

Supplemental Material

Results

Variation in epibenthic invertebrate assemblages among sites without bivalve culture

There was considerable variation in the abundance, richness, and diversity of epibenthic invertebrates at sites without bivalve culture (Fig. 1 -- Supplemental Material). Grouping observations collected at the same times and places revealed that counts ranged from single digits to tens of thousands, richness ranged from single digits to the mid-forties, and diversity ranged from zero to three. Observations collected at the same dates and times tended to be more similar, but there was still variation in observations at the same sites across time. Invertebrates tended to be more abundant, rich, and diverse in eelgrass habitats than in open sand and mud habitats. Indeed, invertebrate abundances were in many cases an order of magnitude greater in eelgrass habitats. Overall, invertebrate assemblages at different places and times were naturally quite variable.

Figures

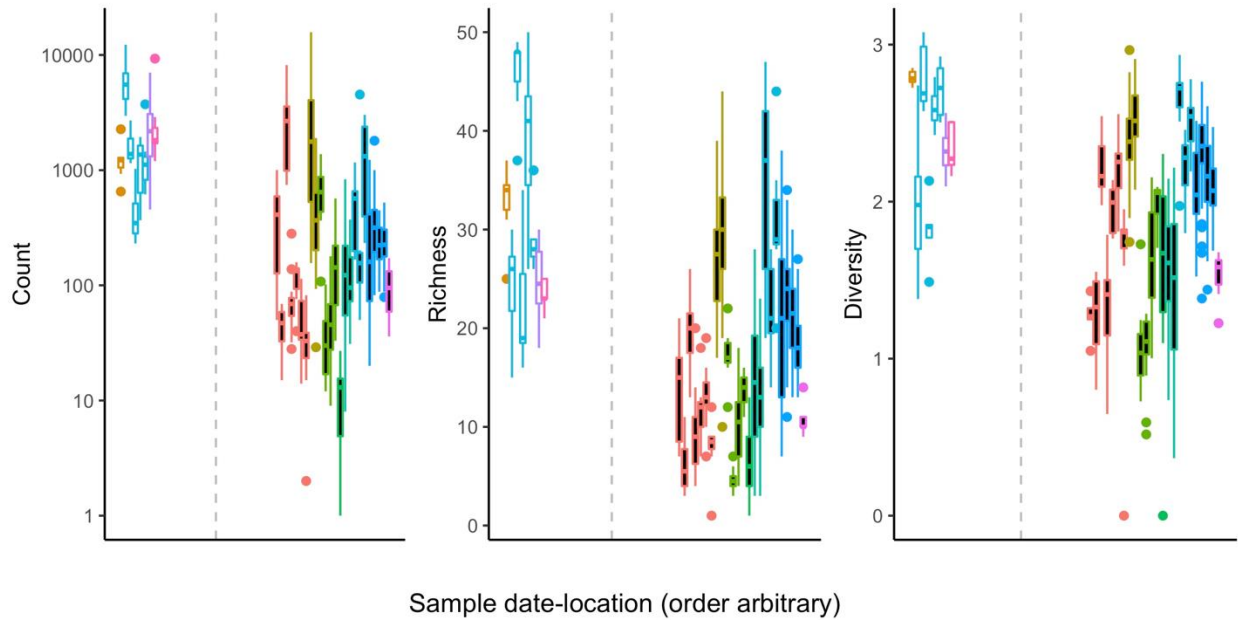


Figure 1. Counts, richness, and diversity of epibenthic invertebrate assemblages at reference (i.e., not cultured) sites. Observations are grouped by sampling that occurred at the same time and place and colored by site. Unshaded plots on the left of the dashed line are eelgrass habitats and shaded plots on the right are sand and mud habitats. Other than grouping by site and habitat type, the order of boxplots on the x axis is arbitrary.

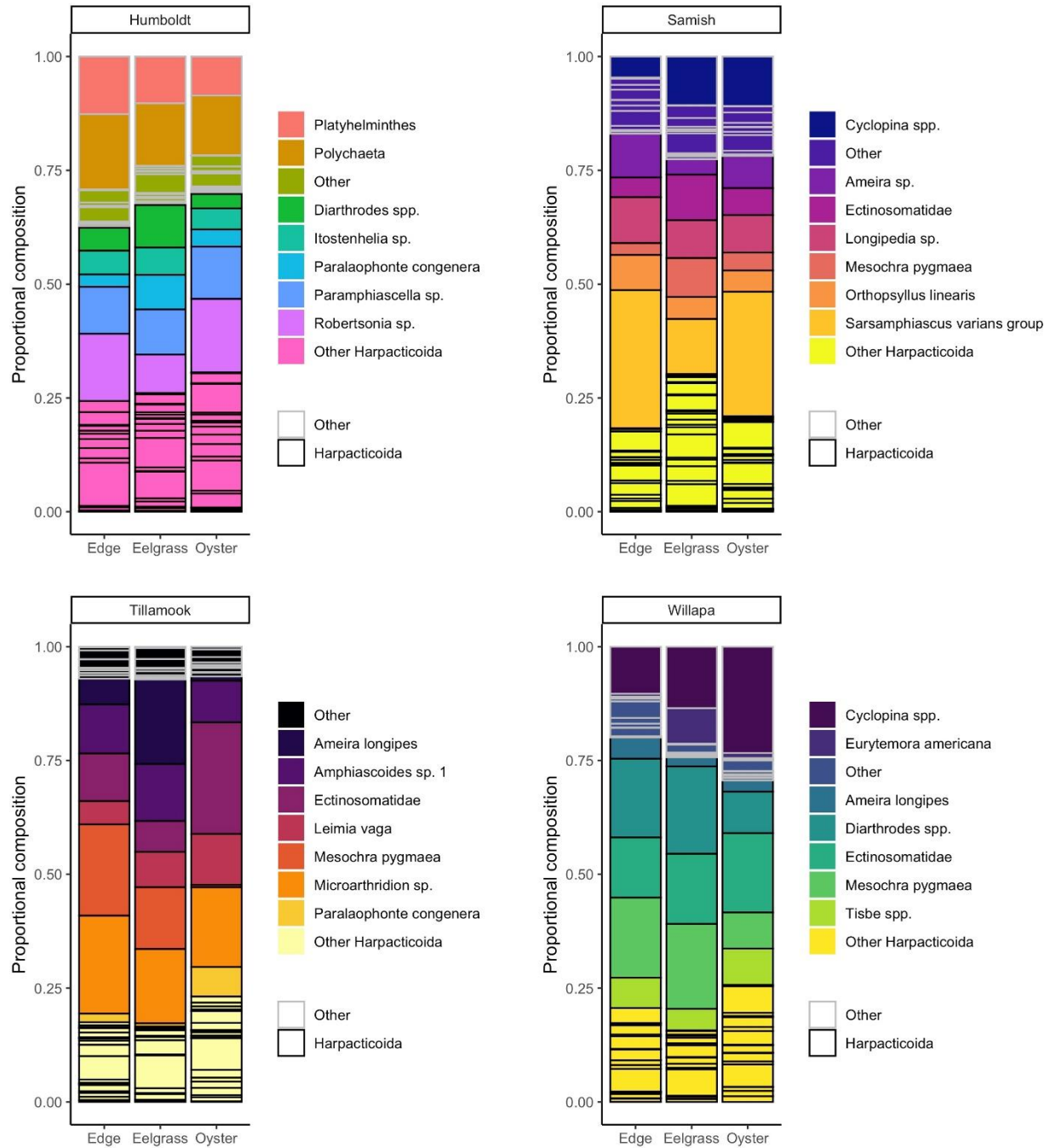


Figure 2. Taxonomic composition of invertebrate assemblage in the Pacific oyster longline study compared across strata and sites.

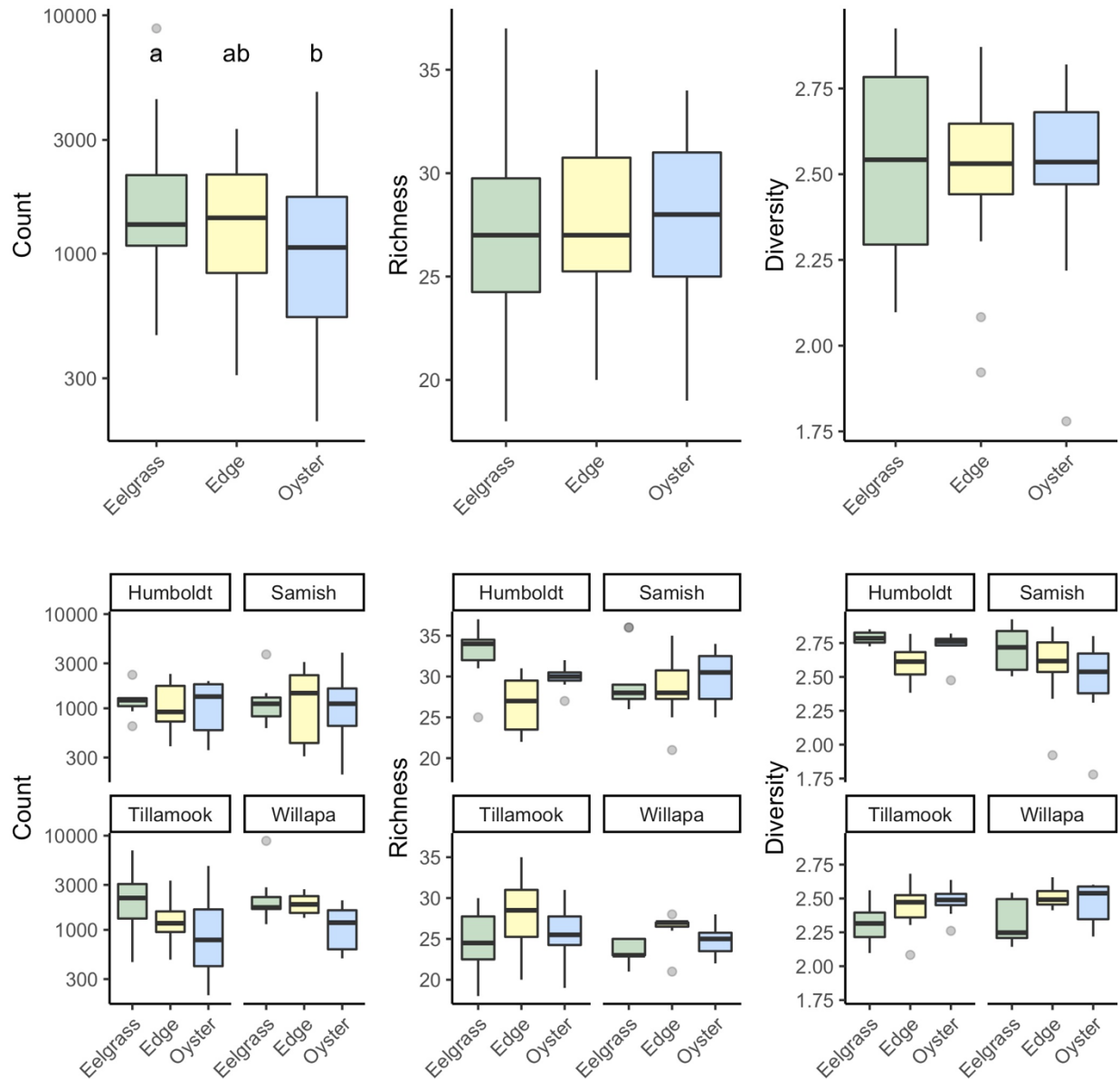


Figure 3. Counts, richness, and diversity of epibenthic invertebrates sampled in the Pacific oyster longline study compared among eelgrass, edge, and oyster strata. Plots on top show measures aggregated across sites and plots below show the same measures separated by sites. This and subsequent boxplots: (1) upper and lower hinges: first and third quartiles; mid-line: median; whiskers: points within $1.5 \times$ interquartile range; dots represent data outside of $1.5 \times$ interquartile range; (2) statistically significant differences among group pairs are indicated by letters.

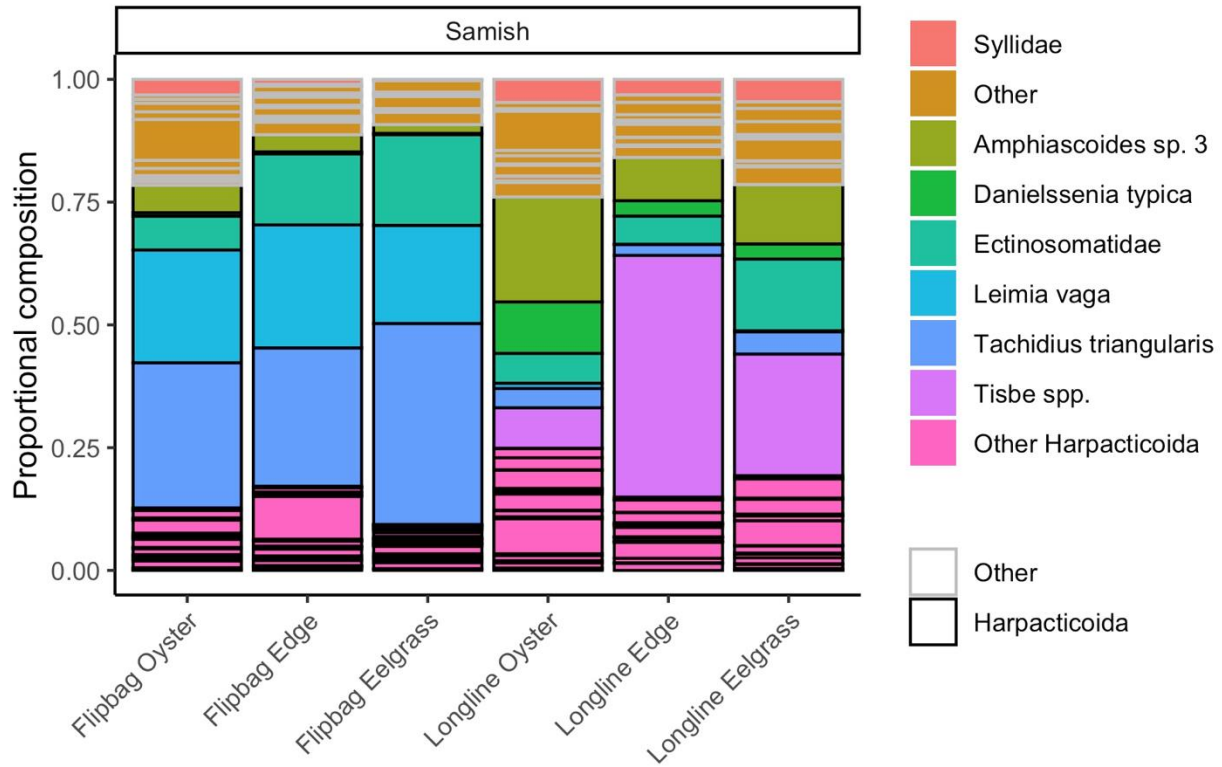


Figure 4. Taxonomic composition of invertebrate assemblages in the Pacific oyster flipbag vs. longline study compared across strata.

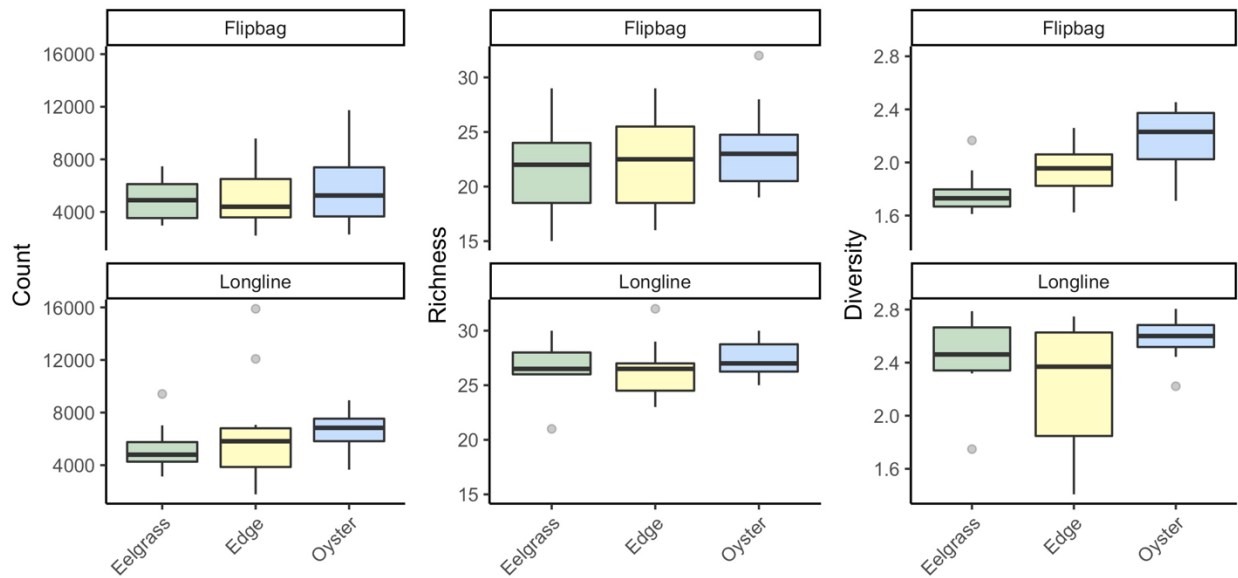


Figure 5. Counts, richness, and diversity of epibenthic invertebrates sampled in the flipbag vs. longline study compared among eelgrass, edge, and oyster strata between flipbag and longline locations.

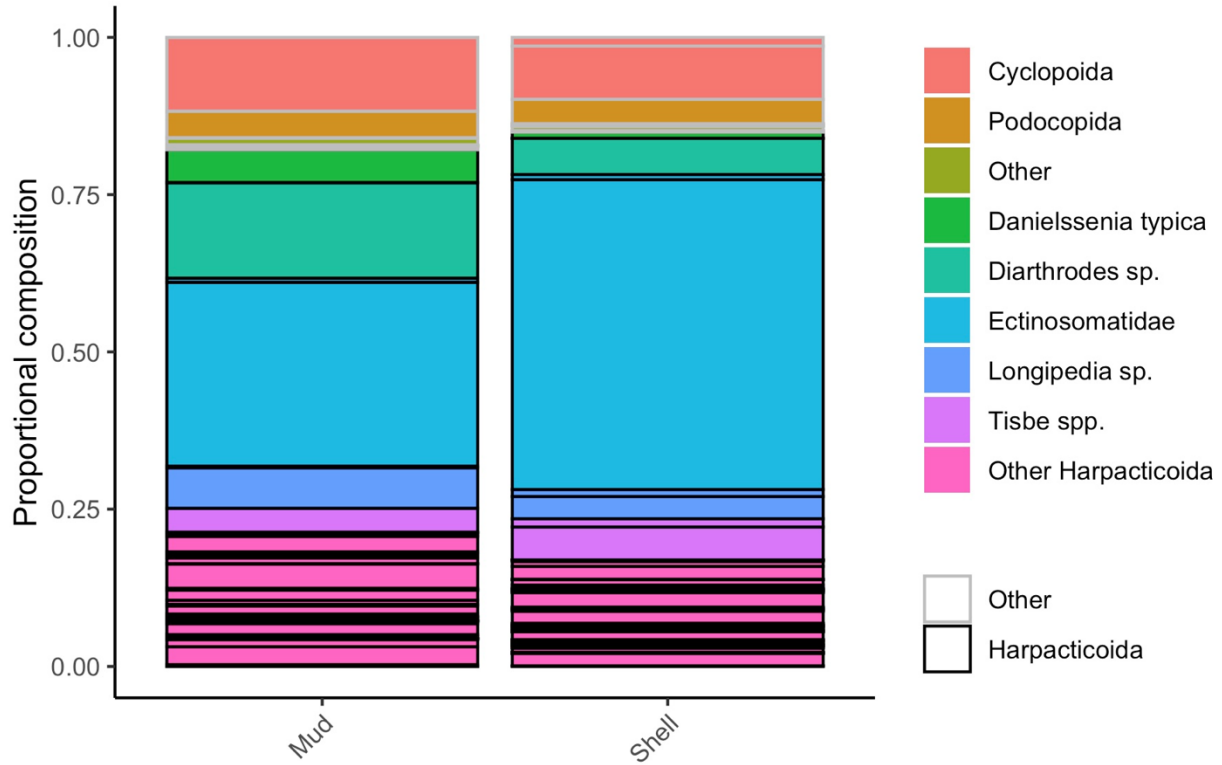


Figure 6. Taxonomic composition of invertebrate assemblage in the Pacific oyster shell introduction study compared across strata.

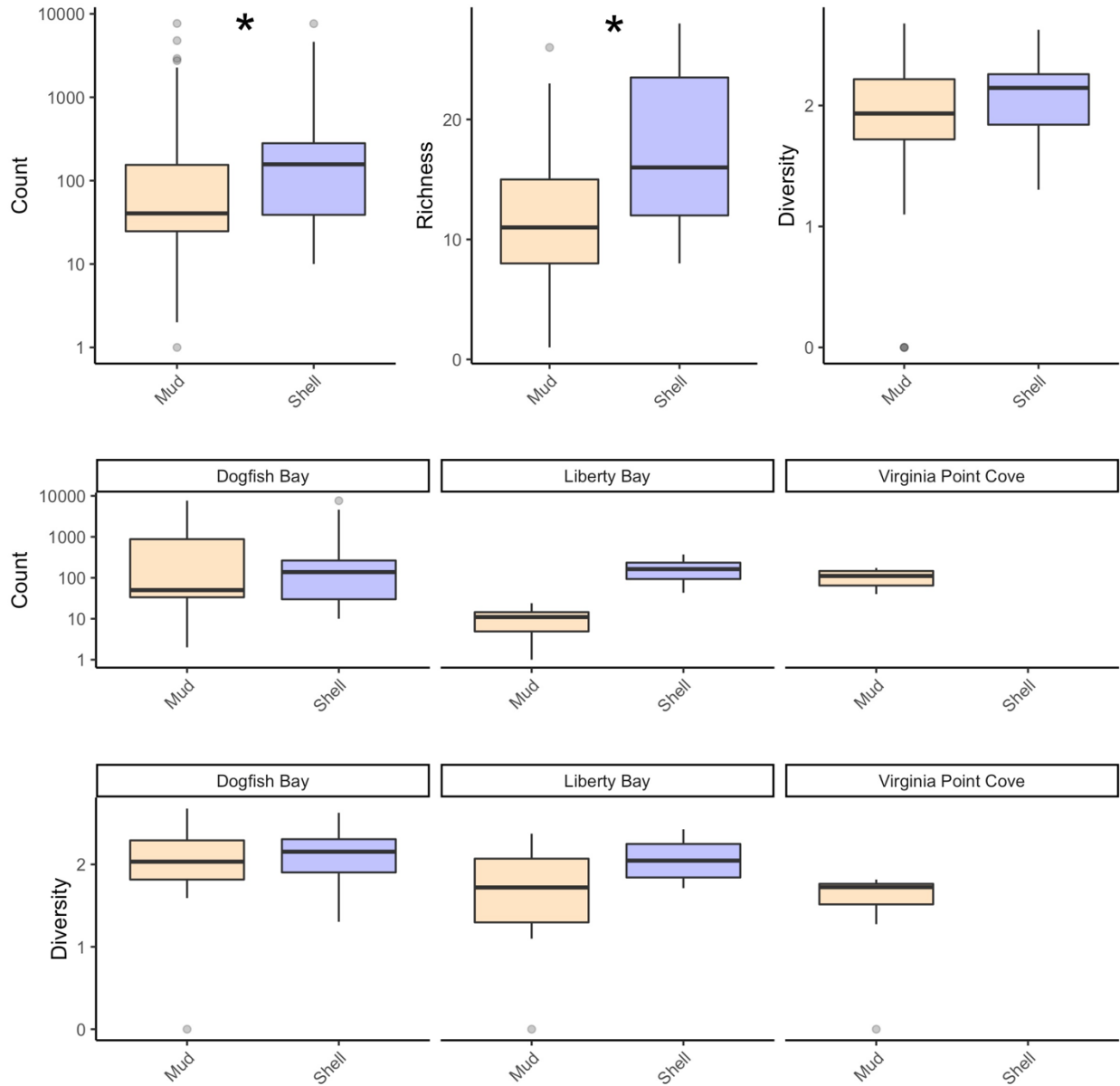


Figure 7. Invertebrate counts, richness, and diversity compared between mud and shell substrates. Asterisks indicate statistically significant differences. Top: all observations combined. Bottom: Observations split by sites for counts and diversity, which differed significantly between mud and shell strata. Note that Virginia Point Cove was a control site that did not receive shells.

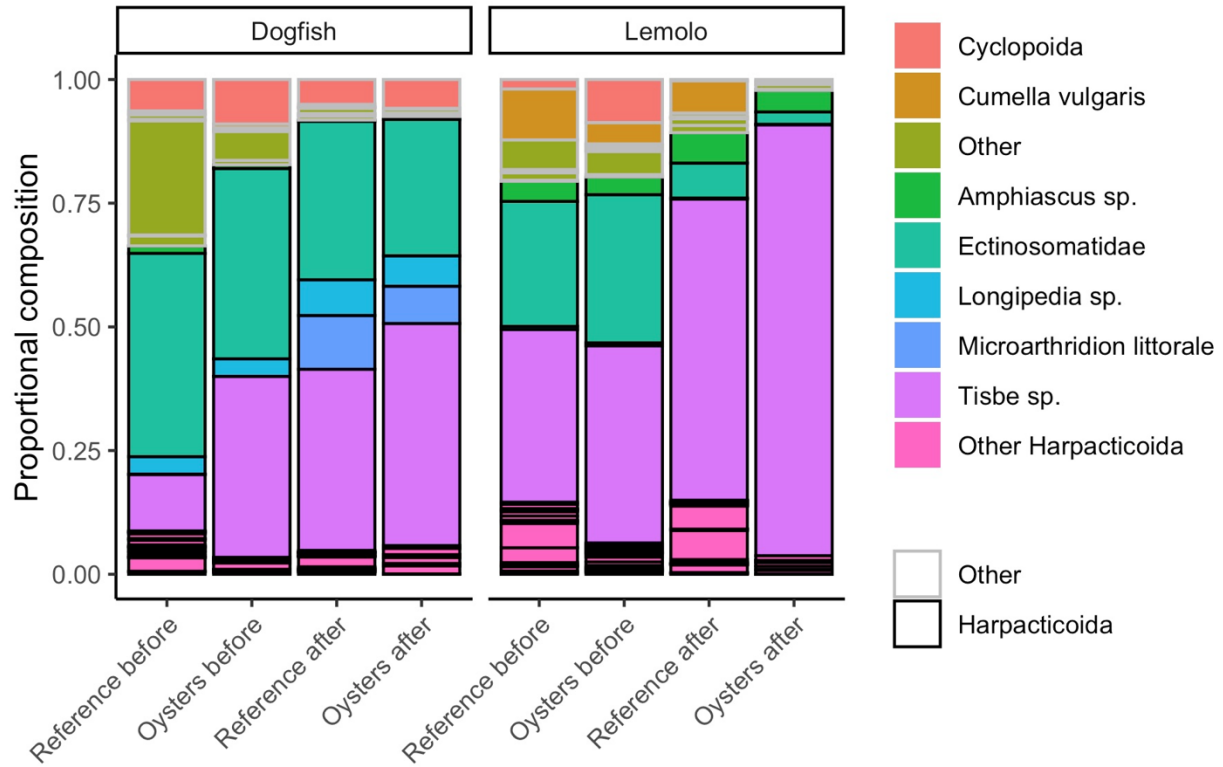


Figure 8. Taxonomic composition of invertebrate assemblage in BACI oyster study one compared across strata and restoration phase.

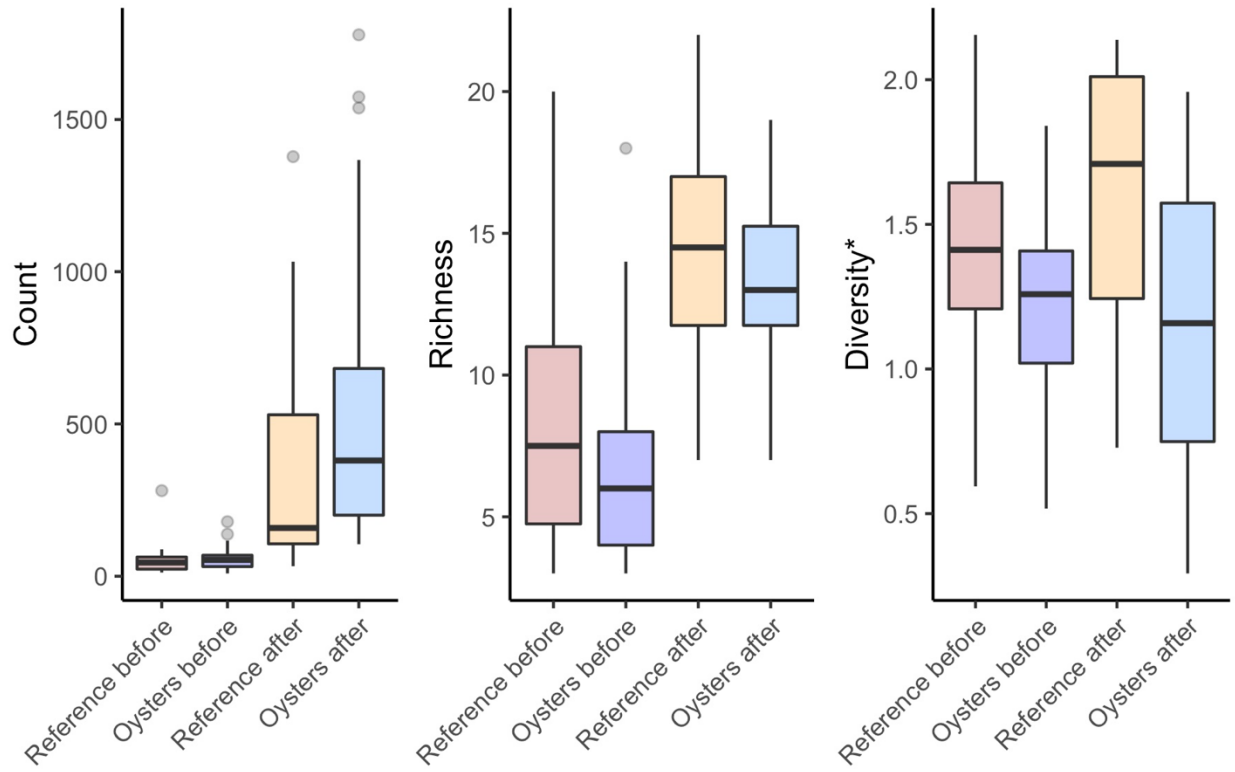


Figure 9. Invertebrate counts, richness, and diversity in BACI oyster study one compared among strata. The asterisk indicates a statistically significant effect of oyster introduction.

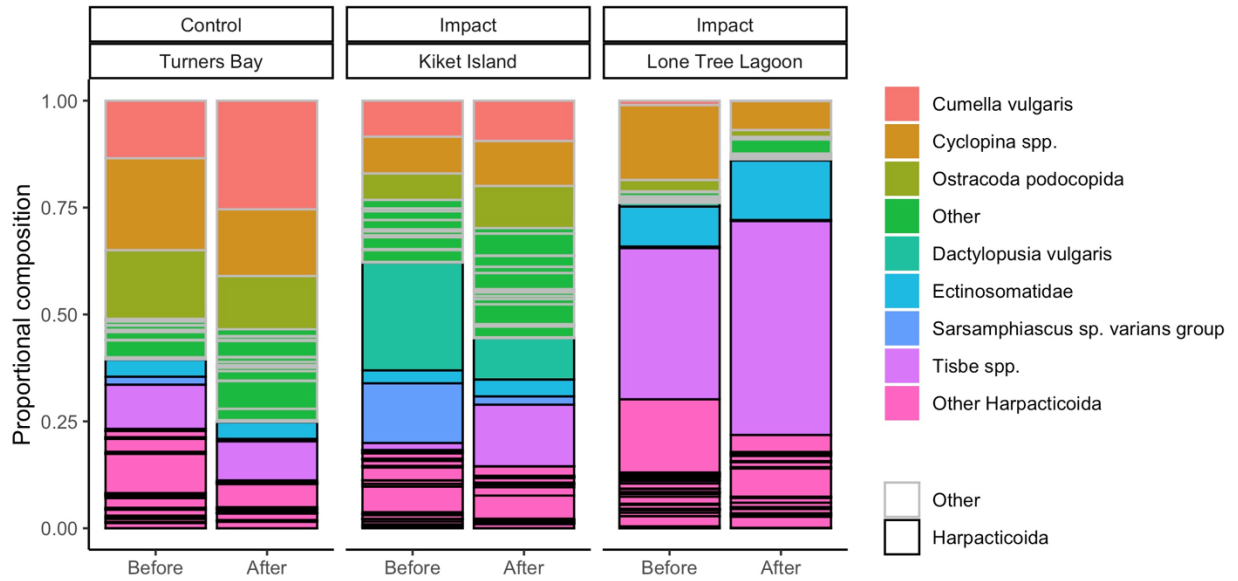


Figure 10. Taxonomic composition of invertebrate assemblage in BACI oyster study two compared across strata and impact phase.

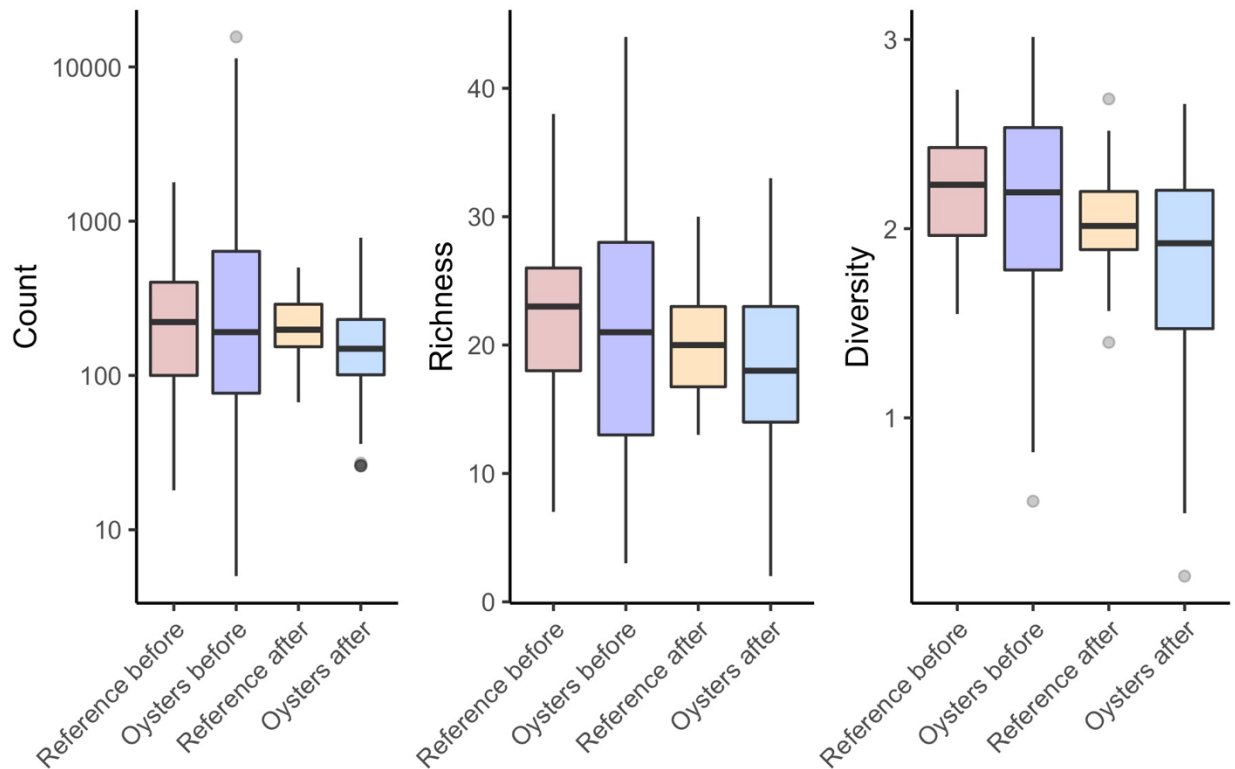


Figure 11. Invertebrate counts, richness, and diversity compared among strata. Note that the y axis showing counts is log-transformed. Top: all sites and years combined. Bottom: separated by sites and years.

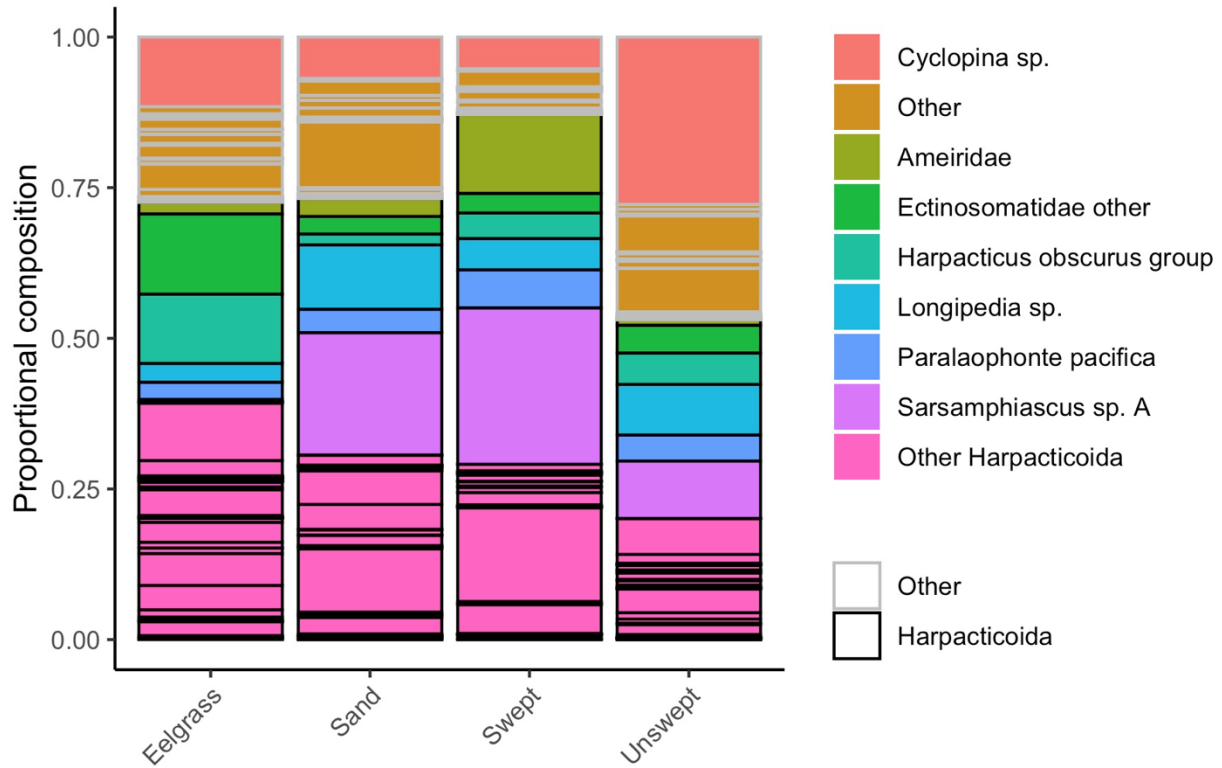


Figure 12. Taxonomic composition of invertebrate assemblages in the Manila clam eelgrass, sand, and antipredator netting study compared across strata.

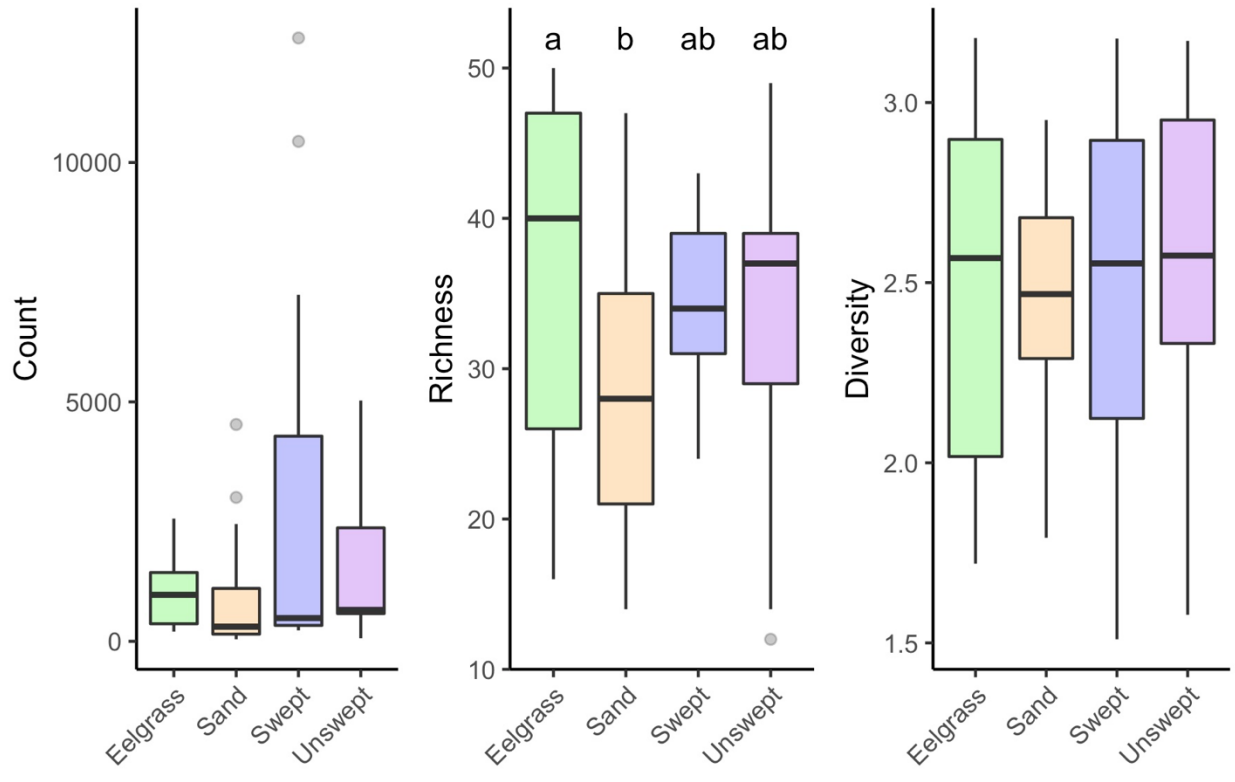


Figure 13. Invertebrate counts, richness, and diversity compared among strata. Letters are shown for comparisons with significant differences and indicate statistically significant pairwise differences per Tukey tests.

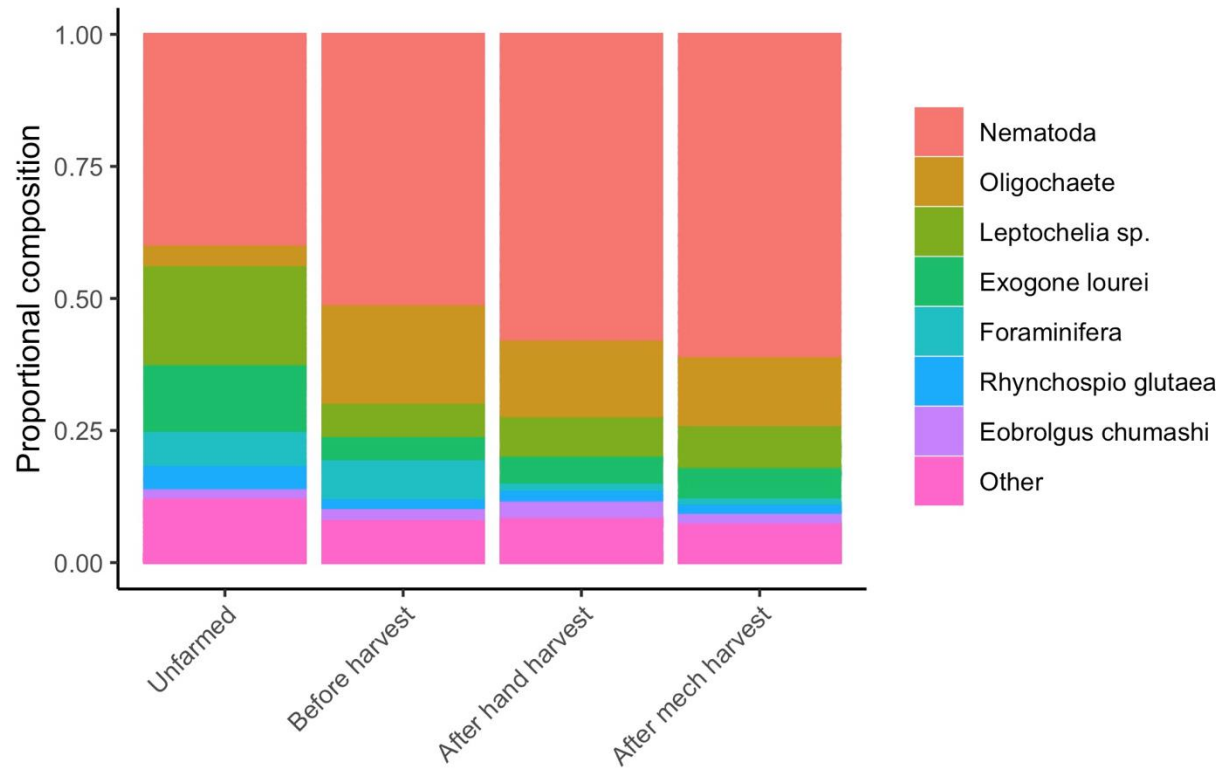


Figure 14. Taxonomic composition of invertebrate assemblages in the Manila clam unfarmed vs. hand harvest vs. mechanical harvest study compared across strata.

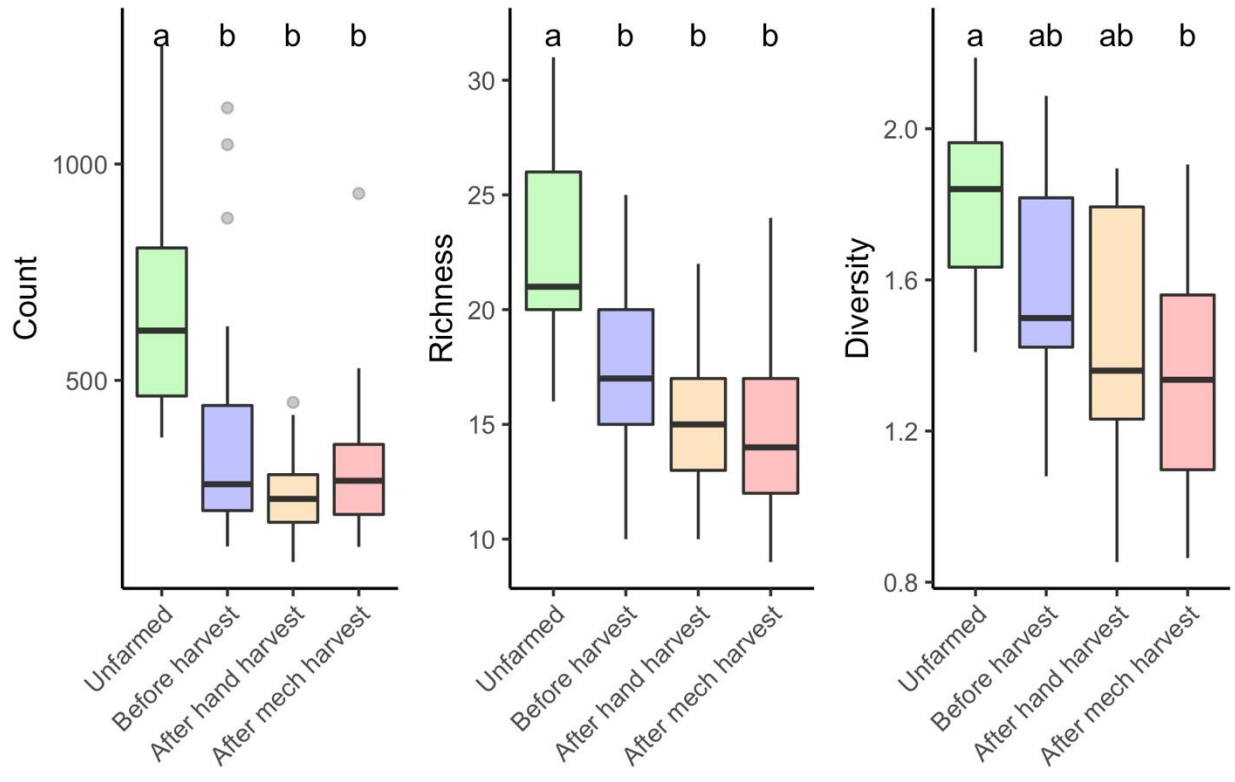


Figure 15. Invertebrate count, richness, and diversity in the Manila clam unfarmed vs. hand harvest vs. mechanical harvest study compared across strata.

Table 1. Summary statistics of PERMANOVA testing for differences in invertebrate assemblage composition among strata.

Study	Parameter	DF	SS	R ²	p
<i>Synthetic</i>	Bare (vs. eelgrass)	1	11.17	0.04	<0.01
	Bottom culture (vs. eelgrass)	1	18.33	0.07	<0.01
	Off-bottom culture (vs. eelgrass)	1	1.13	0.004	<0.01
	Residual	941	230.3	0.88	
	Total	944	260.93	1	
<i>Pacific oyster line</i>	Edge (vs. eelgrass)	1	0.19	0.01	<0.01
	Oyster (vs. eelgrass)	1	0.24	0.02	<0.01
	Residual	98	15.4	0.97	

	Total	100	15.83	1	
<i>Pacific oyster flipbag vs. line</i>	Edge (vs. eelgrass)	1	0.15	0.03	0.02
	Oyster (vs. eelgrass)	1	0.27	0.05	<0.01
	Aquaculture method	1	1.78	0.33	<0.01
	Oyster x aquaculture method	1	0.2	0.04	<0.01
	Edge x aquaculture method	1	0.12	0.02	0.04
	Residual	54	2.81	0.53	
	Total	59	5.33	1	
<i>Pacific oyster shell introduction</i>	Shell (vs. mud)	1	1.55	0.08	<0.01
	Residual	67	18.88	0.92	
	Total	68	20.43	1	
<i>Olympia oyster BACI one</i>	Treatment	1	0.52	0.02	<0.01
	Phase	1	3.67	0.17	<0.01
	Treatment x phase	1	0.26	0.01	0.05
	Residual	108	16.585	0.79	
	Total	111	21.02	1	
<i>Olympia oyster BACI two</i>	Treatment	1	13	0.11	<0.01
	Phase	1	4.8	0.04	<0.01
	Site: Kiket Island	1	27.4	0.24	<0.01
	2015 Apr	1	2.06	0.02	<0.01
	2016 Mar	1	1.01	0.009	<0.01
	2016 Apr	1	3	0.03	<0.01
	2017 Apr	1	1.42	0.012	<0.01
	2018 Mar	1	1.43	0.013	<0.01
	2018 Apr	1	1.55	0.014	<0.01
	Treatment x phase	1	2.07	0.018	<0.01
	Residual	562	56.4	0.49	
<i>Manila clam eelgrass, sand, and anti-predator netting</i>	Sand (vs. eelgrass)	1	0.91	0.09	<0.01
	Swept (vs. eelgrass)	1	0.24	0.02	<0.01
	Unswept (vs. eelgrass)	1	0.35	0.03	<0.01
	Residual	80	8.86	0.86	
	Total	83	10.4	1	
<i>Benthic study: Manila clam unfarmed vs. hand harvest vs. mechanical harvest</i>	Before harvest (vs. unfarmed)	1	0.4	0.04	0
	After hand harvest (vs. unfarmed)	1	0.35	0.03	0
	After mech harvest (vs. unfarmed)	1	0.91	0.08	0
	Residual	101	9.11	0.85	
	Total	104	10.77	1	
	Total	572	114	1	

Table 2. Summary statistics of linear models and their extensions comparing invertebrate counts, richness, and diversity among strata. In these statistics, effect sizes of categorical variables (e.g., eelgrass habitat, oyster habitat) are represented by contrasts with another level of that categorical variable. Because these effect sizes are represented by contrasts, fewer contrasts in the model need be estimated than there are levels in the data (e.g., differences between two habitats can be represented by one contrast). A positive estimate means there are greater counts, richness, or diversity for that variable in contrast to another level of the same categorical variable shown in parentheses.

Study	Response	Parameter	Estimate	SE	p	Random effect	Random effect SD
Synthetic	Count	Intercept	7.43	0.41	<0.01	Site x habitat x date	1.13
		Off-bottom (vs. eelgrass)	0.06	0.66	0.93		
		Bottom (vs. eelgrass)	-1.64	0.48	<0.01		
		Bare (vs. eelgrass)	-2.04	0.45	<0.01		
	Richness	Intercept	30.19	2.78	<0.01	Site x habitat x date	7.68
		Off-bottom (vs. eelgrass)	-3.04	4.47	0.50		
		Bottom (vs. eelgrass)	-10.9	3.28	<0.01		
		Bare (vs. eelgrass)	12.50	3.10	<0.01		
	Diversity	Intercept	2.42	0.17	<0.01	Site x habitat x date	0.49

		Off-bottom (vs. eelgrass)	0.08	0.28	0.78
		Bottom (vs. eelgrass)	-0.66	0.21	<0.01
		Bare (vs. eelgrass)	-0.51	0.20	0.01
Pacific oyster line	Count	Intercept	7.32	0.17	<0.01
		Edge (vs. eelgrass)	-0.22	0.16	0.16
		Oyster (vs. eelgrass)	-0.37	0.16	0.02
		Samish (vs. Humboldt)	0.09	0.19	0.62
		Tillamook (vs. Humboldt)	0.34	0.19	0.07
		Willapa (vs. Humboldt)	0.44	0.21	0.03
	Richness	Intercept	29.71	0.95	<0.01
		Edge (vs. eelgrass)	-0.06	0.89	0.95
		Oyster (vs. eelgrass)	0.09	0.9	0.92
		Samish (vs. Humboldt)	-0.45	1.04	0.67
		Tillamook (vs. Humboldt)	-3.55	1.04	<0.01
		Willapa (vs. Humboldt)	-4.86	1.15	<0.01
	Diversity	Intercept	2.71	0.05	<0.01

		Edge (vs. eelgrass)	0	0.05	0.97	
		Oyster (vs. eelgrass)	0	0.05	0.96	
		Samish (vs. Humboldt)	-0.12	0.05	0.03	
		Tillamook (vs. Humboldt)	-0.29	0.05	<0.01	
		Willapa (vs. Humboldt)	-0.27	0.06	<0.01	
Pacific oyster flipbag vs. line	Count	Intercept	8.51	0.13	<0.01	
		Line (vs. flipbag)	0.05	0.18	0.76	
		Edge (vs. eelgrass)	0.02	0.18	0.93	
		Oyster (vs. eelgrass)	0.16	0.18	0.38	
		Line x edge	0.22	0.25	0.39	
			Line x oyster	0.09	0.25	0.72
	Richness	Intercept	21.8	1.11	<0.01	
		Line (vs. flipbag)	4.8	1.58	<0.01	
		Edge (vs. eelgrass)	0.4	1.58	0.8	
		Oyster (vs. eelgrass)	1.8	1.58	0.26	
		Line x edge	-0.6	2.23	0.79	
			Line x oyster	-1	2.23	0.66
	Diversity	Intercept	1.78	0.09	<0.01	
		Line (vs. flipbag)	0.67	0.13	<0.01	
		Edge (vs. eelgrass)	0.17	0.13	0.18	

		Oyster (vs. eelgrass)	0.39	0.13	<0.01
		Line x edge	-0.41	0.18	0.03
		Line x oyster	-0.26	0.18	0.16
Pacific oyster shell introduction	Count	Intercept	7.87	0.48	<0.01
		Shell (vs. mud)	0.57	0.26	0.03
		Dogfish Bay	-0.3	0.44	0.5
		Liberty Bay	-3.46	0.7	<0.01
		5/22/12 (vs. 4/30/10)	-3.32	0.34	<0.01
		5/27/09 (vs. 4/30/10)	-0.67	0.58	0.25
		5/9/12 (vs. 4/30/10)	-4.42	0.34	<0.01
	Richness	Intercept	13.94	2.18	<0.01
		Shell (vs. mud)	4.34	1.18	<0.01
		Dogfish Bay	4.39	1.98	0.03
		Liberty Bay	-4.28	3.15	0.18
		5/22/12 (vs. 4/30/10)	-3.56	1.54	0.02
		5/27/09 (vs. 4/30/10)	-1.29	2.6	0.62
		5/9/12 (vs. 4/30/10)	-11.5	1.54	<0.01
	Diversity	Intercept	1.37	0.24	<0.01
		Shell (vs. mud)	0.13	0.13	0.33

		Dogfish Bay	0.7	0.22	<0.01		
		Liberty Bay	0.56	0.34	0.11		
		5/22/12 (vs. 4/30/10)	0.08	0.17	0.62		
		5/27/09 (vs. 4/30/10)	-0.3	0.28	0.29		
		5/9/12 (vs. 4/30/10)	-0.33	0.17	0.05		
Olympia oyster BACI one	Count	Intercept	3.87	0.26	<0.01	Site x date	0.45
		Treatment: oyster (vs. no oyster)	0.18	0.18	0.31		
		Phase: After (vs. before)	1.80	0.36	<0.01		
		Treatment: oyster x Phase: after	0.29	0.25	0.24		
	Richness	Intercept	8.32	1.19	<0.01	Site x date	2.06
		Treatment: oyster (vs. no oyster)	-1.46	0.85	0.08		
		Phase: After (vs. before)	5.71	1.69	<0.01		
		Treatment: oyster x Phase: after	0.82	1.20	0.50		
	Diversity	Intercept	1.42	0.20	<0.01		
		Treatment: oyster (vs. no oyster)	-0.20	0.07	<0.01		
		Phase: After (vs. before)	0.15	0.28	0.62		
		Treatment: oyster x Phase: after	-0.25	0.10	0.01		
Olympia oyster BACI two	Count	Intercept	5.42	0.46	<0.01	Site x date	0.92
		Phase: after (vs. before)	-0.04	0.66	0.95		
		Treatment: restoration (vs. control)	0.31	0.57	0.58		
		Phase: after x Treatment: restoration	-0.55	0.80	0.49		

Richness	Intercept	22.00	3.08	<0.01	Site x date	6.09
	Phase: after (vs. before)	-2.09	4.36	0.64		
	Treatment: restoration (vs. control)	-1.19	3.78	0.76		
	Phase: after x Treatment: restoration	-0.65	5.34	0.90		
Diversity	Intercept	2.19	0.19	<0.01	Site x date	0.37
	Phase: after (vs. before)	-0.16	0.27	0.566		
	Treatment: restoration (vs. control)	-0.06	0.23	0.792		
	Phase: after x Treatment: restoration	-0.17	0.33	0.617		
Manila clam eelgrass, sand, and anti-predator netting	Count	Intercept	6.63	0.22	0	
		Sand (vs. eelgrass)	-0.17	0.26	0.5	
		Swept (vs. eelgrass)	0.15	0.26	0.56	
		Unswept (vs. eelgrass)	-0.07	0.26	0.79	
		6/1/11 (vs. 5/7/12)	-0.35	0.22	0.12	
		7/14/11 (vs. 5/7/12)	1.42	0.22	0	
	Richness	Intercept	41.73	2.15	0	

		Sand (vs. eelgrass)	-6.71	2.48	0.01		
		Swept (vs. eelgrass)	-1.57	2.48	0.53		
		Unswept (vs. eelgrass)	-0.62	2.48	0.8		
		6/1/11 (vs. 5/7/12)	-12.11	2.15	0		
		7/14/11 (vs. 5/7/12)	-5.93	2.15	0.01		
	Diversity	Intercept	2.88	0.08	0		
		Sand (vs. eelgrass)	-0.05	0.1	0.6		
		Swept (vs. eelgrass)	0	0.1	0.96		
		Unswept (vs. eelgrass)	0.05	0.1	0.63		
		6/1/11 (vs. 5/7/12)	-0.59	0.08	0		
		7/14/11 (vs. 5/7/12)	-0.53	0.08	0		
Benthic study: Manila clam unfarmed vs. hand harvest vs. mechanical harvest	Count	Intercept	6.51	0.19	<0.01	Site x date	0.29
		Before harvest (vs. unfarmed)	-0.79	0.23	<0.01		

	After hand harvest (vs. unfarmed)	-1.01	0.27	<0.01		
	After mech harvest (vs. unfarmed)	-0.80	0.27	<0.01		
Richness	Intercept	22.76	1.01	<0.01	Site x date	1.08
	Before harvest (vs. unfarmed)	-5.29	1.24	<0.01		
	After hand harvest (vs. unfarmed)	-7.61	1.43	<0.01		
	After mech harvest (vs. unfarmed)	-7.67	1.43	<0.01		
Diversity	Intercept	1.81	0.12	<0.01	Site x date	0.19
	Before harvest (vs. unfarmed)	-0.22	0.15	0.17		
	After hand harvest (vs. unfarmed)	-0.36	0.17	0.06		
	After mech harvest (vs. unfarmed)	-0.46	0.17	0.02		