

Appendix S2

Title: Evaluating historical changes in a mussel bed community in northern California

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Section S1: Additional Sampling Details

Barnacle counts per plot included estimates of individuals on mussel shells plus those on the underlying rocks. In the laboratory, we counted the number of each barnacle species on a subsample of mussels (7.5–22.7% of the total) from each plot across a range of mussel sizes, excluding mussels less than 10mm (since mussels of this size rarely have barnacles). This corresponded to counting barnacles on between 313 to 1,229 mussels within each plot. We then calculated a total number of barnacles living on the mussels per plot by extrapolating from the average number of barnacles present on mussels in each 5mm size bin relative to the number of mussels of that size present in that plot. Large mussels were rare, so in a few cases, mussels of a given size bin for a specific plot were not analyzed for barnacles. In these situations, we assigned these mussels an average barnacle count from size classes just larger or smaller than that size class from the same plot. In the field, we also estimated the total number of *Balanus glandula* and *Chthamalus dalli* that remained on the rock after removing all organisms. The number of barnacles on the rock was much smaller than on the mussel shells, so we obtained a visual estimate for each plot by summing the approximate number of barnacles found in each section of the quadrat. For the first plot sampled (Plot 1) we neglected to estimate the total number of barnacles left on the rock. Thus, we assigned it the average number present from the other plots.

Supplementary Table S1. Many species were grouped or omitted from the final data sets used in the spatial and temporal comparisons. Our raw data (Appendix S1) included as much information as possible about each species/taxonomic group. For our analyses, we took a conservative approach to which organisms the students would have reasonably found and been able to identify in 1941. Thus, we grouped certain species together to have similar taxonomic resolution, and dropped those species that were likely not living within the mussel bed, as well as several small and inconspicuous species that did not appear to be considered in the 1941 survey.

Species Grouped/Lumped	Species Dropped
Nereididae - grouped <i>Nereis vexillosa</i> , <i>Nereis zonata</i> , <i>Nereis latescans</i> , <i>Neanthes brandti</i> , with other Nereididae.	Dropped bryozoans and hydroids because these animals likely washed into the plots and were not attached/living there.
Lumbrineridae - grouped <i>Lumbrinereis zonata</i> with other Lumbrineridae.	Dropped flatworms and sponges. Both taxa were mentioned elsewhere in the 1941 report, but not included on the mussel bed species list. These species are very conspicuous and abundant so likely they were not included in the mussel bed survey.
Polynoidae - grouped <i>Halosydna brevisetosa</i> with Polynoidae.	
Syllidae – grouped <i>Syllis adamantea</i> , <i>Syllis elongata</i> Complex, <i>Syllis pigmentata/provisional</i> sp. nov?, with other Syllidae.	Species/taxa dropped because organisms are small/inconspicuous: Oligochaeta, <i>Sabellaria</i> sp., <i>Neomolgus littoralis</i> , Insect larva, <i>Munna chromatocephala</i> , <i>Pancolus californiensis</i> , <i>Lasaea subviridis</i> , <i>Barleeia haliotiphila</i> , <i>Odostomia tenuisculpta</i> , <i>Runcina macfarlandi</i> , Nematodes/roundworms, <i>Paramorea</i> , Pholoinae genus A species B Harris, <i>Notomastus</i> sp., <i>Polycirrus</i> sp., “ <i>Tetrastemma</i> ” <i>bilineatum</i> , <i>Hiatella arctica</i> .
Sabellidae - grouped <i>Sabella media</i> with Sabellidae.	
Grouped <i>Lottia limatula</i> with <i>Lottia</i> sp.	
Grouped <i>Lottia paradigitalis</i> with <i>Lottia digitalis</i> .	
Grouped <i>Mopalia</i> sp. 1 with <i>Mopalia mucosa</i> .	Dropped organisms that were clearly not the focus of the 1941 study: Staphylinidae (beetles).
Grouped amphipods - <i>Apohyale anceps</i> , <i>Ptilohyale littoralis</i> , <i>Jassa</i> sp., <i>Elasmopus rapax</i> , <i>Paramoera</i> sp.	Species described after 1941 and thus unknown at time of original survey: <i>Macaulaura cerebrosa</i> (described in 2015).

Supplementary Table S2. Size frequency distribution of mussels (*Mytilus californianus*) in the 2019 surveys compared to 1941. Values are the number of mussels in each size class, grouped into 5 mm bins. In the temporal comparison, the plot was 0.70 m², whereas in the spatial comparison, the plot was 0.16 m².

	Temporal Comparison		Spatial Comparison			
Mussel Length Bin (mm)	1941 Survey	2019 Survey	F&H Subsample	Plot 1	Plot 2	Plot 3
(0,5]	713	1367	483	410	485	1050
(5,10]	709	2960	1058	964	890	366
(10,15]	386	2953	1125	1155	745	232
(15,20]	304	2194	846	941	556	217
(20,25]	313	1598	570	626	380	165
(25,30]	394	1113	326	437	278	130
(30,35]	391	759	195	300	193	109
(35,40]	343	477	123	191	172	114
(40,45]	230	328	98	123	116	100
(45,50]	240	197	66	74	110	72
(50,55]	162	116	35	83	90	62
(55,60]	134	69	16	74	55	50
(60,65]	87	23	5	61	57	38
(65,70]	97	22	3	51	32	31
(70,75]	49	9	1	35	16	33
(75,80]	34	6	1	16	7	26
(80,85]	19	6	1	8	1	10
(85,90]	23	0	0	4	1	16
(90,95]	9	1	0	4	0	13
(95,100]	8	1	0	2	0	3
(100,105]	3	0	0	1	0	5
(105,110]	4	0	0	0	0	2
(110,115]	0	0	0	0	0	1
(115,120]	0	0	0	1	0	1

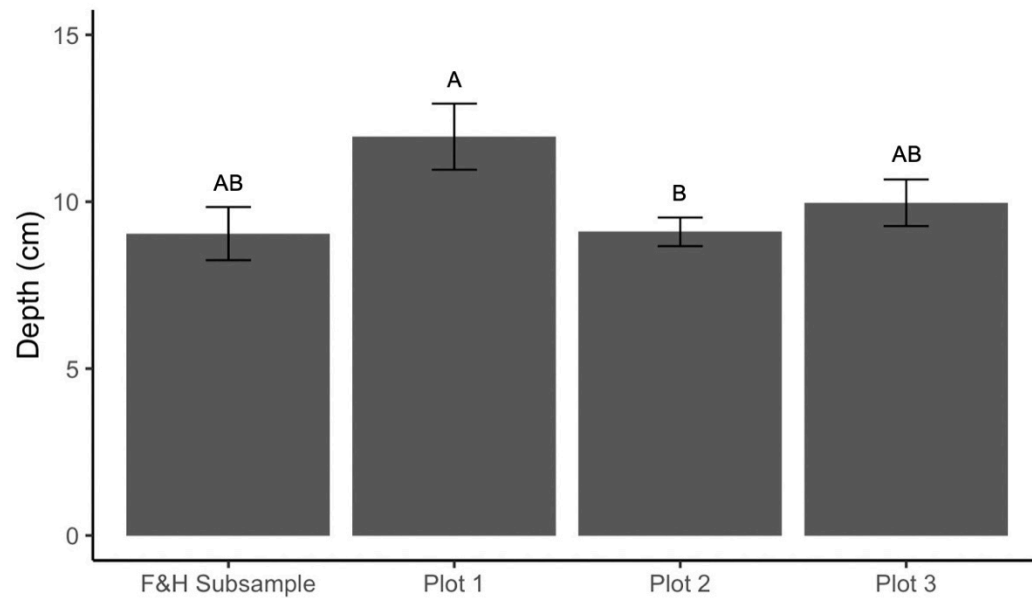
Supplementary Table S3. Species density values (abundance per 1.0 m²) used to analyze changes in mussel bed communities at Dillon Beach, California. Values are scaled based on the size of the plot: 0.70 m² for the temporal comparison and 0.16 m² for the spatial comparison. One of the replicates in the spatial comparison (F&H Subsample) was a subsample of the original plot used in the temporal comparison. Geographic range classified as S = southern, N = northern, C = cosmopolitan (see Methods for details).

Species or Taxon	Class	Range	Temporal Comparison		Spatial Comparison (2019)			
			1941	2019	F&H Subsample	Plot 1	Plot 2	Plot 3
Annelida								
<i>Arabella iricolor</i>	Polychaeta	C	11.43	41.43	125.00	306.25	6.25	318.75
<i>Eulalia quadrioculata</i>	Polychaeta	C	0.00	0.00	0.00	37.50	0.00	12.50
<i>Hemipodia simplex</i>	Polychaeta	C	0.00	1.43	6.25	6.25	0.00	0.00
Lumbrineridae	Polychaeta	C	2.86	1.43	0.00	0.00	0.00	0.00
Nereididae	Polychaeta	C	124.29	17.14	31.25	43.75	50.00	762.50
Oeonidae	Polychaeta	C	0.00	5.71	6.25	0.00	0.00	6.25
Orbiniidae	Polychaeta	C	0.00	2.86	12.50	793.75	6.25	743.75
<i>Pherusa andersonorum</i>	Polychaeta	C	0.00	1.43	6.25	0.00	0.00	0.00
<i>Phragmatopoma californica</i>	Polychaeta	S	82.86	47.14	43.75	368.75	93.75	612.50
Polynoidae	Polychaeta	C	0.00	0.00	0.00	0.00	12.50	6.25
Sabellidae	Polychaeta	C	1.43	0.00	0.00	0.00	0.00	12.50
Syllidae	Polychaeta	C	95.71	280.00	487.50	275.00	506.25	450.00
Sipuncula								
<i>Phascolosoma agassizii</i>	Phascolosomatidea	C	7.14	90.00	275.00	475.00	106.25	925.00
Nemertea								
<i>Amphiporus "imparispinosus" complex</i>	Hoplonemertea	C	0.00	80.00	187.50	12.50	62.50	112.50
<i>Emplectonema viride</i>	Hoplonemertea	C	10.00	11.43	31.25	6.25	381.25	100.00
<i>Paranemertes "peregrina" complex</i>	Hoplonemertea	C	22.86	38.57	81.25	50.00	6.25	12.50
Arthropoda								
Amphipoda	Malacostraca	C	202.86	211.43	131.25	81.25	106.25	1718.75
<i>Cirolana harfordi</i>	Malacostraca	C	1135.71	158.57	225.00	50.00	6.25	12550.00
<i>Fabia subquadrata</i>	Malacostraca	C	5.36	0.00	0.00	3.51	0.00	5.34

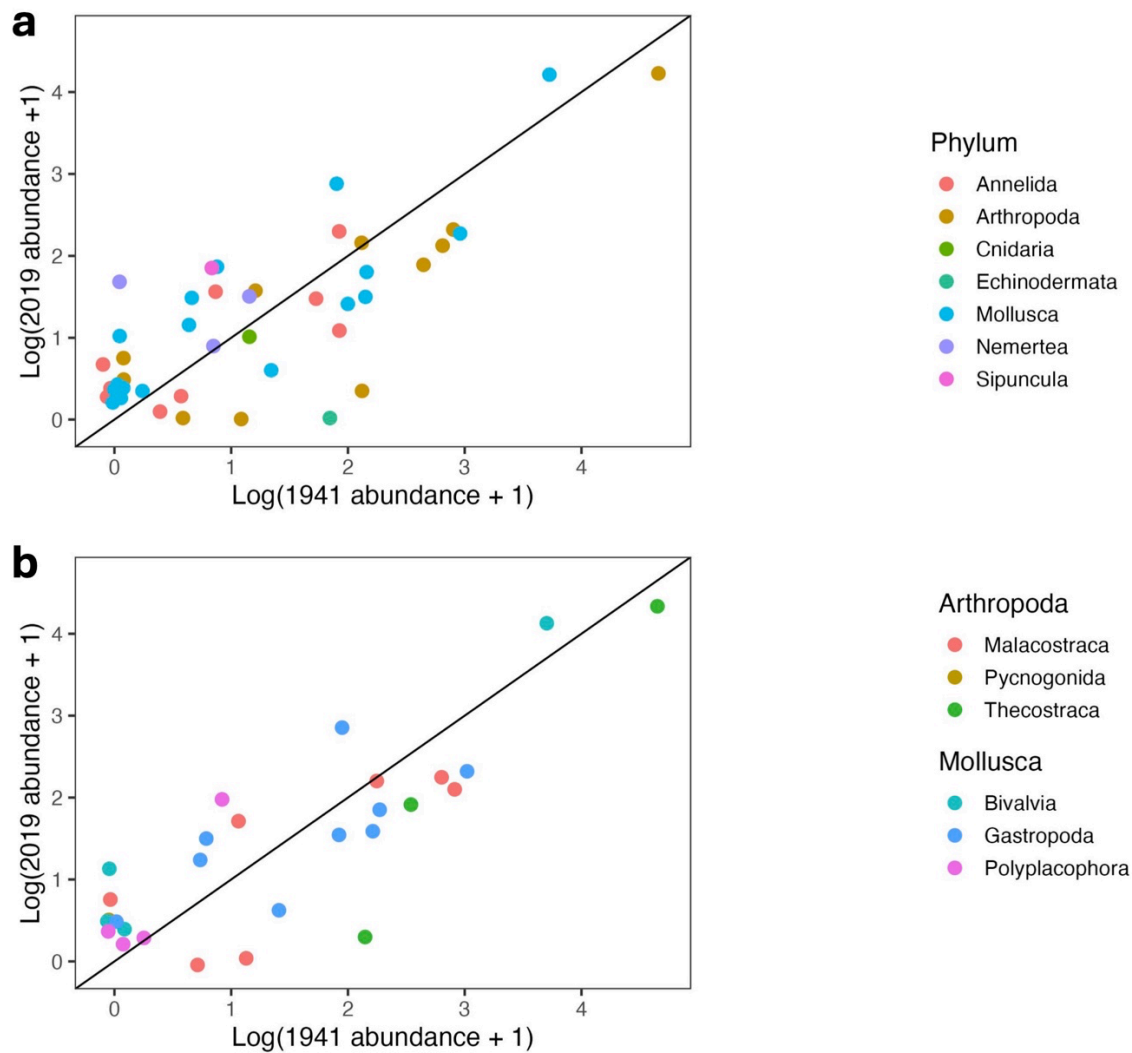
<i>Hemigrapsus oregonensis</i>	Malacostraca	C	0.00	7.14	6.25	18.75	12.50	0.00
<i>Pachygrapsus crassipes</i>	Malacostraca	C	17.14	62.86	93.75	50.00	31.25	6.25
<i>Pachycheles rudis</i>	Malacostraca	C	0.00	0.00	0.00	0.00	0.00	293.75
<i>Pagurus</i> sp.	Malacostraca	C	0.00	0.00	0.00	0.00	0.00	12.50
<i>Pentidotea wosnesenskii</i>	Malacostraca	N	17.14	0.00	0.00	0.00	0.00	12.50
<i>Petrolisthes cinctipes</i>	Malacostraca	N	992.86	314.29	781.25	750.00	93.75	2843.75
<i>Anoplodactylus viridintestinalis</i>	Pycnogonida	C	0.00	2.86	6.25	6.25	6.25	6.25
<i>Pycnogonum stearnsi</i>	Pycnogonida	C	0.00	0.00	0.00	0.00	18.75	12.50
Acorn barnacles (<i>Balanus glandula</i> & <i>Chthamalus dalli</i>)	Thecostraca	C	52857.14	25628.57	22393.75	67931.25	96362.50	89587.50
<i>Pollicipes polymerus</i>	Thecostraca	C	568.57	137.14	306.25	375.00	2912.50	2400.00
<i>Semibalanus cariosus</i>	Thecostraca	N	231.43	1.43	0.00	0.00	6.25	0.00
Cnidaria								
<i>Anthopleura elegantissima</i>	Anthozoa	C	24.29	12.86	43.75	93.75	100.00	50.00
Echinodermata								
<i>Cucumaria pseudocurata</i>	Holothuroidea	N	112.86	0.00	0.00	0.00	0.00	0.00
Mollusca								
<i>Adula californiensis</i>	Bivalvia	C	0.00	14.29	6.25	25.00	293.75	112.50
<i>Leukoma staminea</i>	Bivalvia	C	0.00	1.43	0.00	0.00	0.00	0.00
<i>Modiolus carpenteri</i>	Bivalvia	S	0.00	2.86	6.25	12.50	12.50	12.50
<i>Mytilus californianus</i>	Bivalvia	C	6645.71	20314.29	30968.75	34793.75	26275.00	17825.00
<i>Amphissa versicolor</i>	Gastropoda	C	0.00	0.00	0.00	0.00	0.00	12.50
<i>Lacuna marmorata</i>	Gastropoda	C	0.00	2.86	6.25	6.25	6.25	0.00
<i>Littorina plena</i>	Gastropoda	C	5.71	22.86	0.00	18.75	81.25	50.00
<i>Lottia digitalis</i>	Gastropoda	C	227.14	95.71	75.00	25.00	637.50	25.00
<i>Lottia pelta</i>	Gastropoda	C	1194.29	291.43	312.50	893.75	1968.75	3512.50
<i>Lottia scabra</i>	Gastropoda	S	5.71	50.00	56.25	12.50	18.75	0.00
<i>Lottia</i> sp.	Gastropoda	C	207.14	48.57	12.50	0.00	43.75	118.75
<i>Nucella canaliculata</i>	Gastropoda	N	28.57	5.71	12.50	18.75	93.75	500.00
<i>Nucella ostrina</i>	Gastropoda	N	120.00	42.86	50.00	206.25	112.50	1000.00
<i>Tegula funebris</i>	Gastropoda	C	128.57	895.71	1087.50	2493.75	418.75	2250.00
<i>Cyanoplax dentiens</i>	Polyplacophora	C	11.43	110.00	31.25	6.25	18.75	0.00
<i>Mopalia lionota</i>	Polyplacophora	S	0.00	1.43	6.25	6.25	0.00	0.00
<i>Mopalia muscosa</i>	Polyplacophora	C	1.43	1.43	6.25	6.25	6.25	56.25
<i>Nuttallina californica</i>	Polyplacophora	C	0.00	1.43	0.00	0.00	6.25	0.00

Supplementary Figure S1. Depth of mussel bed for spatial comparison of four replicate plots.

“F&H Subsample” is a subsample of the original plot sampled in 1941. 10–16 depth measurements were taken per plot before destructively sampling plots. Bars depict mean \pm standard error. Shared letters above bars indicate means that did not differ (Tukey HSD, $p > 0.05$).



Supplementary Figure S2. Change in the log abundance of species within the mussel bed plot at Dillon Beach in 1941 versus 2019. (a) Variation in abundance among species colored by their Phylum. (b) Variation in abundance among species grouped by class within the arthropods and molluscs. Line is the one-to-one line. Points are slightly jittered to be able to see overlapping species. Taxonomic groups did not show consistent changes in abundance between timepoints.



Supplementary Figure S3. Monthly seawater temperature from Bodega Head from 1956 to 2023. Monthly data were calculated from measurements taken at ~ 8:00am daily.

