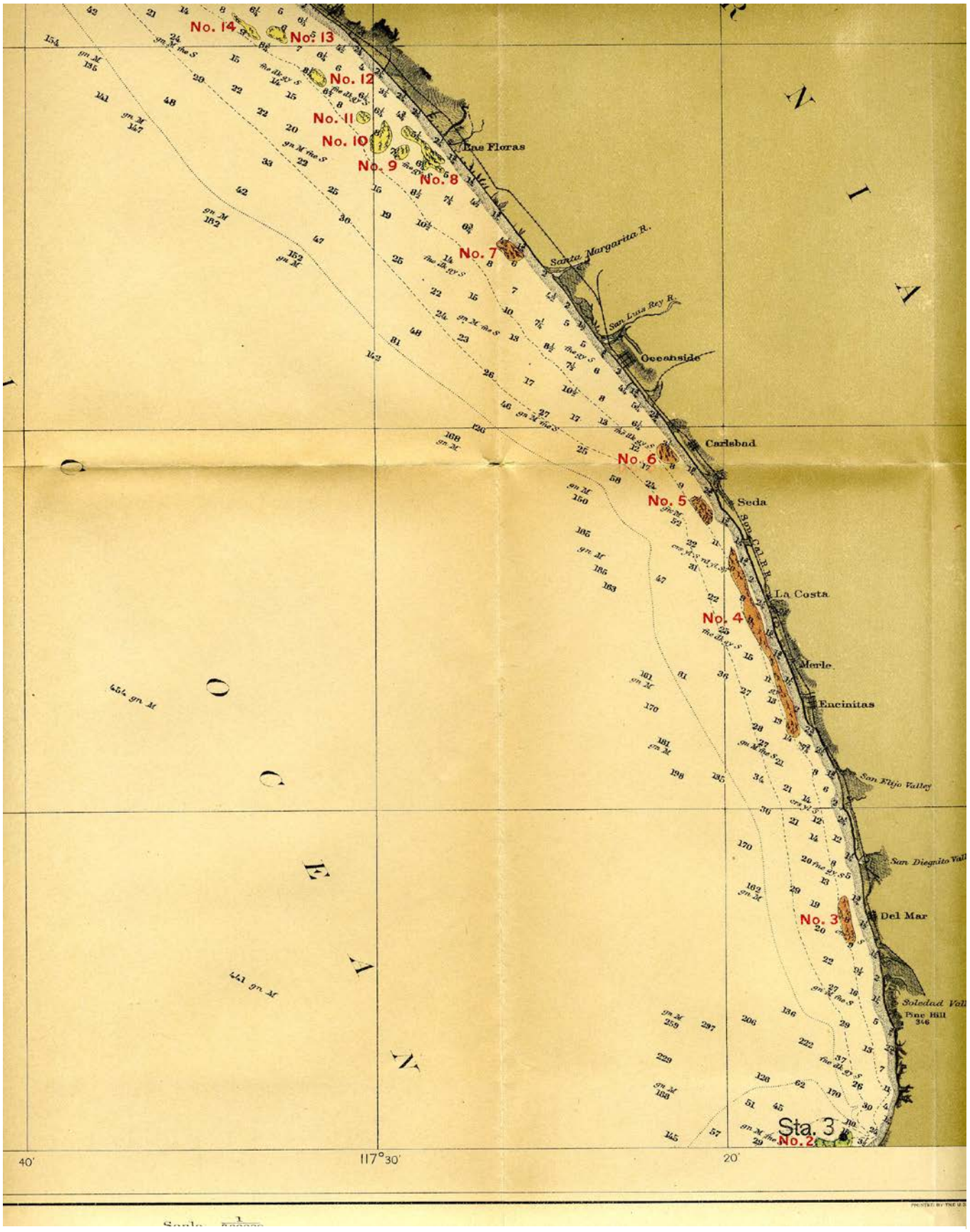


Appendix B.5 Crandall's 1911 kelp survey Deer Creek to Ballona Creek.

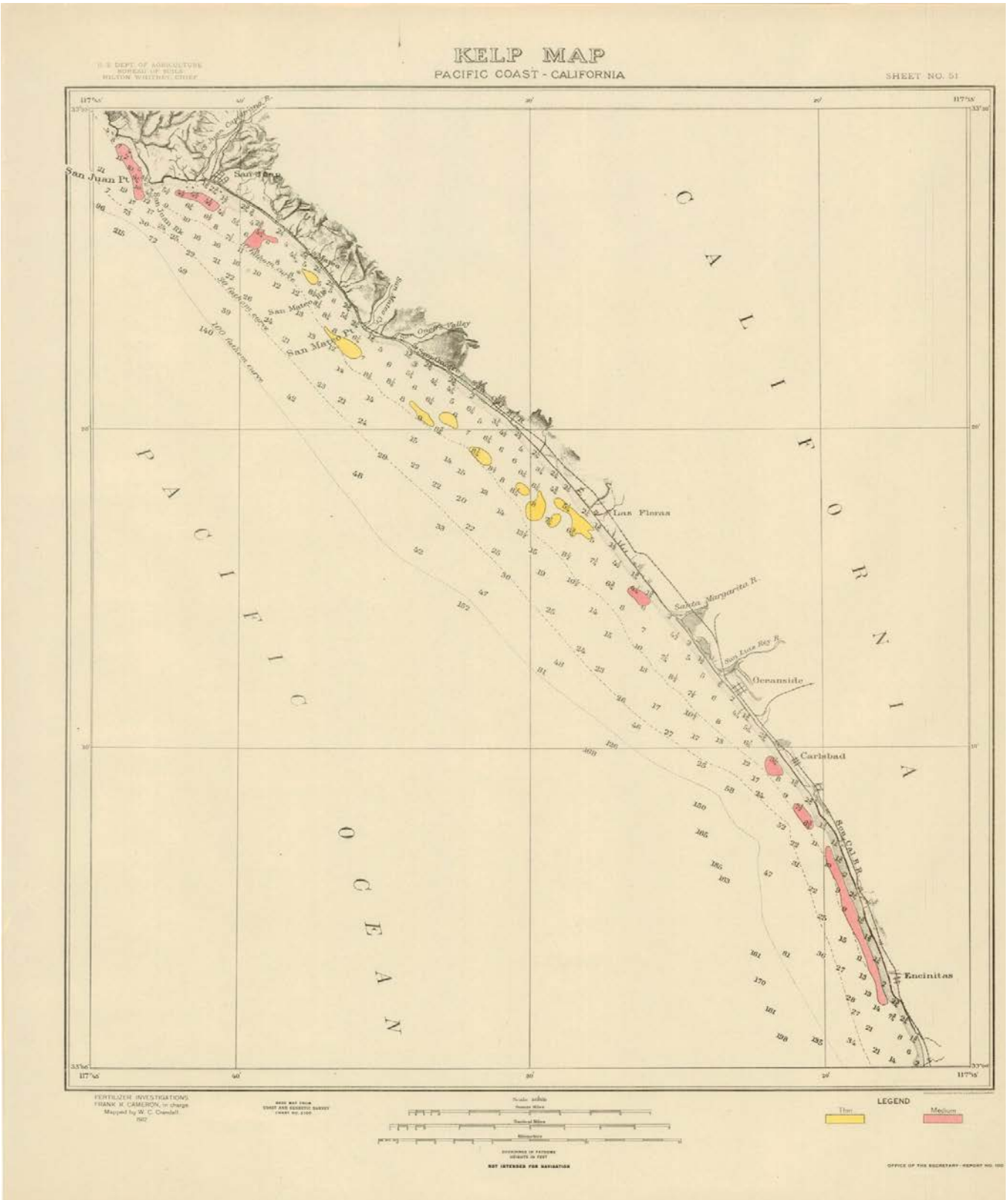


Appendix B.6 Crandall's 1911 kelp survey Palos Verdes to Los Angeles Harbor.

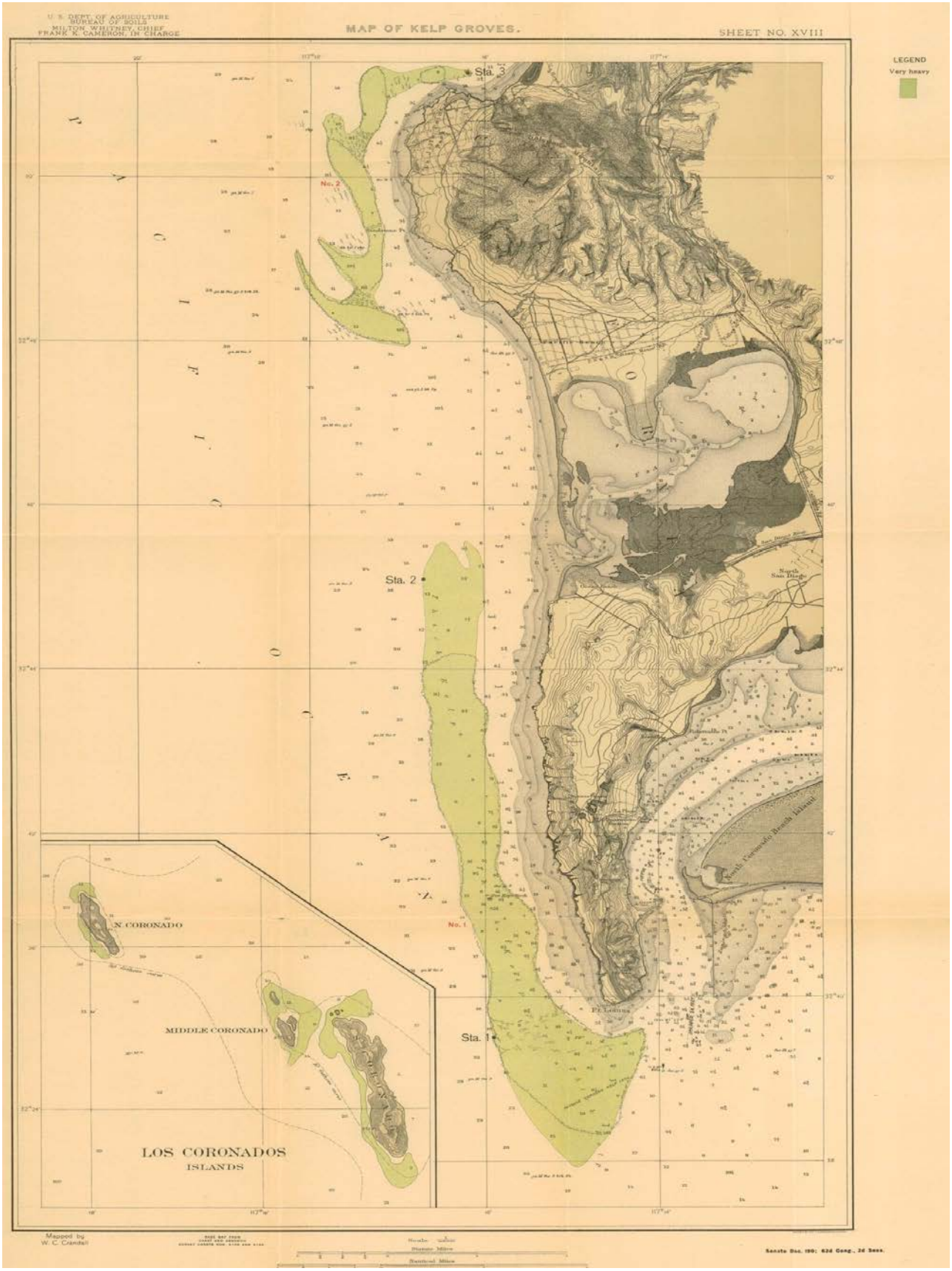
Appendix B.7 Crandall's 1911 kelp bed survey Newport to San Onofre.



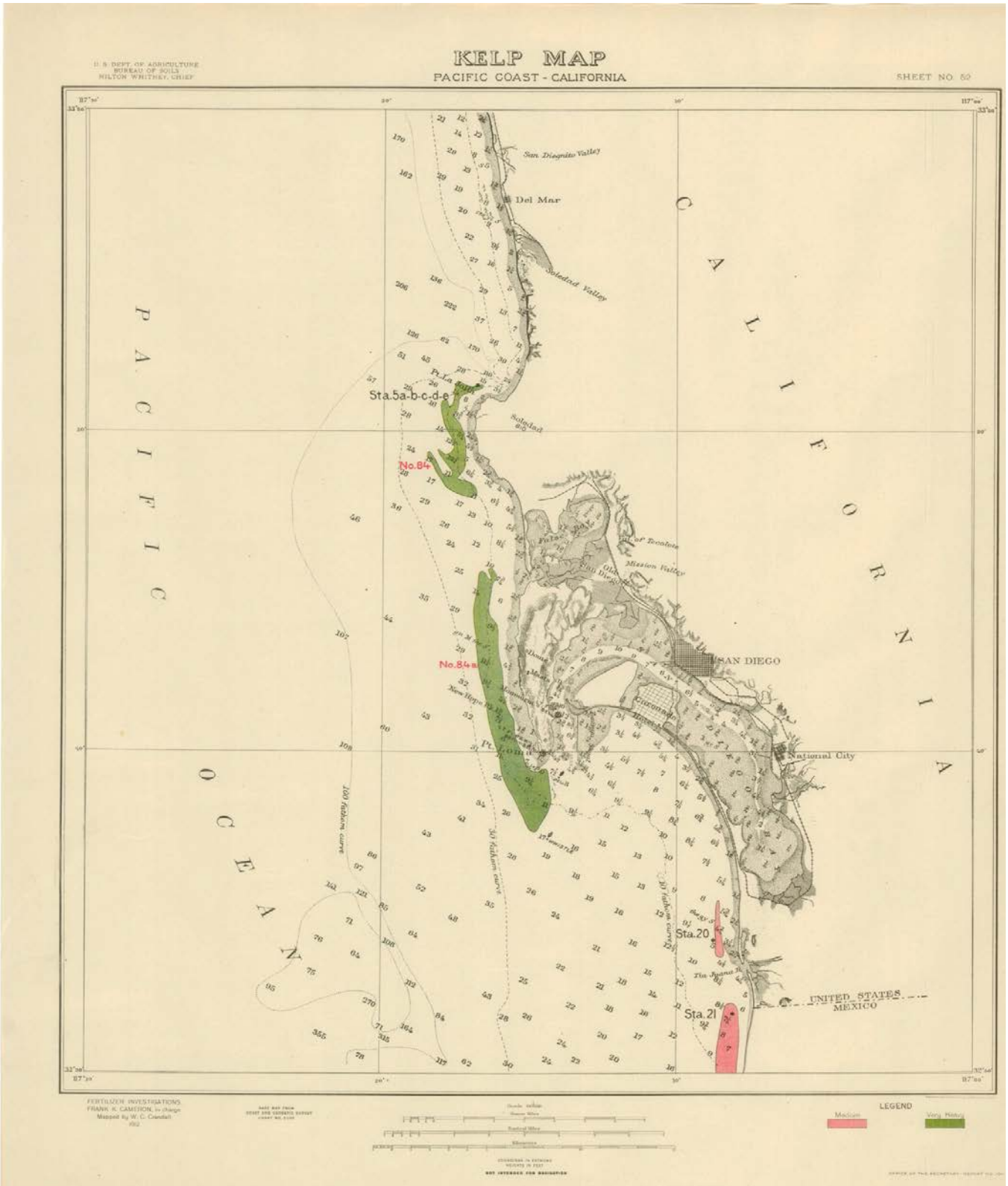
Appendix B.8 Crandall's 1911 kelp bed survey San Onofre to Del Mar.



Appendix B.9 Crandall's 1911 kelp bed survey San Juan to Encinitas.



Appendix B.10 Crandall's 1911 kelp bed survey La Jolla to Point Loma.



Appendix B.11 Crandall's 1911 kelp bed survey La Jolla to Imperial Beach.