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Assessment of Benthic Effects of Anchor Presence and Removal

A study conducted on the Oregon Central Coast

Prepared by
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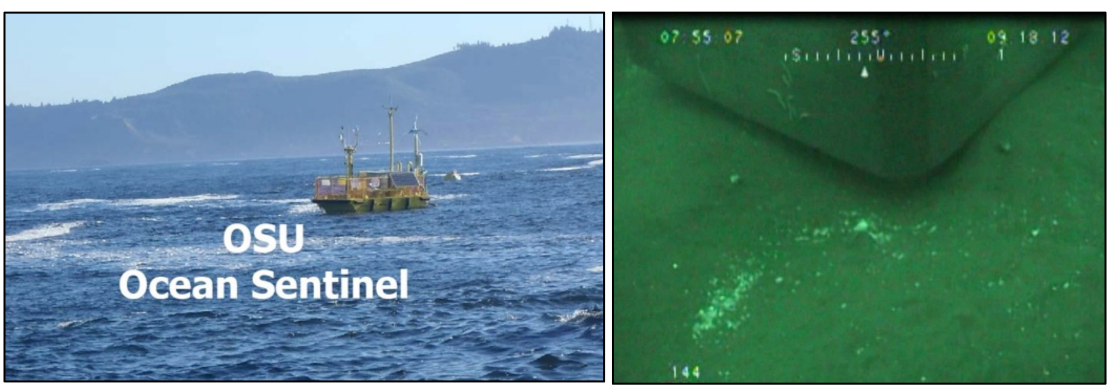
Assessment of Benthic Effects of Anchor Presence and Removal on the Oregon Coast

Principle Investigator: Sarah K. Henkel

Executive Summary

It has been anticipated that the placement of anchors or other bottom hardware associated with offshore renewable energy devices could result in localized areas of scour or deposition. As macrofaunal organism distributions are highly influenced by sediment characteristics, there is potential for changes to organismal distributions and or abundances. When anchors are removed, there may be scour holes or settlement pits remaining on the seafloor that will be void of macrofauna (due to the previous existence of the anchor). We sought to assess potential changes to sediment characteristics and macrofaunal communities around anchors deployed from 2013 to 2015 at Oregon State University's PacWave-North test site (formerly called PMEC-NETS and referred to as such throughout this document) off Newport, Oregon, and to determine the degree to which any effects were detectable in spring 2016, five months after anchor removal.

With the anchors in place, box core samples collected around the anchors had a significantly larger proportion of residual material: small gravel and shell hash (broken pieces of mostly bivalve shells) relative to reference locations. However, the median grain size of the collected sediment samples and the macrofaunal organism communities were not statistically different from reference locations of similar depths. In our single survey five months after anchor removal, the anchor stations still showed relatively higher residual proportions than reference locations, and one of the anchor locations had the second highest proportion of gravel ever recorded. Again, the median grain size of the sediment samples and macrofaunal organism communities were not statistically different from the reference locations.



L: The Ocean Sentinel deployed at the test site just north of Yaquina Head Newport, OR
R: Scour undercutting sediment under the concrete anchor and accumulation of shell hash

Table of Contents

INTRODUCTION

Sedimentary (soft bottom) habitat is the predominant habitat on the continental shelf and slope throughout the Pacific Northwest. Organisms living in and on the sediment have to contend with significant changes to their habitat as a result of wave action and ocean currents, making them generally resilient to disturbance. Macrofaunal invertebrates modify the sediment, structure the habitat, and serve as prey for many higher trophic level organisms from fish to whales to diving birds making them key species despite their individual small sizes. Macrofaunal invertebrates tend to inhabit specific ranges in sediment grain size; therefore, changes to sediment distributions or characteristics due to ocean energy extraction or alterations of flow around bottom mounted components may affect the distribution of macrofaunal soft-bottom organisms.

It is anticipated that the placement of anchors or other bottom hardware associated with offshore renewable energy devices could result in localized areas of scour or deposition. Whitehouse (1998) mentions that there is only a limited amount of experimental data and numerical studies of the flow field and scouring around gravity installations. Based on reviews of bottom changes resulting from deployment of artificial reefs and offshore oil platforms, sedimentary changes were expected to occur at least 20 m away from an anchor installation (Henkel et al. 2013). When anchors are removed, there may be scour holes or settlement pits remaining on the seafloor potentially void of macrofauna (due to the previous existence of the anchor). It is difficult to predict recovery times of the sediment and benthic organisms because their respective recoveries are dependent upon several variables; namely, the near-bottom current magnitudes and directions following disturbance. High energy events (e.g., winter storms) may act to reshape the seafloor rapidly following disturbances; however, milder hydrodynamics may result in longer periods before the sediment is re-worked and benthic organisms migrate back to the disturbed areas. It is generally assumed that communities found in dynamic sandy habitats will recover more quickly following physical disturbance than those found in less energetic muddy environments based on the adaptive strategies of the differing assemblages (Kaiser 1998; Ferns et al. 2000). Dernie et al. (2003) compared recovery rate of benthic assemblages and habitat parameters in different sediment types and determined a time on the order of 100 days to return to pre-disturbed conditions; Collie et al. (2000) came to similar conclusions.

Oregon State University's Northwest National Marine Renewable Energy Center (OSU-NNMREC) operates the North Energy Test Site of the Pacific Marine Energy Center (PMEC-NETS) off Newport, Oregon. This 1 nm^2 permitted square of the seafloor is 99.75% sand, on average, and is energetic, located right at the depth of the winter storm wave base and off a prominent headland. Thus, there is potential for significant sediment dynamics resulting in natural disturbances to macrofaunal communities. We hypothesized, therefore, that the potential effects of deploying anchors in this habitat on sediment conditions and the macrofauna therein would be small and that the seafloor and macrofaunal communities would recover quickly following hardware removal if significant changes were realized.

BACKGROUND

In anticipation of scaled wave energy converter (WEC) testing at PMEC-NETS, the Henkel lab at OSU has sampled a grid of permanent stations from 30 – 50 m water depth north and south of Yaquina Head, Oregon (Appendix Figure 1). These surveys were supported by the Oregon Wave Energy Trust 2010 to 2011 (Henkel 2011) and then supported by the U.S. Department of Energy 2012 to 2015. The findings of these surveys are available in the annual reports for PMEC-NETS produced by NNMREC.

From August 22 to October 5, 2012, a WEC was tested at PMEC-NETS. This WEC was connected to a wave energy analysis buoy (the Ocean Sentinel, a modified NOMAD buoy), and each was on a three-point mooring for a total of 6 gravity anchors on the seabed. Box core samples collected from the standard grid of stations both during the deployment and after the removal of all equipment did not detect any changes to the sediment or macrofaunal organisms. However, all sampling stations were at least 1 km away from the site of the actual test, and the devices and associated anchors were present for a very limited duration.

On July 29, 2013 OSU-NNMREC deployed only the Ocean Sentinel analysis buoy at PMEC-NETS. On October 4, 2013, the buoy was removed but the three 8,500 lb. ($4^1/_4$ ton) anchors were left in place. The Henkel lab began taking box core samples around the anchors starting October 24, 2013 through June 2015. We collected samples 10 m, 50 m, 150 m, and 250 m shoreward from the northeast anchor (NE) and offshore (as currents allowed) from the northwest (NW) anchors (2 of the 3 deployed), collectively referred to as "anchor grab stations" as well at the reference stations we had been sampling since 2010, the closest of which were about 1.2 km (shoreward) and 1.4 km (offshore) away from the anchor locations.

Figure 1. Residuals from an anchor grab box core.

In the anchor grab samples, we retained (on a 1 mm mesh sieve) a significantly larger proportion of gravel and shell hash (broken pieces of mostly bivalve shells) – collectively referred to as the residuals (Figure 1) – relative to the reference locations. This increased proportion was present across all the "anchor grabs", including those 250 m away; however, the amount was far greater in shoreward collections from the NE anchor than offshore collections from the NW anchor (Figure 2). This increased proportion of coarse material could be an indication of scour around the anchors if the material was typically found deeper in the sediments in this area and erosion of sand due to scour around the anchors exposed it. Alternatively, the increased proportion could be due to entrainment of shell material normally transported offshore. Since the large residual proportion was comprised of both gravel and broken shells of clearly coastal and bay clams, both processes could be contributing.

Despite the high proportion of coarse material around the anchors, the median grain sizes of the sediments sampled from the top of the box core grabs were not different from the reference stations over most of the sampling period. One exception was around the shoreward collections (of the NE anchor) in June 2015 only, which did have significantly larger median grain size as compared to both the 40 m (eastward) and 50 m (westward) reference stations for that single sampling event. The median grain sizes in samples collected offshore the NW anchor were not significantly different from reference stations. [See PMEC-NETS 2015 Annual Report (Henkel and Hellin 2016) for details on methods and results.]

As hypothesized, few differences were detected in macrofaunal organisms collected from around the anchors in 2013 to 2015 as compared to reference stations. The number of species (richness) collected in grabs from around the anchors (~45 m deep) was not significantly different from the number collected at 40 m reference stations (p = 0.999) and was narrowly significantly different from 50 m (p = 0.041). It should be noted that in 2014 richness was higher (+ 2 species) around the anchors while in 2015 it was lower (- 4 species), so the differences were variable over the years. These slight differences in richness did not result in statistically significant differences in Shannon diversity (H'). [See PMEC-NETS 2015 Annual Report (Henkel and Hellin 2016) for details on methods and results.]

Although the changes to the seafloor we recorded from 2013 to 2015 associated with the anchors in place was very localized and did not appear to have ecological consequences (few changes to macrofaunal species composition and no changes to abundance), there are still concerns about the potential for greater effects with the deployment of larger and more anchors for a commercial array of WECs. In order to fully evaluate the potential effects of WEC installations, the recovery time post anchor removal also must be investigated. It is particularly relevant for NNMREC's South Energy Test Site (PMEC-SETS) project, where the goal is to have a variety of different devices (potentially with different anchor systems) tested over the 25-year life of the project.

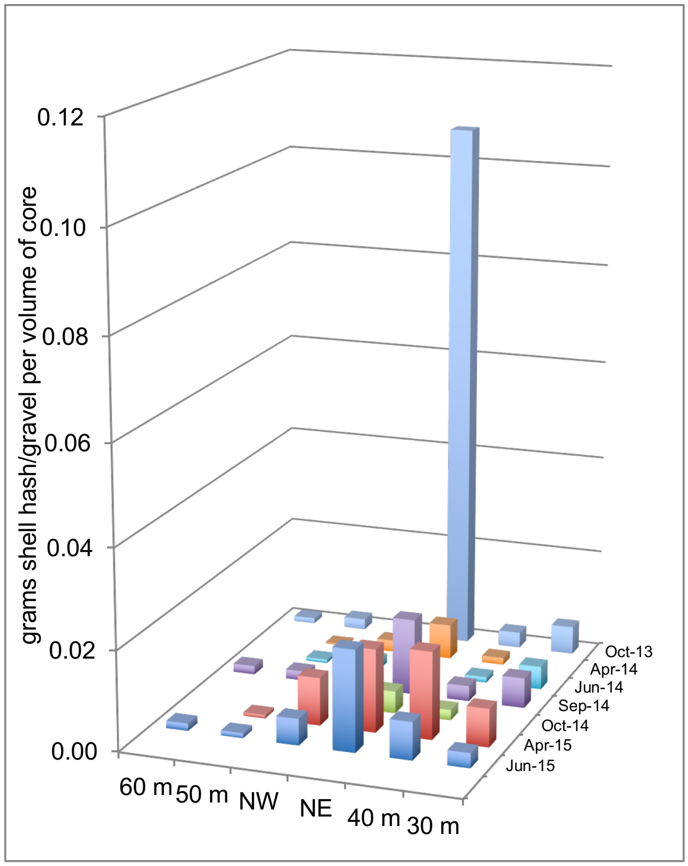


Figure 2. Proportion of residuals in previous box core collections from PMEC-NETS. NW bars show the mean proportion of residuals across the 4 samples from different distances from the northwest Ocean Sentinel anchor. NE is the mean data for the northeast anchor. (Error bars are not shown so that all bars may be seen.)

The previous surveys at PMEC-NETS (2012 – 2015) funded by the U.S. Department of Energy concluded when all hardware was removed from the site in November 2015. Thus, we conducted the following OWET-funded study after the Ocean Sentinel anchors were removed from PMEC-NETS. We conducted a single survey in spring 2016, five months after the anchors were removed. We hypothesized that natural processes, particularly winter storms, would result in seafloor conditions at the previous anchor stations being indistinguishable from the reference locations.

METHODS

Field Collections

Oregon State University had the anchors removed from PMEC-NETS on November 7, 2015. In previous years, samples were collected (mostly) in April, June, August, and October. Thus, we conducted post-removal surveys in April 2016 to be able to compare with previous data collected in the same season. On April 20, 2016, we collected samples from 11 of the 12 reference stations that have been sampled since June 2010 (sediment at one 30 m station was densely packed, and we could not get an acceptable grab) as well as at the GPS coordinates of the 8 anchor grabs taken in the previous collection (June 2015) within PMEC-NETS. For this report, the stations sampled in 2016 are still referred to according to their relative location to the anchors, even though the anchors were no longer in place.

Macrofaunal invertebrates and sediment for grain size samples were obtained using a modified Gray-O'Hare 0.1 m^2 box core (Figure 3). Upon landing each box core back on the boat, a sub-sample of sediment was taken from the undisturbed top layer of the collected sample for grain size analysis. The remaining sediment was sieved onboard through a 1.0 mm mesh sieve. All retained organisms were collected from the sieve and preserved in 5 % buffered formalin. All non-living material (broken shells, large grain size sediment) retained on the 1.0 mm mesh screen was considered the residual material and returned to the lab for quantification.

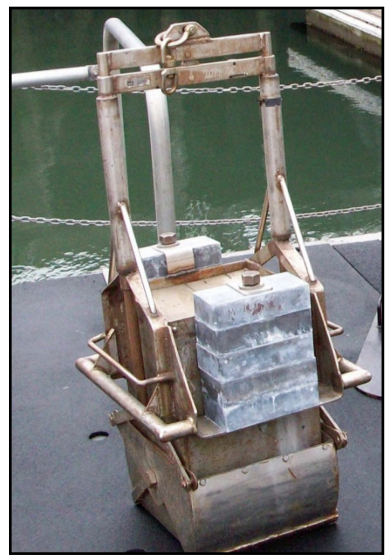


Figure 3. Box corer used for collecting macrofaunal invertebrates.

After 48 h, organism samples were transferred to 70 % ethanol. Macrofauna were sorted into major taxonomic groups by laboratory staff. All groups except crustaceans and polychaetes were identified by laboratory staff using a stereomicroscope and, when necessary, a compound scope. Contracted taxonomic experts identified the crustaceans and polychaetes.

Sediment samples were analyzed using a Beckman Coulter Laser Diffraction Particle Size Analyzer (LD-PSA) to determine median grain size and percent silt/clay. These sediment samples were treated with H_2O_2 to remove any organic matter which would have removed bits of shell hash from the sediment. However, they were not sieved to remove large grain sizes before running on the PSA. Thus, the median grain sizes reported herein include the larger "residual" sediment retained on the 1.0 mm organism retaining sieve.

Residual material was quantified by weighing the retained residual material and standardizing by the volume of collected material (obtained by multiplying the core penetration depth by the area of the box corer). Thus, the proportion of residual material is reported in grams per m^3.

Data Analysis

ANOVAs were used to investigate differences in sediment characteristics (residual proportion & median grain size) and macrofaunal community indices [abundance (N), Shannon–Wiener diversity (H'), and species richness (S)] among depth bins, impact status, and years (June 2010 to April 2016). Tukey's HSD *post hoc* tests were used to identify specific differences among factor levels. Factor levels for "depth bin" were 30 m, 40 m, NE, NW, and 50 m, with 40 m and 50 m considered reference depths for the samples collected around the anchors, which ranged 44 to 48 m deep. Factor levels for "impact status" were the four distances away from the anchors (10, 50, 150, and 250 m), reference-north (the 40 and 50 m stations north of Yaquina Head, adjacent to PMEC-NETS) and reference-south (the 40 and 50 m stations south of Yaquina Head). This impact status factor was created and split between north and south to be certain that the 40 and 50 m stations around the test facility (north) had not been affected by the installation at PMEC-NETS and remained similar to the 40 and 50 m south of Yaquina Head, far from potential influence of the project.

RESULTS

Sediment Characteristics

On average, residual material collected in April 2016 shoreward of the northeast anchor (NE) was the second highest recorded (Figure 4). However, this large proportion was due almost exclusively to the NE 50 m grab that had 4 times more residual material than the other NE grabs and consisted mostly of gravel, rather than shell hash. Residuals at the other three shoreward grabs were consistent with collections that had been made in the previous two site visits. For comparison, the left photo in Figure 5 shows the residuals from the NE 50 grab (mostly gravel) while the right photos is all the residuals from the other 18 stations sampled that day, combined (mostly shell hash). Residuals from offshore the NW anchor continued to decline as they had been doing over the previous collections.

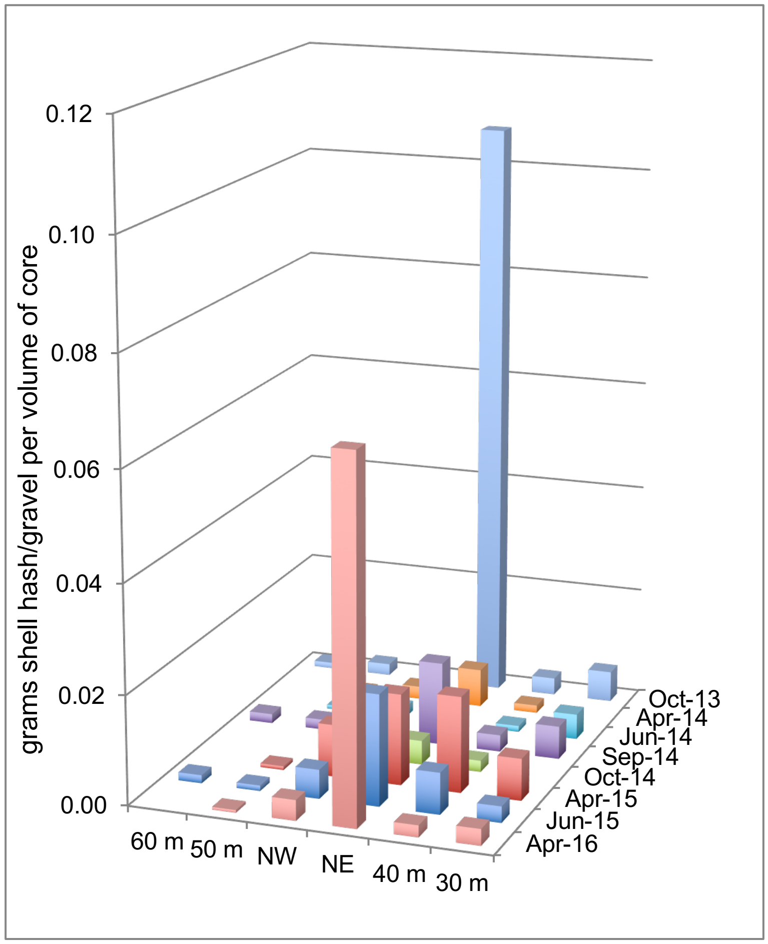


Figure 4. Proportions of residuals collected October 2013 to April 2016.

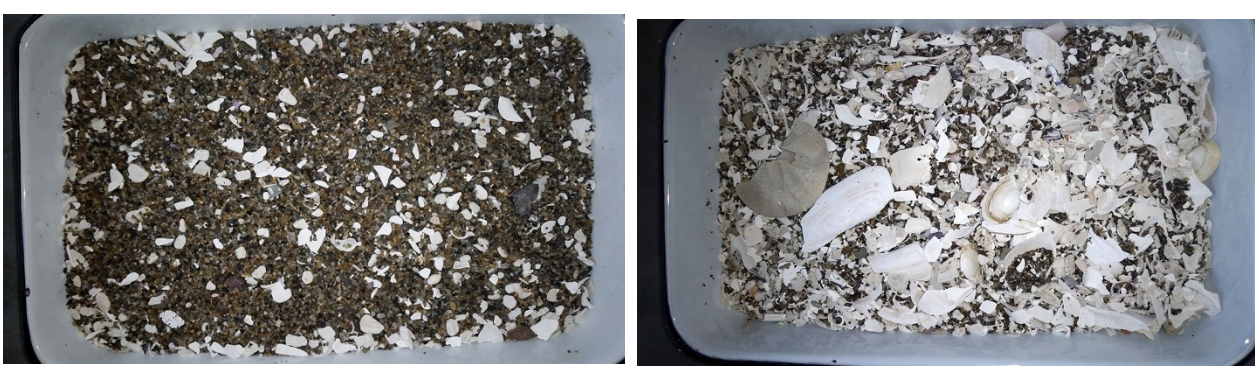


Figure 5. (L) Residuals from NE 50 m in April 2016. (R) Residuals from all 18 other sampled stations in April 2016.

Significant differences were detected in the proportion of residuals in response to depth bin, impact status, and year (Table 1). The proportions of residuals in collections from around the NE anchor were different from all reference depths as well as the NW anchor; however, the NW anchor was not different from any of the reference depths (Table 2). Also, 2013 had significantly higher proportion of shell hash (across depth bins) than all the other years (even 2016) while no other pairwise comparisons of years showed differences (Table 2). In terms of impact status, residual proportions in the samples collected from 150 m away from the position of the anchors were statistically distinct from all the other distances, which were not different from the reference areas (Table 2). However, this difference at 150 m away is driven by one sampling event with extremely high residuals at that single location. When analyzing impact status versus year, much greater differences were detected among years; in this case 2016 (post removal) was not different from 2015 and 2014 but all other year comparisons were different (Table 2).

Table 1. Two-way ANOVA results of the factors depth bin and year on all the residual data from 2013 to 2016 and of the factors impact status and year on only the 40 m, 50 m, and anchor stations from 2013 to 2016.

	Df	F value	Pr(>F)		Df	F value	Pr(>F)
Depth Bin	4	4.2652	0.003*	Impact Status	5	23.29	< 0.001*
Year	3	3.675	0.014*	Year	3	47.423	< 0.001*
Depth Bin*Year	11	3.0947	0.001*	Impact Status*Year	10	125.874	< 0.001*
Residuals	109			Residuals	82		

Table 2. Tukey HSD *post-hoc* pairwise comparisons for the factors depth bin and year on proportion of residuals and for the factors impact status and year as tested with ANOVA in Table 1 above.

Depth Bin	**p-adj**	**Impact Status**	**p-adj**
40-30	1.000	Ref-S-Ref-N	0.874
50-30	1.000	Ref-N-250	0.131
50-40	1.000	Ref-S-250	0.585
NE-30	0.045*	Ref-N-150	0*
NW-30	1.000	Ref-S-150	0*
NE-40	0.009*	Ref-N-50	0.463
NW-40	1.000	Ref-S-50	0.944
NE-50	0.016*	Ref-N-10	0.130
NW-50	1.000	Ref-S-10	0.601
NW-NE	0.020	50-10	0.991
		150-10	< 0.001*
Year	**p-adj**	250-10	1.000
2014-2013	0.018*	50-150	0*
2015-2013	0.156	50-250	0.987
2016-2013	0.708	250-150	< 0.001*
2015-2014	0.688		
2016-2014	0.216	**Year**	**p-adj**
2016-2015	0.744	2014-2013	0*
		2015-2013	0*
		2016-2013	0*
		2015-2014	0.006*
		2016-2014	0.422
		2016-2015	0.967

Median grain sizes from the sediment samples collected from the surface of the box cores taken at the different distances away from the anchors were more variable over time as compared to the reference stations. When all depths sampled over 2010 to 2016 were analyzed, depth bin was a significant factor (Table 3). However, Tukey *post-hoc* comparisons indicated no differences in median grain size between the NE or NW collections versus the 40 m or 50 m reference stations, which were also not different from each other (Figure 6, Table 4). In other words, median grain size at 30 m was unique from all other depth bins, which did not differ. When just analyzing the grabs different distances from the anchor as compared to the reference stations (thus excluding the 30 m depth bin), significant differences in median grain size were again not detected between any of the impact status distances or either of the groups of reference stations (Figure 7, Table 3). Median grain size did not differ among years.

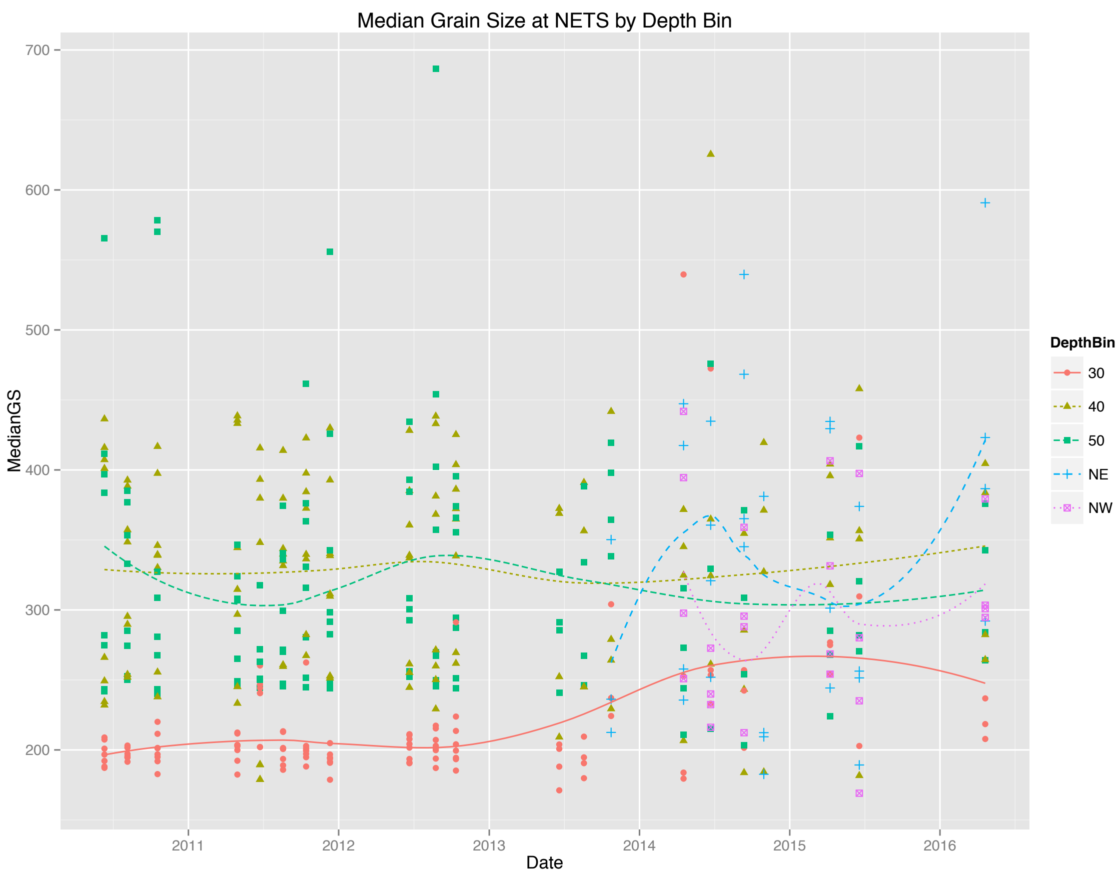


Figure 6. Median grain size at PMEC-NETS 30 m, 40 m, 50 m, and NE and NW anchor stations. All four distances from the anchors are combined and the loess moving average is plotted. Similarly, all four stations for each reference depth are combined.

Table 3. Two-way ANOVA results of the factors depth bin and year on all the median grain size data and of the factors impact status and year on only the grain size from the 40 m, 50 m, and anchor stations.

	Df	F value	Pr(>F)		Df	F value	Pr(>F)
Depth Bin	4	45.6433	< 0.001*	Impact Status	5	0.7532	0.5843
Year	1	2.6943	0.101	Year	1	0.01	0.9205
Depth Bin*Year	4	3.268	0.012*	Impact Status*Year	5	1.8108	0.1106
Residuals	415			Residuals	294		

Table 4. Tukey HSD *post-hoc* pairwise comparisons for the factor depth bin on median grain size. Differences were detected between the 30 m stations and all deeper depths. However, no differences were detected between 40 m and 50 m or any of the anchor stations and those reference depths.

Depth Bins	P-adj MGS
40-30 m	0*
50-30 m	0*
50-40 m	0.821
NE-30 m	0*
NW-30 m	< 0.001*
NE-40 m	0.990
NW-40 m	0.306
NE-50 m	0.785
NW-50 m	0.684
NW-NE	0.308

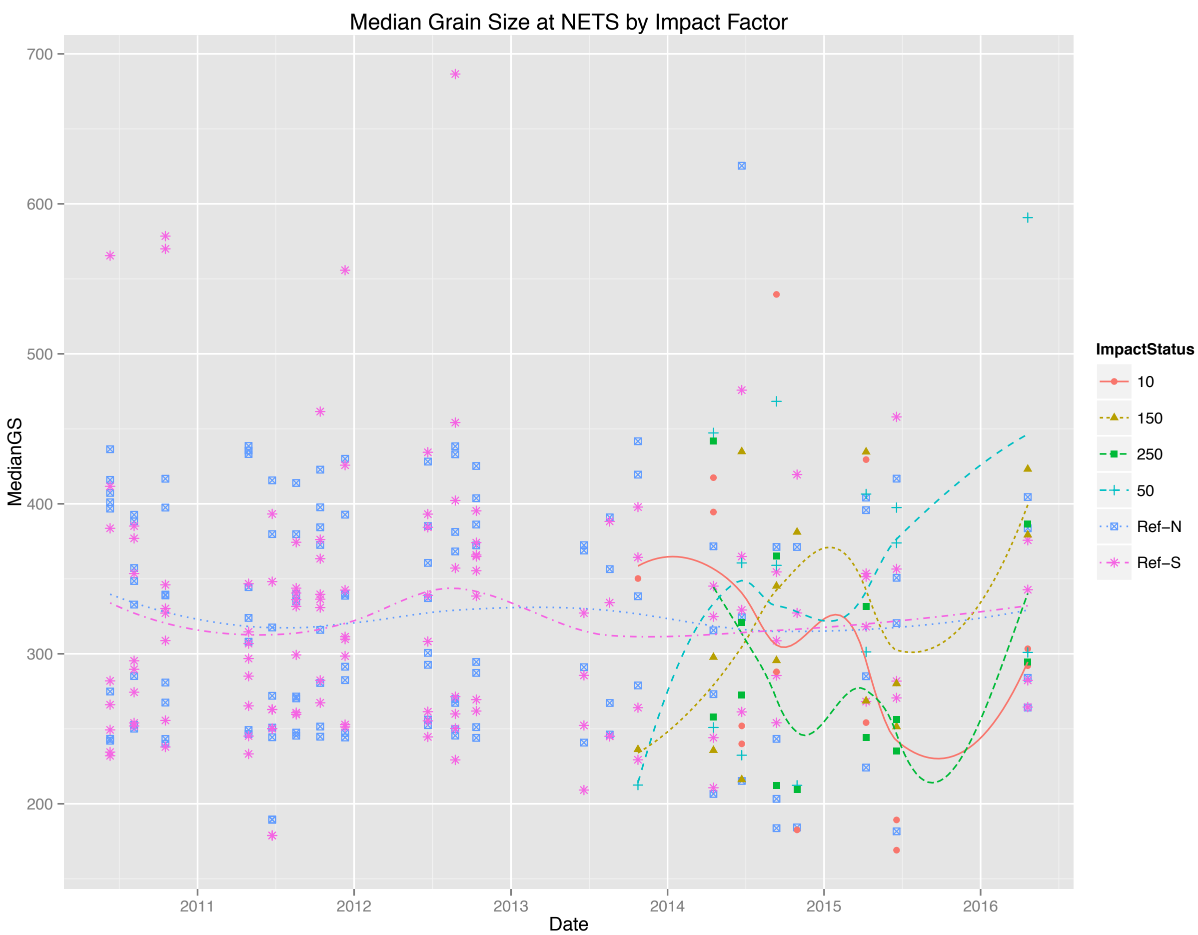


Figure 7. Median grain size at PMEC-NETS at each sampled distance away from the anchors (NE and NW anchors combined with loess moving average) and at 40 m and 50 m reference stations. In this case, Ref-N are the northern (above Yaquina Head) 40 and 50 m stations combined and Ref-S are the southern (below Yaquina Head) 40 and 50 m stations combined with the loess moving average plotted.

Macrofaunal Assemblages

Significant differences were found across depth bins and years for each of the organismal indices: abundance, diversity, and richness. As with median grain size, for all organismal indices the 30 m depth bin differed from the rest of the depth bins (results not shown). In order to more closely investigate potential differences between the anchor grabs and reference locations, all organismal analyses reported below were conducted on just the 40 – 50 m depth data (the 30 m data are included on the figures for reference). When analyzing just the data from 40 m to 50 m, no differences were detected in the abundance of organisms either across the four (40 m, NE, NW, 50 m) tested "depth" bins ($p = 0.381$; Table 5) or across the six tested impact status levels ($p = 0.825$; Table 7). For diversity, depth bin was a significant factor ($p = 0.029$; Table 5); however, only the 40 m and 50 m reference stations were slightly different from each other ($p = 0.055$); the samples from around the anchors were not significantly different in any pairwise comparisons (Table 6). No differences were detected in diversity in response to impact status ($p = 0.865$, Table 7). The most differences were detected in richness (Table 5) where 40 m differed from 50 m (similar to the observations for diversity) and the grabs shoreward of the NE anchor differed from the 50 m reference stations (Table 6). There also was an effect of impact status on richness; however, Tukey's post hoc comparison tests indicated the only significant pairwise comparison was between the north and south reference stations ($p = 0.017$); the north reference was also nearly significantly different from the station 50 m away from the anchor ($p = 0.061$). All other pairwise comparisons were $p > 0.05$. The significant differences among years for all these organismal indices are likely due to quite variable ocean conditions over the seven sampling years and will be discussed further in other publications.

Table 5. Two-way ANOVA comparisons of organismal indices again the factors depth bin (40, 50, NE, NW) and year from 2010 to 2016.

	Abundance			**Diversity**			**Richness**		
	Df	F value	Pr(>F)	Df	F value	Pr(>F)	Df	F value	Pr(>F)
Depth Bin	3	1.0268	0.381	3	3.0605	0.029*	3	10.163	<0.001*
Year	6	13.6133	<0.001*	6	7.0643	<0.001*	6	11.1332	<0.001*
Depth Bin*Year	11	1.438	0.155	11	1.5708	0.107	11	0.7511	0.6887
Residuals	285			285			285		

Table 6. Tukey HSD post-hoc pairwise comparisons for depth bins as analyzed in Table 5.

Depth Bins	**p-adj Abundance**	**p-adj Diversity**	**p-adj Richness**
50 m-40 m	0.765	0.055	<0.001*
NE-40 m	0.407	0.902	0.482
NW-40 m	0.750	0.697	0.814
NE-50 m	0.785	0.105	<0.001*
NW-50 m	0.970	0.984	0.305
NW-NE m	0.988	0.504	0.288

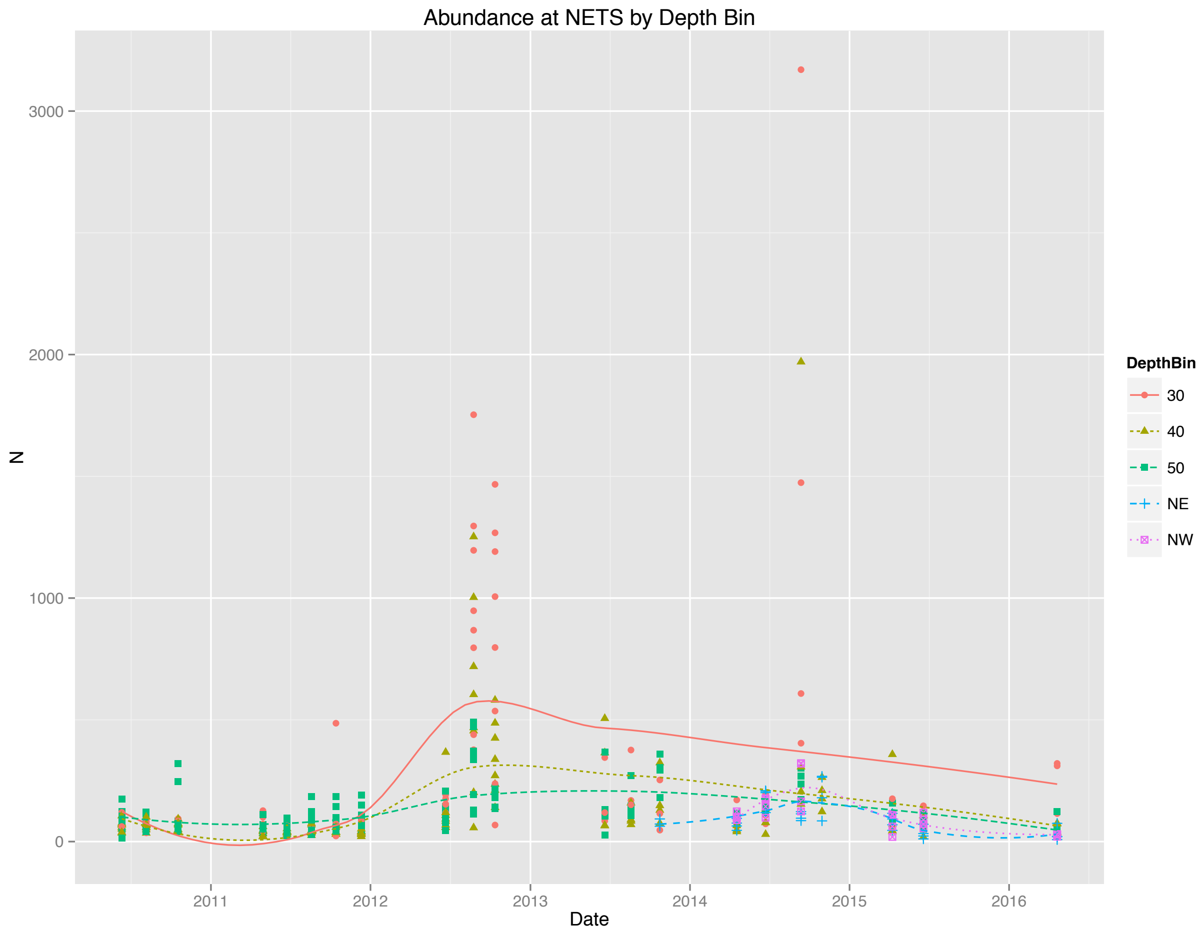


Figure 8. Abundance at PMEC-NETS 30 m, 40 m, 50 m, and NE and NW anchor stations. All four distances from the anchors are combined and the loess moving average is plotted. Similarly, all four stations for each reference depth are combined.

Figure 9. Diversity (Shannon-Weiner, H') at PMEC-NETS 30 m, 40 m, 50 m, and NE and NW anchor stations. All four distances from the anchors are combined and the loess moving average is displayed. Similarly, all four stations for each reference depth are combined.

Figure 10. Richness (number of species) at PMEC-NETS 30 m, 40 m, 50 m, and NE and NW anchor stations. All four distances from the anchors are combined and the loess moving average is displayed. Similarly, all four stations for each reference depth are combined.

Table 7. Two way ANOVA comparisons of organismal indices again the factors impact status (Ref-N, Ref-S, and varying distances away from the anchors) and year from 2010 to 2016.

	Abundance			Diversity			Richness		
	Df	F value	Pr(>F)	Df	F value	Pr(>F)	Df	F value	Pr(>F)
Impact Status	5	0.4342	0.825	5	0.3756	0.865	5	3.4419	0.005
Year	6	12.9492	< 0.001	6	6.62	< 0.001	6	9.9496	< 0.001
Impact Status*Year	17	0.5732	0.910	17	0.5417	0.930	17	0.548	0.927
Residuals	277			277			277		

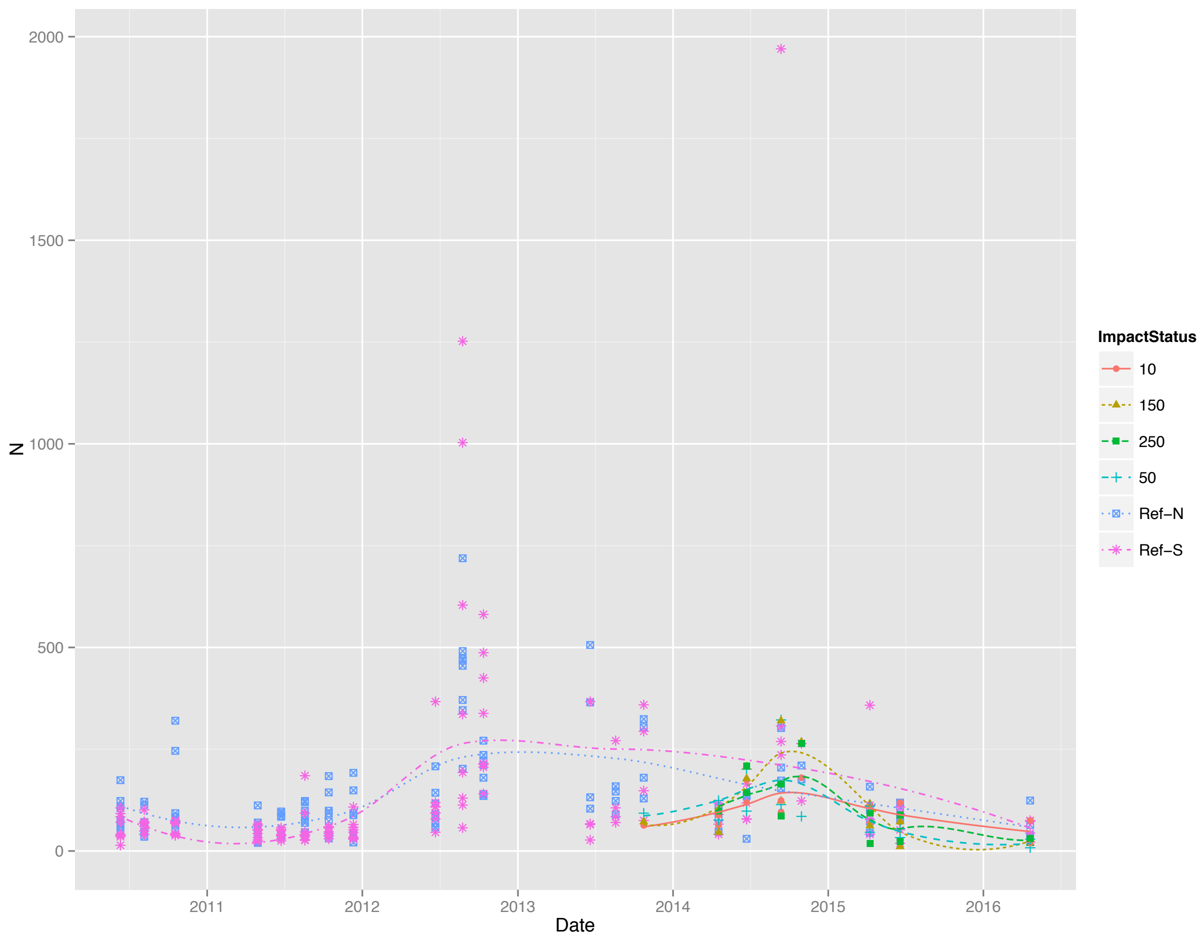


Figure 11. Abundance at PMEC-NETS at each sampled distance away from the anchors (E and W anchors combined with loess moving average of distance) and at reference stations (40 m and 50 m deep). In this case, Ref-N are the northern (above Yaquina Head) 40 and 50 m stations combined and Ref-S are the southern (below Yaquina Head) 40 and 50 m stations combined with the loess moving average displayed.

Figure 12. Diversity at PMEC-NETS at each sampled distance away from the anchors (NE and NW anchors combined with loess moving average of distance) and at 40 m and 50 m reference stations. In this case, Ref-N are the northern (above Yaquina Head) 40 and 50 m stations combined and Ref-S are the southern (below Yaquina Head) 40 and 50 m stations combined with the loess moving average displayed.

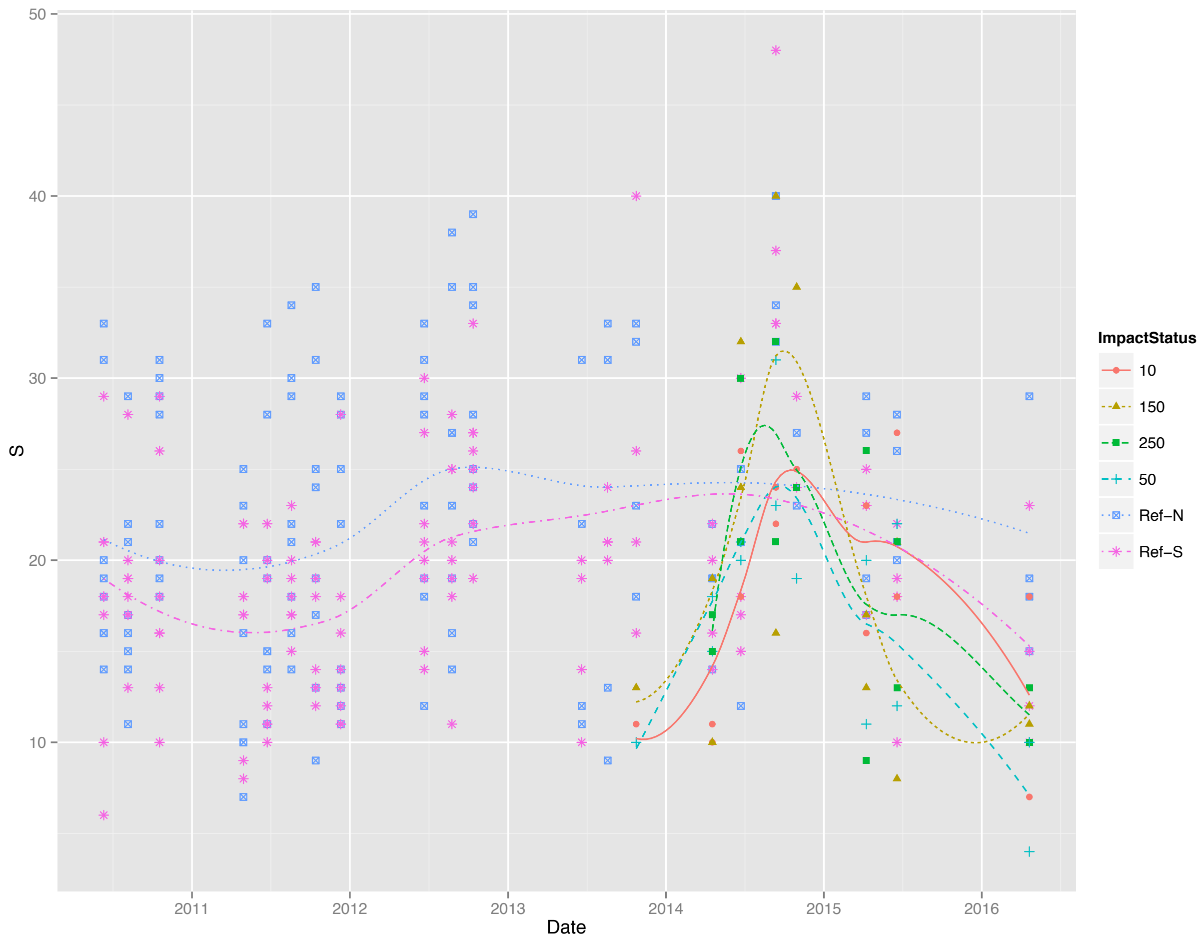


Figure 13. Richness at PMEC-NETS at each sampled distance away from the anchors (NE and NW anchors combined with loess moving average of distance) and at 40 m and 50 m reference stations. In this case, Ref-N are the northern (above Yaquina Head) 40 and 50 m stations combined and Ref-S are the southern (below Yaquina Head) 40 and 50 m stations combined with the loess moving average displayed.

DISCUSSION

The presence of coarse material around the anchors was visually detected shortly after installation via ROV surveys. Box core collections indicated it persisted throughout the deployment of the anchors, and the seafloor had not recovered five months following the removal of the anchors. While we did not quantify the proportion of coarse material in our pre-installation surveys, the presence of large quantities of coarse material was not notable prior to anchor installation, and the relatively low levels in the reference locations suggests the accumulation was unique to the stations associated with the anchors.

The proportion of coarse material retained on the sieve was vastly different between collections made shoreward of the NE anchor as compared to collections moving offshore from the NW anchor. Further, the proportion of this coarse material varied across the collection dates. This seasonal and directional variability in the amount of this material indicates that this effect is likely dependent on the placement of the anchors relative to the prevailing flow. The seasonal variability in the amount of coarse material we retained could be due to variability in the sampling locations relative to the anchor, as the prevailing current affected the trajectory of our sampling away from the anchor at the time of sampling. For example, the station locations plotted in the appended map are from April 2014. On that sampling date, the grabs moving "offshore" from the NW anchor curved northward as we moved away.

A major limitation to this study is that we only made collections shoreward of the nearshore anchor and offshore from the offshore anchor. Thus, we cannot determine if the difference in observations is due to the placement of the anchor or the direction of the sampling. However, in this small test deployment, if we had made collections shoreward of the NW anchor and offshore the NE anchor, the sampling transects would have overlapped. In future deployments of larger-scale devices and thus anchoring systems, we plan to sample in multiple directions from multiple anchors to better address questions of placement versus directionality of sampling.

As described in the introduction, it is not known if the mechanism for the higher proportion of this coarse material is due to scour around the anchors exposing material typically found deeper in the sediments or if it is due to entrainment of shell material normally transported offshore, or a combination. Since the large residual proportion was comprised of gravel, broken shells of clearly coastal and bay clams, and large sand dollars (typically found less than 25 m deep) both scour and entrainment of offshore-transported material could be contributing. Regardless of whether its presence is via excavation by scour or entrainment of offshore transported materials, seasonal variability and differences with respect to prevailing flow are to be expected.

We hypothesized that this phenomenon would not persist after a winter following anchor removal. We anticipated that our April 2016 anchor samples would be similar to the reference stations, assuming the sediment had been reworked by winter storms in the places where the anchors had been removed. We had to reject this hypothesis, as there was clearly just as much, if not more material, as before they were removed (still far more residual material in the collections made at the former anchor locations than at reference locations). This was a very interesting development, and we are still considering mechanisms for this.

Despite the larger proportions of residual material around the anchors throughout the sampling period, when comparing the stations around the anchors to the 40 m and 50 m reference stations, no statistically significant differences were detected in sediment median grain size. This seems counter-intuitive: if more coarse material was collected, one would expect grain size to increase.

We did observe that times when the proportion of residuals was high, the grain size was slightly higher; however, the variability in the grain size in the anchor grabs encompassed the grain sizes collected at the reference stations, making them statistically indistinguishable. Also, a major component of the residual material was shell hash, which is not considered in the sediment analysis since all the organic matter is removed before processing.

Even without statistically significant changes in median grain size, we expected that macrofaunal organisms living in and on the sediment would respond to the much greater proportion of the coarse broken shells. However, no response in the abundance or overall diversity of the macrofauna was detected. While differences were detected in the richness measure (number of species) this is difficult to attribute to the anchor-induced seafloor changes. Collections made shoreward of the NE anchor were different from the 50 m deep reference stations but not different from 40 m depths (the closer reference depth for the NE anchor). The 50 m reference stations also were different from the 40 m reference stations, but the 50 m reference stations were not different from the collections made offshore of the NW anchor (moving closer to the 50 m reference). Collections made around the two anchors were not statistically distinct. Thus, this pattern seems more like a cross-shelf/depth difference than a response to the anchors.

In our collections from 2010 to 2016, year was a significant factor in all the organismal indices. This is not surprising considering the variable climatic and ocean conditions (La Niña, El Niño, Warm Blob) experienced over the course of the study. However, no significant effects were detected for the interaction between year and either depth bin or impact status, indicating the assemblages around the anchors did not respond differently to the temporal oceanographic variability as compared to the assemblages collected from the reference locations.

The findings reported herein indicate few statistically detectable effects on macrofaunal communities due to anchor installation in this sandy, offshore habitat. However, we recognize that the seafloor off Newport, Oregon, is atypical relative to the rest of Oregon. Here on the central coast, the shelf is very gently sloping and medium to coarse sand is found to at least 70 m, potentially out to 100 m deep. Since there is almost no silt in this habitat, the potential for significant changes to the grain size is reduced, as there are no fine particles to be winnowed away. We hypothesize that in areas with mud and silt and consequently greater potential change in grain size distributions, greater effects on the macrofaunal communities that utilize those soft sediment habitats might be realized.

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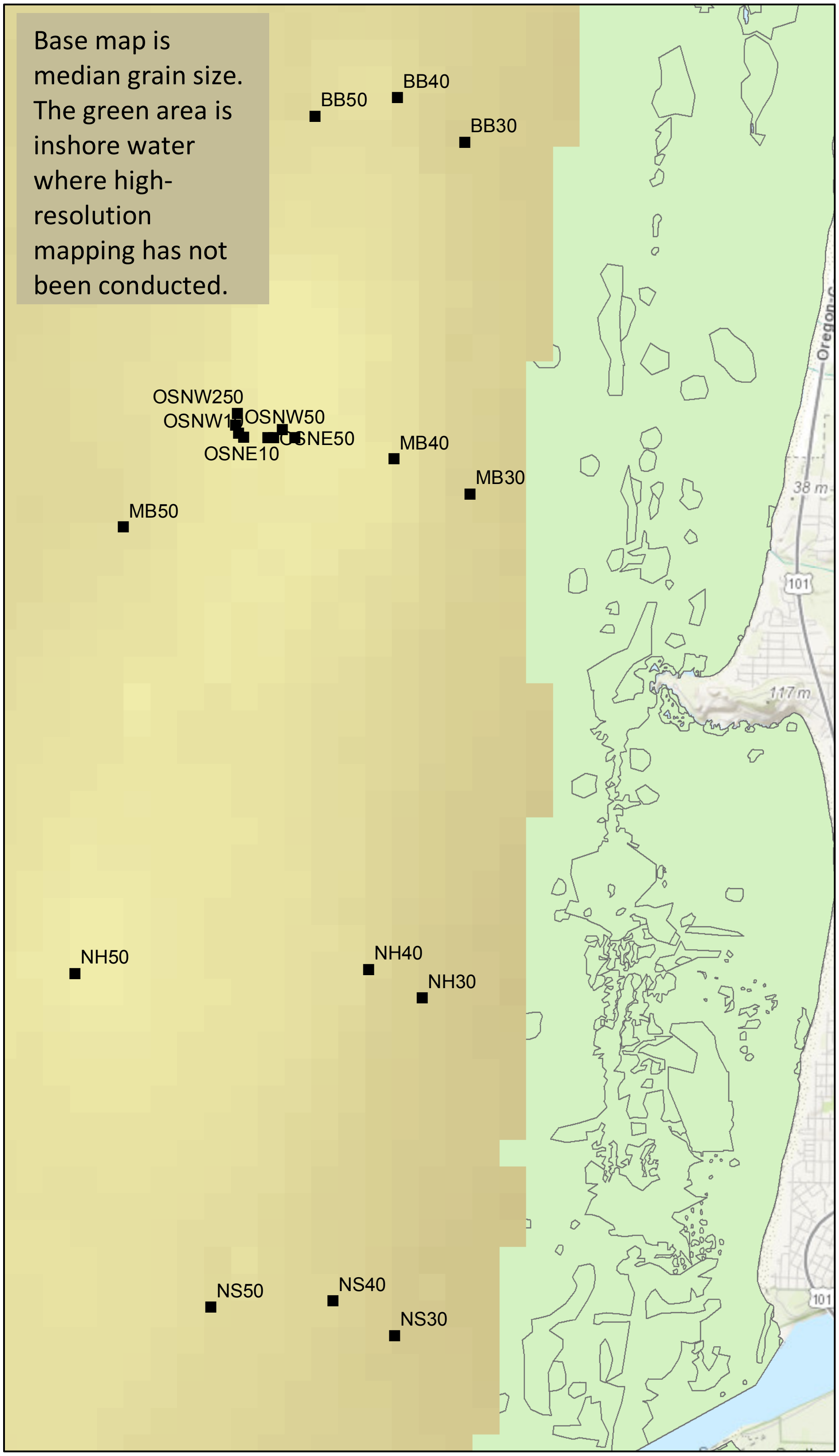

Appendix Figure 14. Locations of stations sampled north and south of Yaquina Head, Oregon, in April 2014. The reference stations (NS, NH, MB, BB: 30, 40, 50) were sampled 21 times from June 2010 to April 2016. The OS stations (around anchors deployed at PMEC-NETS) were sampled 8 times from October 2013 to April 2016.