

Impact of habitat structure on fish populations in kelp forests at a seascape scale

K. T. Sievers*, R. J. Barr, J. M. Maloney, N. W. Driscoll, T. W. Anderson

*Corresponding author: ktsievers2@gmail.com

Marine Ecology Progress Series 557: 51–63 (2016)

Table S1: Summary data for response and predictor variables separated by region displaying mean and (standard deviation) values. Fish, Macroalgae, and Bathymetry variables are density per transect (Fish are per 360 m³, Macroalgae and Bathymetry are per 120 m²). Configuration variables are values per reef.

Fish Species	Fish Population Variable	Laguna	Encinitas	La Jolla	Point Loma
Kelp Perch	Density	3.3 (0.7)	4.1 (1.0)	0.8	1.5
	Biomass	33.8 (7.4)	41.3 (10.0)	8.2	9.5
	Mean Size (TL)	9.0 (0.8)	7.8 (0.5)	9.5	8.8
	Max Size (TL)	11.8 (1.1)	14.64 (1.37)	14.1	16.2
Black Surfperch	Density	1.3 (0.2)	1.48 (0.56)	0.5	0.4
	Biomass	83.4 (15.6)	67.0 (26.0)	31.2	27.4
	Mean Size (TL)	12.2 (0.5)	5.7 (1.1)	14.3	13.8
	Max Size (TL)	16.7 (1.8)	14.6 (2.3)	27.3	28.1
Senorita	Density	8.6 (1.5)	8.2 (1.9)	6.1	8.6
	Biomass	448.1 (136.6)	155.4 (70.6)	69.1	139.3
	Mean Size (TL)	12.9 (0.5)	8.5 (0.7)	8.6	10.8
	Max Size (TL)	20.9 (0.9)	17.5 (2.0)	20.0	26.5
Kelp Bass	Density	2.2 (0.4)	4.6 (0.8)	2.0	1.2
	Biomass	546.5 (185.0)	714.3 (138.0)	582.5	253.1
	Mean Size (TL)	21.3 (1.0)	17.9 (1.0)	22.6	23.3
	Max Size (TL)	37.3 (1.8)	37.7 (2.9)	50.4	48.6
Sheephead	Density	1.7 (0.4)	0.6 (0.1)	0.8	0.3
	Biomass	663.1 (192.0)	177.1 (49.4)	321.0	67.4
	Mean Size (TL)	22.1 (2.1)	4.2 (0.7)	26.2	25.1
	Max Size (TL)	33.5 (3.8)	31.2 (6.8)	68.5	55.8
Seascape Component	Predictor Variable				
Algae	<i>Cystoseira osmundacea</i>	8.3 (3.7)	2.1 (1.1)	45.1	104.3
	<i>Egregia menziesii</i>	15.9 (5.9)	28.9 (7.8)	5.1	5.2
	<i>Eisenia arborea</i>	48.2 (19.1)	7.0 (2.9)	10.3	1.6
	<i>Laminaria farlowii</i>	10.5 (4.9)	0.9 (0.4)	66.3	144.5
	<i>Macrocystis pyrifera</i>	15.5 (2.3)	17.8 (1.9)	9.5	5.0
	<i>Macrocystis pyrifera</i> juv	19.9 (5.6)	12.6 (2.6)	5.8	2.5
	<i>Macrocystis stipes</i>	167.2 (18.2)	240.6 (36.2)	109.6	92.0
	<i>Pterygophora californica</i>	10.9 (5.1)	0.6 (0.6)	35.8	51.4
Bathymetry	Depth (m)	9.6 (0.8)	10.8 (0.5)	16.0	12.5
	Relief	2.7 (0.2)	1.8 (0.1)	1.8	1.8
	SD relief	0.9 (0.1)	0.4 (0.1)	0.5	0.5

Seascape					
Component	Predictor Variable	Laguna	Encinitas	La Jolla	Point Loma
	Fractal Dimension	1.159 (0.1)	1.148 (0.02)	1.264	1.213
	Percent Habitat 100	4.6 (1.0)	8.5 (3.5)	1.04	0.36
	Percent Habitat 250	10.7 (2.1)	7.5 (1.5)	2.09	1.51
	Percent Habitat 500	14.1 (2.4)	6.4 (1.5)	1.89	1.66
	Percent Habitat 750	13.7 (2.3)	7.4 (1.6)	1.48	1.45
	Percent Habitat 1000	12.1 (1.9)	8.0 (1.3)	1.16	1.26
	Proximity Index 100	54.8 (27.8)	84.7 (38.2)	74.44	49.65
	Proximity Index 250	66.7 (27.7)	85.0 (38.2)	76.13	54.81
	Proximity Index 500	67.1 (27.7)	88.3 (37.6)	76.22	55.36
	Proximity Index 750	67.7 (27.7)	88.6 (37.6)	76.22	55.42
	Proximity Index 1000	67.9 (27.7)	88.9 (37.5)	76.22	55.42
	Connectivity Index 100	0.9174 (0.01)	0.9357 (0.1)	1.0000	1.0000
	Connectivity Index 250	0.9352 (0.01)	0.9423 (0.0)	0.9586	0.8354
	Connectivity Index 500	0.9386 (0.01)	0.9487 (0.0)	0.9531	0.9054
	Connectivity Index 750	0.9448 (0.00)	0.9562 (0.01)	0.9509	0.9605
	Connectivity Index 1000	0.9452 (0.01)	0.9638 (0.01)	0.9595	0.9605

Table S2a: Model Output Results for All Regions Combined Analysis

Species	Fish Population Variable	R ²	Model p-value	Metrics	p-value	Corr	Partial R ²			
Kelp Perch	Numerical Density	0.424	0.001	Cohesion 100	0.029	-0.488	0.104			
				% Habitat 250	0.070	0.457	0.070			
				Algae PCA 3	0.029	-0.429	0.106			
	Biomass Density	0.367	0.035	% Habitat 250	0.035	0.367	0.135			
				Average Size (TL)	0.399	0.002	Proximity Index 100	0.003	-0.513	0.222
							750 Cohesion	0.060	0.016	0.079
	Maximum Size (TL)	0.360	0.001	Depth	0.066	-0.403	0.075			
				Proximity Index 250	0.035	-0.190	0.104			
				Area	0.001	0.506	0.324			
	Black Surfperch	Numerical Density	0.384	< 0.001	Algae PCA 3	0.003	0.593	0.200		
Proximity Index 1000					0.035	-0.493	0.091			
Biomass Density		0.572	< 0.001	Algae PCA 3	0.000	0.689	0.359			
				Cohesion 1000	0.014	-0.462	0.097			
Average Size (TL)		0.452	< 0.001	Algae PCA 3	0.010	0.552	0.138			
				Relief	0.008	0.561	0.147			
Maximum Size (TL)		0.604	0.001	Area	0.001	0.422	0.183			
				Algae PCA 1	0.080	-0.106	0.045			
				Algae PCA 3	0.000	0.640	0.367			
Seniorita		Numerical Density	0.575	< 0.001	Fractal Dimension	0.007	-0.460	0.134		
	Proximity Index 100				0.018	-0.518	0.100			
	S.D. Relief				0.040	-0.192	0.073			
	Clumpiness 1000				0.014	-0.468	0.109			
	Biomass Density	0.451	0.000	Area	0.066	-0.233	0.058			
				Proximity Index 250	0.000	-0.597	0.284			
	Average Size (TL)	0.603	<0.001	S.D. Relief	0.031	0.408	0.094			
				Proximity Index 750	0.007	-0.375	0.120			
				Algae PCA 1	0.016	-0.194	0.092			
				% Habitat 750	0.042	0.316	0.065			
Maximum Size (TL)	0.487	< 0.001	S.D. Relief	0.001	0.643	0.203				
			750 Cohesion	0.002	0.408	0.207				
			S.D. Relief	0.007	0.475	0.147				
Kelp Bass	Numerical Density	0.562	<0.001	Algae PCA 3	0.039	0.362	0.082			
				S.D. Relief	0.014	-0.442	0.112			
				Area	0.002	-0.350	0.186			
				Algae PCA 2	0.070	0.252	0.056			
	Biomass Density	0.269	0.009	Proximity Index 100	0.004	0.425	0.154			
				Proximity Index 100	0.013	0.275	0.168			
	Average Size (TL)	0.332	0.002	Cohesion 500	0.008	-0.318	0.168			
				Clumpiness 1000	0.002	-0.402	0.262			
	Maximum Size (TL)	0.259	0.011	Algae PCA 1	0.010	-0.265	0.171			
				% Habitat 250	0.014	-0.415	0.171			
Proximity Index 100				0.069	0.296	0.087				
CA Sheephead	Numerical Density	0.479	0.001	Depth	0.008	0.178	0.153			
				S.D. Relief	0.001	0.399	0.253			
				Proximity Index 100	0.034	0.184	0.092			
				Clumpiness 1000	0.008	-0.233	0.151			
	Biomass Density	0.341	0.006	Clumpiness 500	0.101	-0.181	0.065			
				Proximity Index 1000	0.022	0.204	0.132			
				S.D. Relief	0.004	0.437	0.223			
	Average Size (TL)	0.734	<0.001	Algae PCA 1	0.000	-0.417	0.383			
				Clumpiness 500	0.088	-0.333	0.030			
				Algae PCA 2	0.047	0.094	0.041			
Maximum Size (TL)	0.538	<0.001	Relief	0.000	0.544	0.394				
			Relief	0.039	-0.008	0.075				
			Area	0.000	0.658	0.372				
				Proximity Index 1000	0.036	0.631	0.077			

Table S2b: Model Output Results for Laguna Beach Analysis

Species	Fish Population Variable	Model R ²	Model p-value	Habitat Metrics	p-value	Corr	Partial R ²				
Kelp Perch	Numerical Density	0.306	0.011	% Habitat 250	0.011	0.553	0.306				
				% Habitat 250	0.036	0.476	0.227				
	Average Size (TL)	0.446	0.021	Proximity Index 100	0.053	-0.482	0.151				
				Algae PCA 1	0.057	-0.251	0.145				
				Clumpiness 100	0.033	0.251	0.189				
	Maximum Size (TL)	0.318	0.038	Proximity Index 250	0.113	-0.200	0.112				
Clumpiness 250				0.017	0.455	0.279					
Black Surfperch	Numerical Density	0.635	0.001	Proximity Index 1000	0.012	-0.631	0.221				
				Algae PCA 3	0.036	0.669	0.119				
				Algae PCA 2	0.115	0.068	0.064				
	Biomass Density	0.721	<0.001	Depth	0.000	-0.758	0.350				
				Area	0.077	-0.084	0.063				
				Clumpiness 1000	0.011	-0.529	0.147				
	Average Size (TL)	0.816	<0.001	Proximity Index 750	0.009	-0.354	0.110				
				S.D. Relief	0.035	0.496	0.066				
				Algae PCA 1	0.087	-0.354	0.041				
				Clumpiness 250	0.000	0.604	0.516				
				Maximum Size (TL)	0.890	<0.001	Proximity Index 750	0.014	-0.418	0.062	
				Algae PCA 1	0.054	-0.298	0.035				
				S.D. Relief	0.071	0.446	0.030				
				Algae PCA 3	0.056	0.569	0.034				
				Clumpiness 250	0.000	0.625	0.432				
Senorita				Numerical Density	0.399	0.003	Proximity Index 100	0.003	-0.632	0.399	
	Biomass Density	0.377	0.004				Proximity Index 250		-0.614	0.377	
	Average Size (TL)	0.524	0.019	Algae PCA 2	0.024	-0.129	0.201				
				Algae PCA 1	0.039	0.179	0.163				
				% Habitat 100	0.035	0.427	0.171				
				S.D. Relief	0.017	0.311	0.228				
				Maximum Size (TL)	0.344	0.028	% Habitat 1000	0.079	-0.490	0.135	
				Algae PCA 3	0.120	0.458	0.104				
				Kelp Bass	Numerical Density	0.759	<0.001	Cohesion 500	0.000	-0.315	0.465
								Relief	0.005	-0.253	0.169
								Proximity Index 100	0.000	0.502	0.446
					Biomass Density	0.577	0.003	Depth	0.045	0.059	0.077
Proximity Index 250	0.003	-0.584	0.334								
Depth	0.010	-0.070	0.228								
	Average Size (TL)	0.707	0.001	Algae PCA 3	0.031	0.370	0.148				
				Clumpiness 750	0.000	-0.606	0.394				
				% Habitat 250	0.043	-0.348	0.095				
				Depth	0.005	-0.001	0.205				
				Algae PCA 3	0.025	0.334	0.122				
	Maximum Size (TL)	0.774	<0.001	% Habitat 500	0.000	-0.542	0.268				
				Cohesion 500	0.000	-0.516	0.447				
				Proximity Index 100	0.002	0.234	0.195				
CA Sheephead	Numerical Density	0.617	0.001	% Habitat 1000	0.053	-0.316	0.105				
				Depth	0.000	0.453	0.465				
				S.D. Relief	0.005	0.281	0.260				
	Biomass Density	0.611	0.001	Cohesion 500	0.000	-0.362	0.520				
				Algae PCA 3	0.042	-0.189	0.118				
				Area	0.001	0.218	0.432				
	Average Size (TL)	0.613	<0.001	Area	0.000	0.258	0.461				
				Cohesion 500	0.000	-0.390	0.546				
	Maximum Size (TL)	0.661	0.002	% Habitat 250	0.035	-0.519	0.122				
				Cohesion 100	0.035	-0.565	0.121				
Depth				0.033	0.114	0.125					
S.D. Relief				0.012	0.410	0.186					

Table S2c: Model Output Results for Encinitas Analysis

Species	Fish Population Variable	Model R ²	Model p-value	Habitat Metrics	p-value	Corr	Partial R ²
Kelp Perch	Numerical Density	0.920	0.002	Proximity Index 1000	0.007	-0.573	0.212
				Cohesion 500	0.002	-0.540	0.358
				Depth	0.008	0.467	0.203
				Fractal Dimension	0.021	0.227	0.130
	Biomass Density	0.747	0.004	Proximity Index 1000	0.002	-0.782	0.671
				Algae PCA 2	0.073	-0.277	0.135
Black Surfperch	Average Size (TL)	0.642	0.003	Proximity Index 1000	0.003	-0.801	0.642
				Maximum Size (TL)	0.854	0.000	Proximity Index 100
	Numerical Density	0.552	0.040	Algae PCA 1	0.000	0.841	0.823
				Depth	0.053	-0.593	0.288
				Cohesion 100	0.095	0.514	0.200
				Depth	0.010	-0.716	0.506
Biomass Density	0.648	0.015	Algae PCA 2	0.117	0.379	0.136	
			Depth	0.002	-0.814	0.663	
			Depth	0.001	-0.706	0.702	
			Proximity Index 100	0.141	-0.930	0.067	
Seniorita	Average Size (TL)	0.793	0.002	Algae PCA 1	0.008	0.316	0.317
				Maximum Size (TL)	0.831	0.004	Depth
	Numerical Density	0.809	0.001	Proximity Index 100	0.141	-0.930	0.067
				Algae PCA 1	0.008	0.316	0.317
				Fractal Dimension	0.002	-0.767	0.524
				Proximity Index 500	0.016	-0.533	0.221
Biomass Density	0.603	0.025	Proximity Index 500	0.011	-0.658	0.537	
			S.D. Relief	0.101	0.256	0.170	
			1000 clump	0.005	-0.673	0.392	
			Proximity Index 250	0.007	-0.633	0.340	
Kelp Bass	Average Size (TL)	0.930	<0.001	1000 clump	0.041	-0.645	0.176
				Fractal Dimension	0.009	0.766	0.347
	Maximum Size (TL)	0.841	0.003	% Habitat 250		0.836	0.699
				% Habitat 750	0.003	0.814	0.412
				Algae PCA 3	0.034	-0.634	0.151
				Relief	0.003	-0.547	0.203
CA Sheephead	Average Size (TL)	0.587	0.029	Depth	0.000	-0.595	0.489
				Cohesion 750	0.012	0.587	0.111
	Maximum Size (TL)	0.873	<0.001	Area	0.004	0.574	0.406
				Algae PCA 3	0.008	-0.544	0.305
				Proximity Index 1000	0.067	0.477	0.106
				Proximity Index 500	0.015	0.640	0.445
Kelp Bass	Numerical Density	0.699	0.001	S.D. Relief	0.043	-0.234	0.266
				750 Cohesion	0.120	0.263	0.136
	Biomass Density	0.799	0.008	Proximity Index 500	0.026	0.587	0.226
				Algae PCA 3	0.060	-0.404	0.144
				Area	0.009	0.573	0.373
				Algae PCA 1	0.028	0.495	0.372
Average Size (TL)	0.587	0.029	% Habitat 500	0.033	0.464	0.342	
			Algae PCA 3	0.022	-0.359	0.129	
Maximum Size (TL)	0.873	<0.001	Algae PCA 1	0.000	0.862	0.743	