From: Cheryl Brown

Date 10/12/2016

Subject: Review of Pteropod and aragonite saturation state data from 2011 and 2013

In 2014, a study was published which showed shell dissolution of pteropods off the coast of Washington, Oregon and California (Bednarsek et al., 2014). This study demonstrated there was a relationship between aragonite saturation state and pteropod shell damage (Figure 3 in Bednarsek et al. (2014, based on a 2011 dataset). In July of 2016, NOAA and University of Washington provided the data published in Bednarsek et al. (2014), as well as more recent data collected in 2013 and 2014. Datasets provided included carbonate chemistry data for 2007, 2011, 2012 and 2013 as well as pteropod damage data for 2011 and 2013 ("West-Coast-OA-Data_2007_2011_2012_2013_for_WSDE (002).xlsx"). Additional pteropod data from 2014 was provided but all of these data points were within Puget Sound. This review focuses on information from coastal waters off of Oregon.

The goal of the present document is to examine the subset of the pteropod data which was collected off the coast of Oregon to see if a similar relationship to Figure 3 in Bednarsek et al. (2014) is present and see where data from within Oregon State Waters falls on this relationship. Oregon State waters are those within marine waters within three miles from the Oregon Coastline. Previous examination of sampling sites in Bednarsek et al. (2014) found that none of the 2011 sampling sites were within Oregon State Waters (within 3 miles of the Oregon coastline). For location of 2011 and 2013 stations with pteropod data, see the following location: [HYPERLINK "http://www.arcgis.com/home/webmap/viewer.html?webmap=a1e9b341091f4fde9bc850ac4608530f"].

This document explains how Figure 3 in Bednarsek et al. (2014) was recreated using the 2011 data provided by University of Washington (UW) and NOAA (email from Rochelle Labiosa to Cheryl Brown on 7/6/2016 in file "West-Coast-OA-Data_2007_2011_2012_2013_for_WSDE (002).xlsx"). The data from the 2013 UW/NOAA cruise included one station with pteropod damage data that was within Oregon State waters (Station 104). Station 104 is located at latitude 44.65 deg North, and longitude 124.13 deg West and is estimated to be about 3 miles from shore. There were seven stations in 2013 dataset that were offshore of Oregon but not within Oregon State waters (stations 36, 37, 38, 40, 46, 47 and 50).

The percentage of the water column in the upper 100 m that was undersaturated with respect to aragonite ($\Omega_{arg} < 1$) was calculated, since this variable was not provided in the dataset. In the Bednarsek et al (2014) paper it states the following with regard to the calculation of the percent of the water column which is undersaturated:

In Statistical analysis section (on page 4):

"We evaluated whether the fraction of undersaturated waters in the top 100 m of the water column (as inferred from our modelled based estimation of Ω_{arg}) was associated with the

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incidence of severe shell damage (Type II or Type III damage) in this natural habitat of pteropods. At onshore stations where bottom depths were shallower than 100 m, we estimated the fraction of the total water column that was undersaturated."

And in the Results section (on page 4):

"To estimate the aragonite saturation state across the full water column, we used the fitted model to predict Ω_{arg} at all depths based on CTD temperature, salinity, and oxygen sensor measurements, from which we calculated the vertically integrated percentage of undersaturation in the first 100 m based on the depth at which the aragonite saturation horizon occurred."

All the carbonate chemistry data for the 2011 and 2013 cruises had corresponding temperature, salinity and oxygen data and consisted of full profiles. It is unclear how the "percent of water column undersaturated" was modeled (e.g., Were the models developed using an individual profile or were that based on all stations sampled? Was spatial interpolation involved, if so what additional temperature, salinity, and oxygen data was used to model Ω_{arg}?). For listing purposes, it might be more useful to use carbonate chemistry data from where the biological indicator was collected rather than a modeled metric. Therefore, in the present review, the "percent of water column that was undersaturated" with respect to aragonite was re-calculated using each individual station profile that matched the pteropod sample collection station. Profiles were extracted and plotted, and linear regression was used to interpolate between two points that demarked the boundary between saturated and undersaturated condition (see graphs in Appendix). Figure 1 shows an example of how this was done. If the station was shallower than 100 m, the maximum station depth was used in calculating the "percent of the water column that was undersaturated".

The coordinates of the pteropod data were compared to the coordinates of the carbonate chemistry data for each station in 2011 and for the 2013 stations off the coast of Oregon. Seven discrepancies were found: the coordinates of pteropod stations 65 and 75 did not match the carbonate chemistry data for these stations in sheet "2011", and similarly for Stations 36, 37, 38, 40, and 104 from 2013. Table 1 shows the carbonate chemistry stations which had latitude and longitude data matching the pteropod stations, which were used in this analysis.

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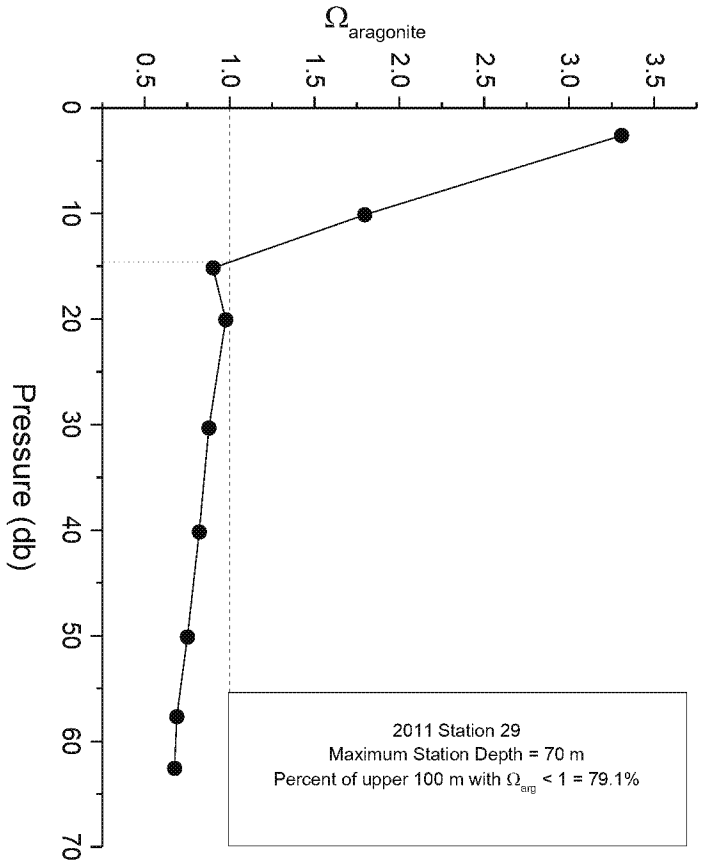

Figure [SEQ Figure * ARABIC]. Station 29 with line showing where Ω_{arg} <1. The percent of water column undersaturated was calculated as 79%.

Table 1. Pteropod stations with location discrepancies matched to carbonate chemistry stations.

Year	Pteropod Station	Carbonate Chemistry Station
2011	65	64
	75	74
2013	36	40
	37	38
	38	37
	40	36
	104	45

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"The percent of water column undersaturated" was calculated for the 2011 data and compared to that plotted in Figure 3 of Bednarsek et al. Since the data for "percent of water column undersaturated" used to create Figure 3 were not tabulated in the paper, Figure 3 from Bednarsek et al was digitized. For all datapoints except one, the proportion of individuals with dissolution from the digitized (y-values) values agreed exactly with those provided in the Excel spreadsheet (which provides a QA on the digitization); however, one discrepancy was found between the data published in Figure 3 of Bednarsek et al. and the data provided. The "proportion of individuals with dissolution" at Station 75 was about 0.25 in the published figure; however, in the dataset provided this station has a value for the metric "percent with damage" of 0.25. We assumed this was a typo in the dataset provided and the percent was 25% as published in Bednarsek et al. (2014).

There were differences in "proportion of water column undersaturated" between the values calculated using the individual station profile as compared with their modeled values (see Table 2), with some differences as large as 21%. Note: no value was calculated for Station 57 since there was a spike in the profile (see Appendix A; 2011 Station 57, maximum station depth 55 m).

Figure 2 shows the "proportion of pteropods exhibiting dissolution" and "percent of water column undersaturated" for 2011 stations (calculated using the linear interpolation of profile data), for 2013 stations off the coast of Oregon, and for the one station within Oregon State waters from 2013. The trends observed in Bednarsek et al. (2014) are similar to the trends in the 2013 data from off the coast of Oregon and the datapoint from within Oregon State waters falls along the same relationship. Figure 3 shows the same data as in Figure 2; however only 2011 & 2013 stations offshore of Oregon are included (2011: Stations 15, 21, 28, 29 , 31 and 37; 2013 stations off coast of Oregon: 36, 37, 38, 40, 46, 47, and 50; 2013 station within Oregon State Waters: 104). Figure 3 shows that the percent of water column undersaturated ($\Omega < 1$) and percent of pteropods exhibiting shell damage increases close to shore. Figures 4 and 5 show the strong dependence on station depth for "percent of water column undersaturated" and "percent of pteropods with shell damage" for the subset of the data offshore of Oregon. Figure 6 shows the "percent of pteropods with shell damage" for the full 2011 dataset. The proportion of undersaturated water increases close to shore; and there is the expectation that the percent of pteropods exhibiting shell damage would be expected to increase.

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Table 2. Comparison of "percent of water column undersaturated" digitized from Figure 3 in Bednarsek et al. (2014) and that calculated using the individual profiles (see Appendix) and stations off the coast of Oregon from 2013. The last row (in bold) shows the 2013 data point that is within Oregon State Waters (Station 104).

Station	Station Depth (m)	Percent of Pteropods with Type II & Type 3 damage	Percent of water column undersaturated from Figure 3 (digitized)	Percent of water column undersaturated Calculated from Profile	Absolute Difference
2011 Stations					
6	121	57	82.9	79.2	-3.7
13	90	60	77.6	84.7	7.1
14	45	67	40.0	49.3	9.4
15	46	100	83.3	90.7	7.4
21	2550	25	0.0	0	0.0
28	79	75	82.8	87.2	4.4
29	70	75	65.0	79.1	14.2
31	413	25	40.0	51.3	11.3
37	304	33	31.2	41.7	10.5
57	55	29	15.5		
61	932	33	12.1	12.9	0.7
65 (64 CTD)	60	60	52.7	69.7	17.0
69	518	25	13.0	15.5	2.5
73	4487	0	0.0	0	0.0
75 (74 CTD)	2216	25	30.1	51.3	21.2
87	45	0	0.0	0	0.0
95	41	0	0.0	0	0.0
2013 Stations off the coast of Oregon					
36 (40 CTD)	92	88	NA	90.9	NA
37 (38 CTD)	360	57	NA	60.8	NA
38 (37 CTD)	1334	36	NA	10.2	NA
40 (36 CTD)	1379	29	NA	5.9	NA
46	81	73	NA	61.4	NA
47	298	44	NA	40.5	NA
50	653	33	NA	26.9	NA
104 (45 CTD)	**43**	**52**	**NA**	**70.2**	**NA**

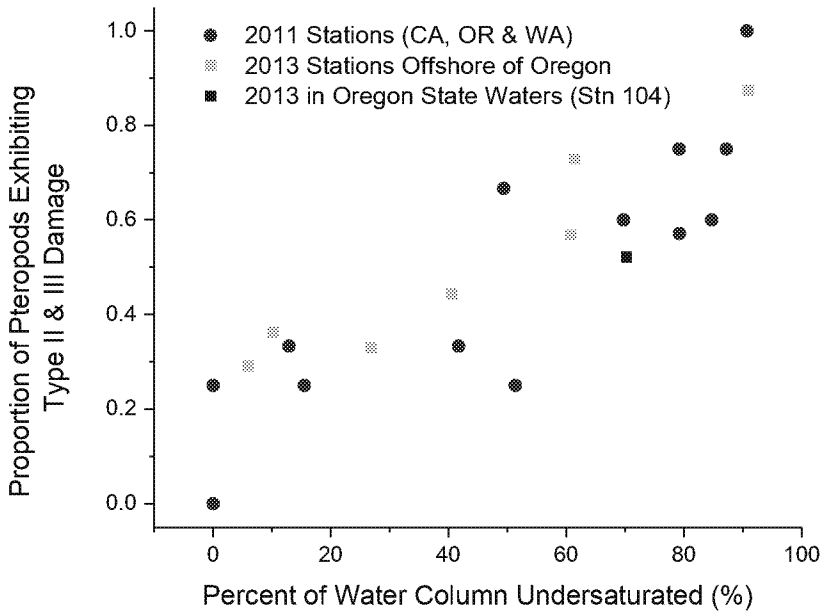

Figure 2. "Percent of water column undersaturated" and "proportion of pteropods exhibiting Type II & III damage" with red circles representing 2011 data (including data off the coast of California, Oregon and Washington; as in Bednarsek et al. Figure 3), green squares representing 2013 data off the coast of Oregon, and blue square representing the 2013 station within Oregon State waters.

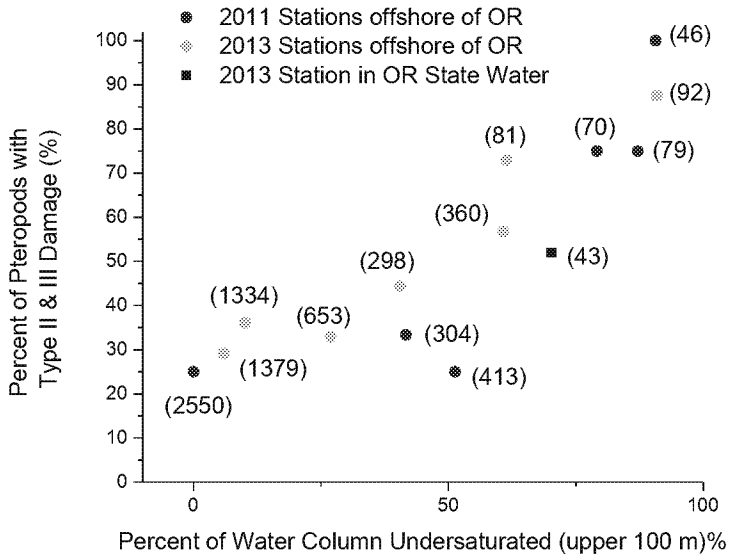

Figure 3. "Percent of pteropods with damage" versus "percent of water column undersaturated" only using only data points off the coast of Oregon. Red dots represent 2011 stations outside of Oregon state waters and green dots represent 2013 stations outside of Oregon state waters, and the blue square is the 2013 station within Oregon state waters. Each datapoint is labeled with station depth (m) in parentheses.

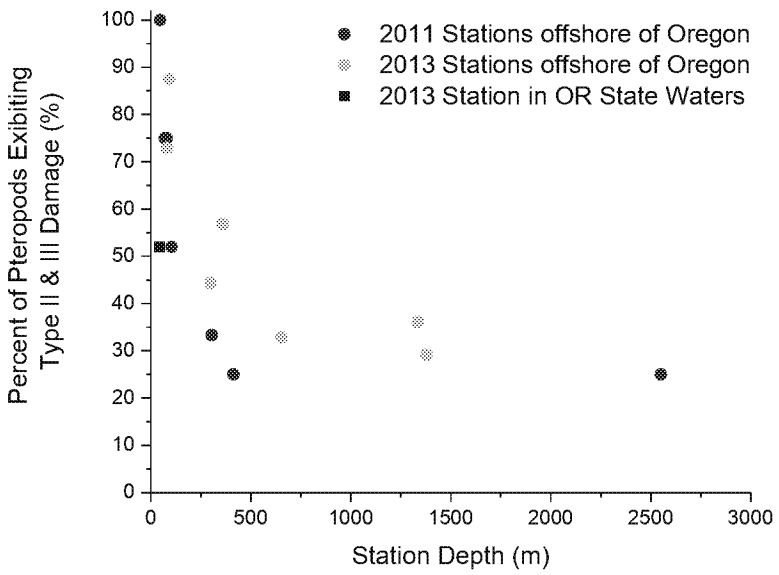

Figure 4. "Percent of pteropods exhibiting type II & III damage" versus "station depth" for 2011 stations offshore of Oregon (stations 15, 21, 28, 29, 31, and 37), 2013 stations offshore of Oregon, and the 2013 station within Oregon State Waters (station 104).

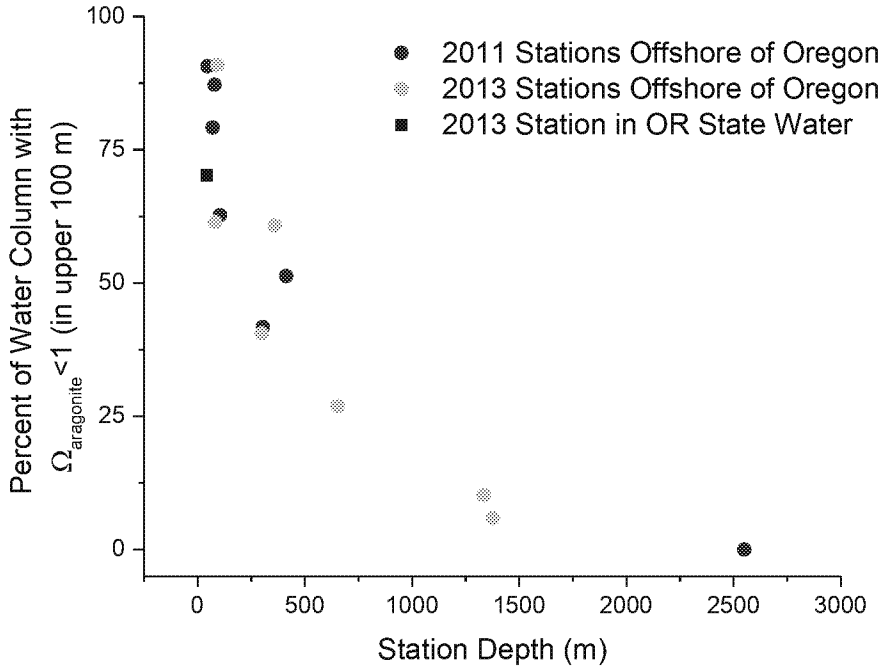

Figure 5. Percent of water column undersaturated (Ω<1) in upper 100 m versus station depth for 2011 stations offshore of Oregon (stations 15, 21, 28, 29, 31, and 37), 2013 stations offshore of Oregon (stations 36, 37, 38, 40, 46, 47 & 50) and the 2013 station within Oregon State Waters (station 104).

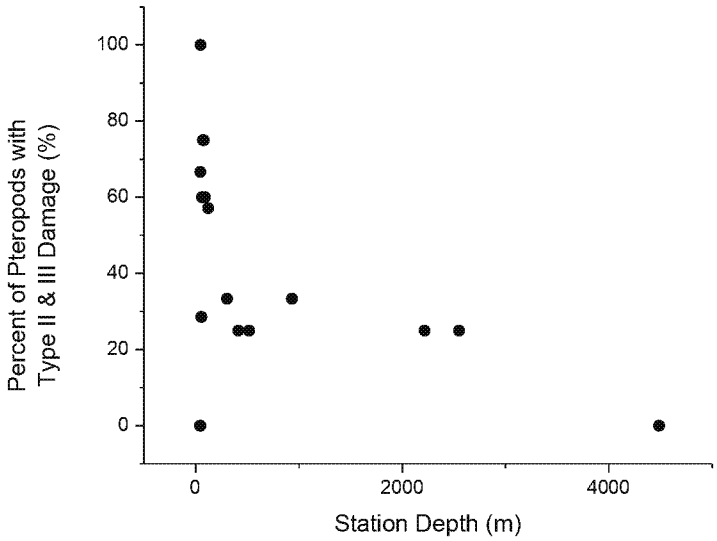

Figure 6. Percent of pteropods with type II & III damage versus station depth (all stations 2011).

References

Bednarsek N, Feely RA, Reum JCP, Peterson B, Menkel J, Alin SR, Hales B. 2014. *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proc. R. Soc. B 281:20140123. [HYPERLINK "http://dx.doi.org/10.1098/rspb.2014.0123"]

Disclaimer

This document has been reviewed in accordance with U.S. Environmental Protection Agency, Office of Research and Development, and approved for publication.

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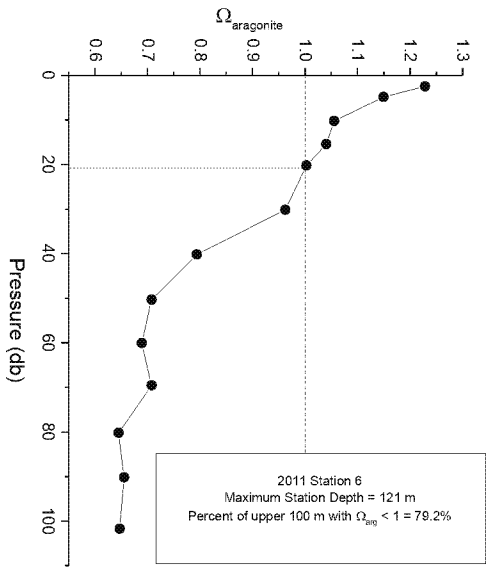
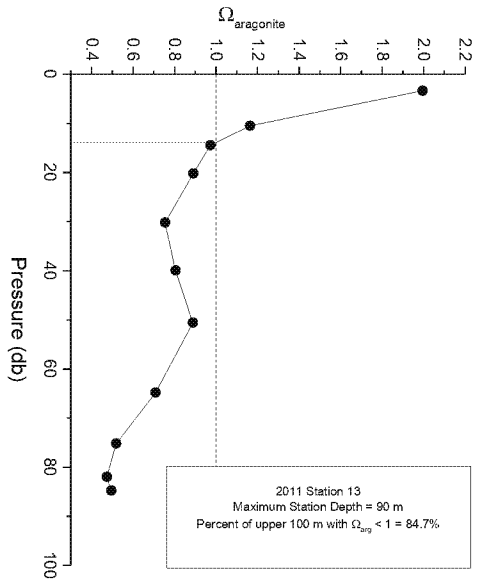
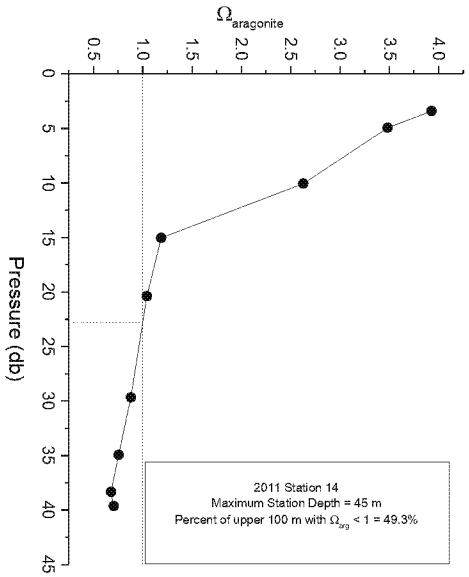
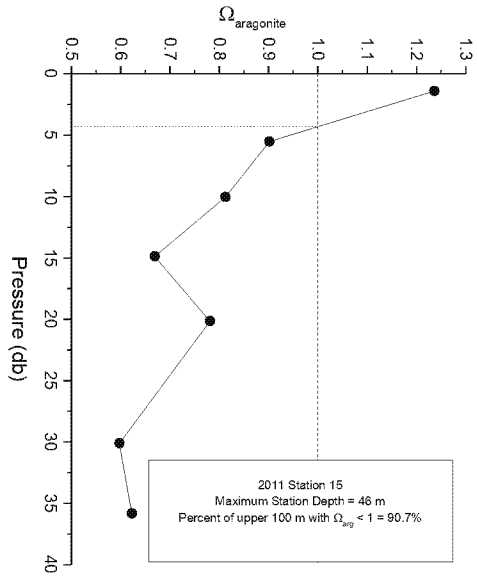
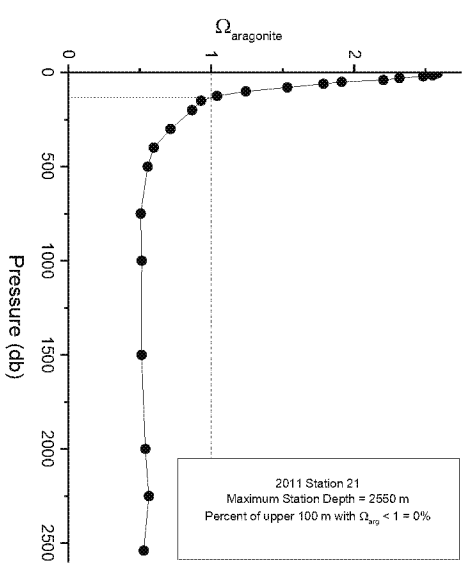
Appendix A: Profiles of 2011 stations with pteropod data used in Benarsek et al. (2014) and 2013 stations offshore of Oregon.

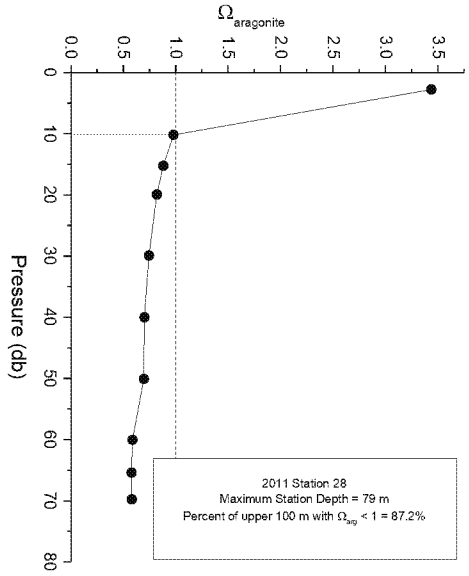


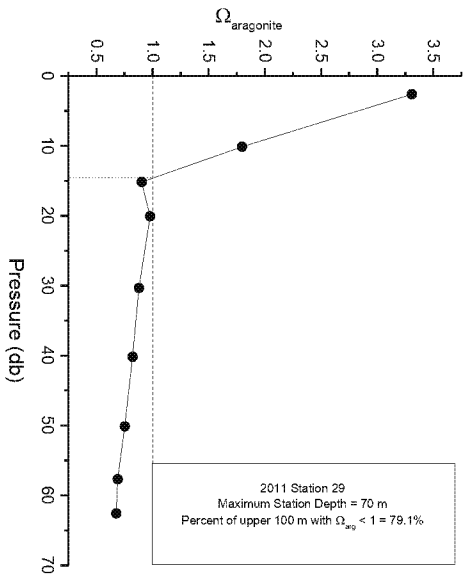


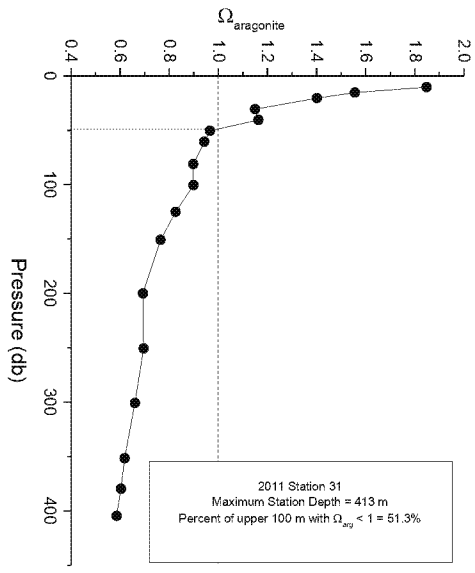


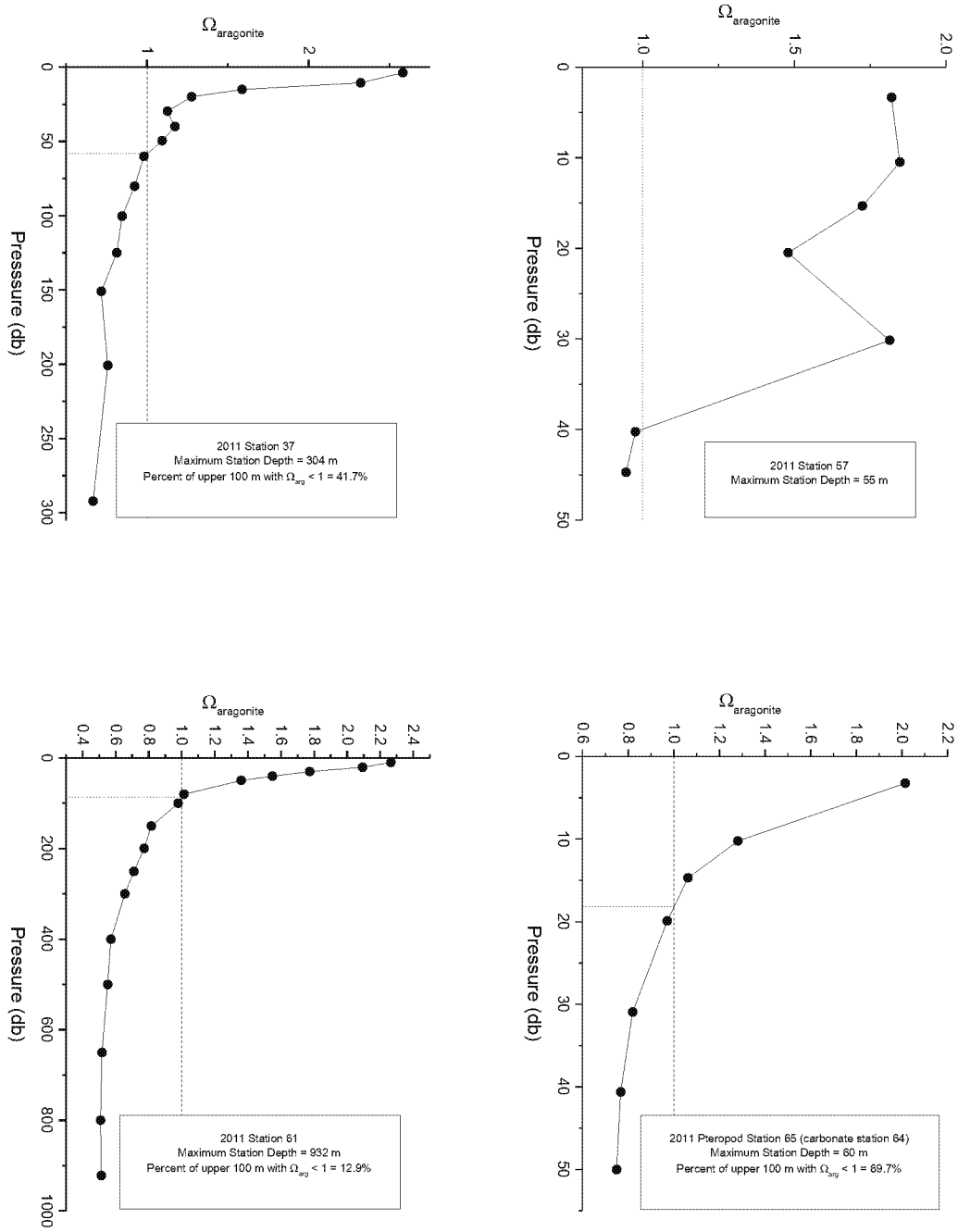


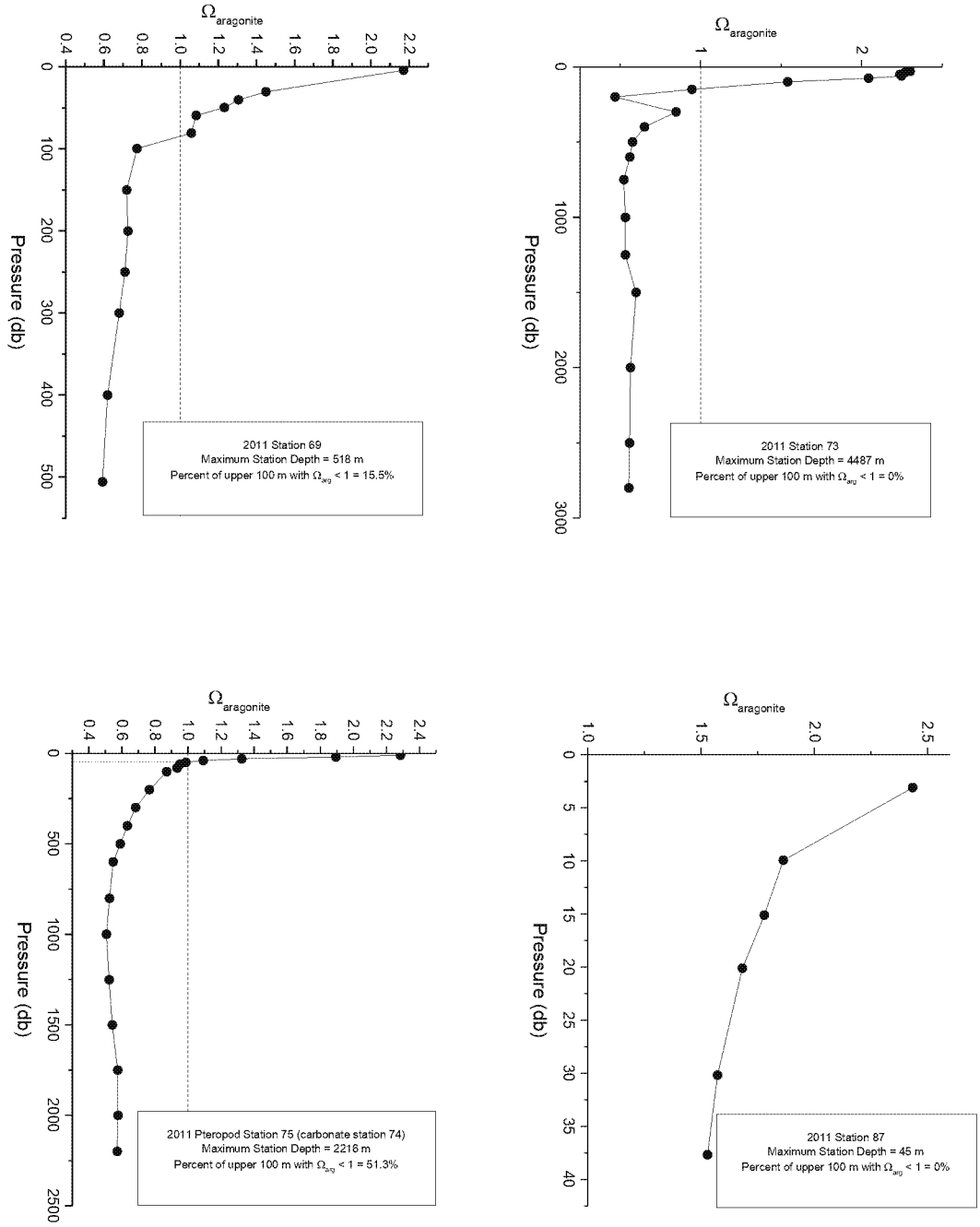

2011 Station 21
Maximum Station Depth = 2550 m
Percent of upper 100 m with Ω_{arg} < 1 = 0%
$\Omega_{aragonite}$
Pressure (db)

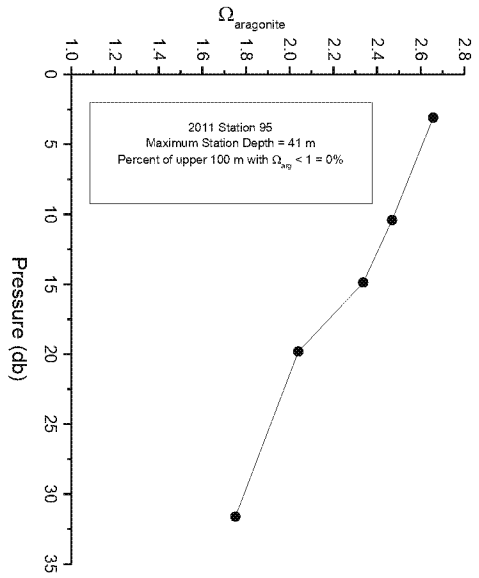

2011 Station 28
Maximum Station Depth = 79 m
Percent of upper 100 m with Ω_{arg} < 1 = 87.2%
$\Omega_{aragonite}$
Pressure (db)

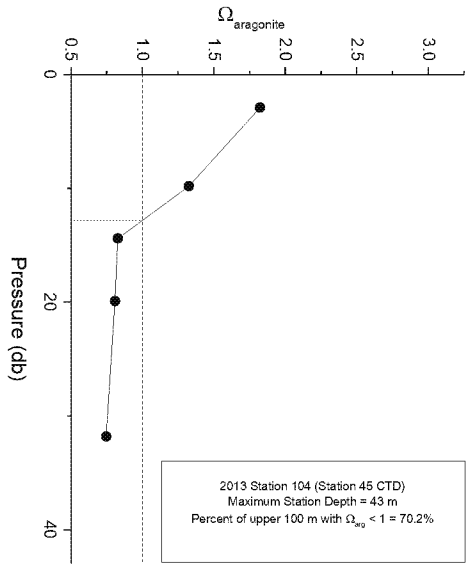

2011 Station 29
Maximum Station Depth = 70 m
Percent of upper 100 m with Ω_{arg} < 1 = 79.1%
$\Omega_{aragonite}$
Pressure (db)

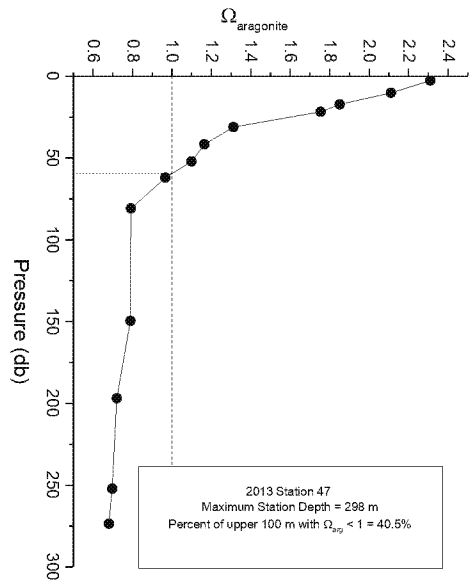

2011 Station 31
Maximum Station Depth = 413 m
Percent of upper 100 m with Ω_{arg} < 1 = 51.3%
$\Omega_{aragonite}$
Pressure (db)

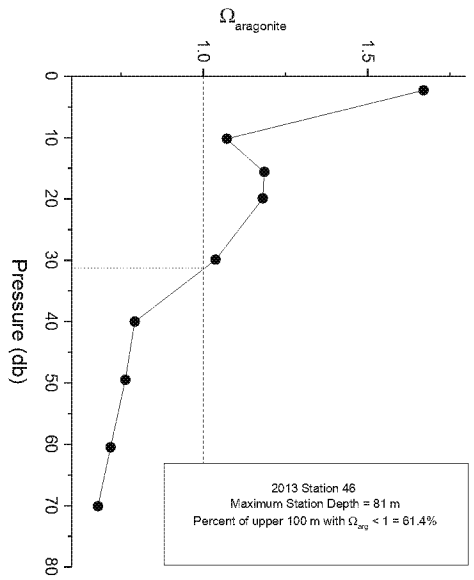

Ωaragonite
Pressure (db)
2011 Station 57
Maximum Station Depth = 55 m
2011 Station 37
Maximum Station Depth = 304 m
Percent of upper 100 m with Ωarg < 1 = 41.7%
2011 Pteropod Station 65 (carbonate station 64)
Maximum Station Depth = 60 m
Percent of upper 100 m with Ωarg < 1 = 69.7%
2011 Station 61
Maximum Station Depth = 932 m
Percent of upper 100 m with Ωarg < 1 = 12.9%

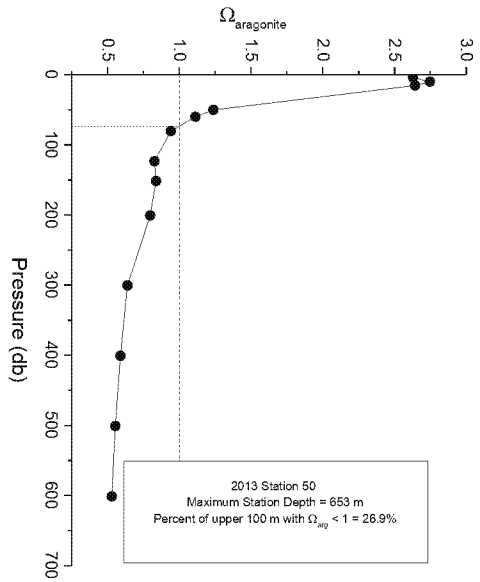

$\Omega_{aragonite}$
Pressure (db)
2011 Station 73
Maximum Station Depth = 4487 m
Percent of upper 100 m with Ω_{arg} < 1 = 0%
2011 Station 69
Maximum Station Depth = 518 m
Percent of upper 100 m with Ω_{arg} < 1 = 15.5%
2011 Station 87
Maximum Station Depth = 45 m
Percent of upper 100 m with Ω_{arg} < 1 = 0%
2011 Pteropod Station 75 (carbonate station 74)
Maximum Station Depth = 2218 m
Percent of upper 100 m with Ω_{arg} < 1 = 51.3%

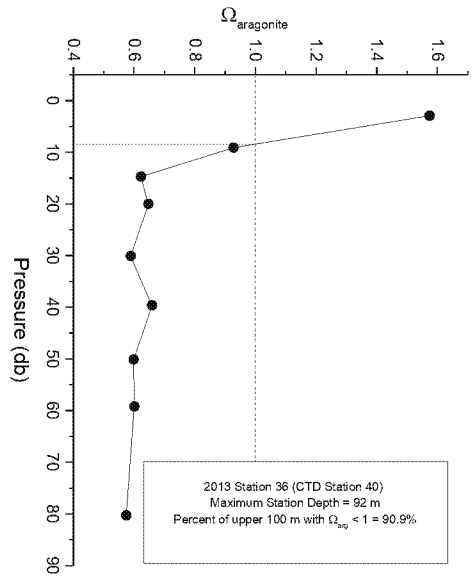

2011 Station 95
Maximum Station Depth = 41 m
Percent of upper 100 m with Ω_{arg} < 1 = 0%
$\Omega_{aragonite}$
Pressure (db)

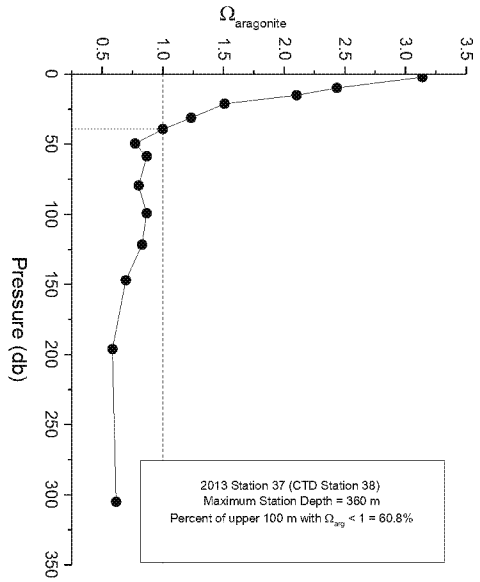

2013 Station 104 (Station 45 CTD)
Maximum Station Depth = 43 m
Percent of upper 100 m with Ω_{arg} < 1 = 70.2%
$\Omega_{aragonite}$
Pressure (db)

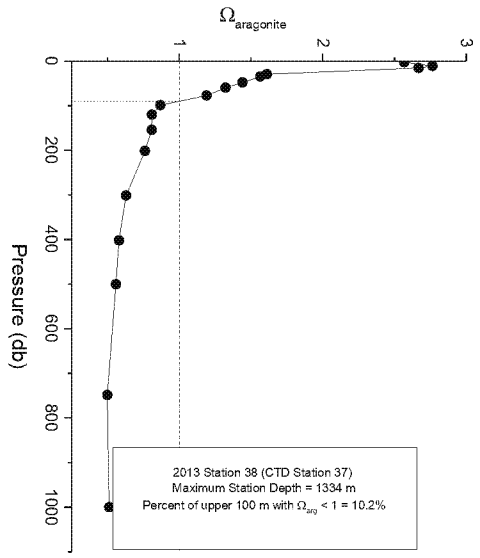

2013 Station 47
Maximum Station Depth = 298 m
Percent of upper 100 m with Ω_{arg} < 1 = 40.5%
$\Omega_{aragonite}$
Pressure (db)

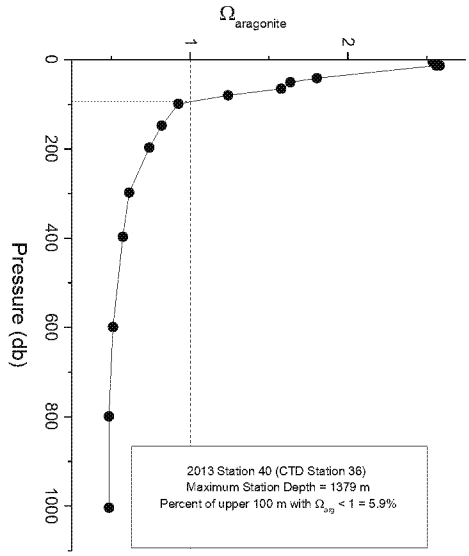
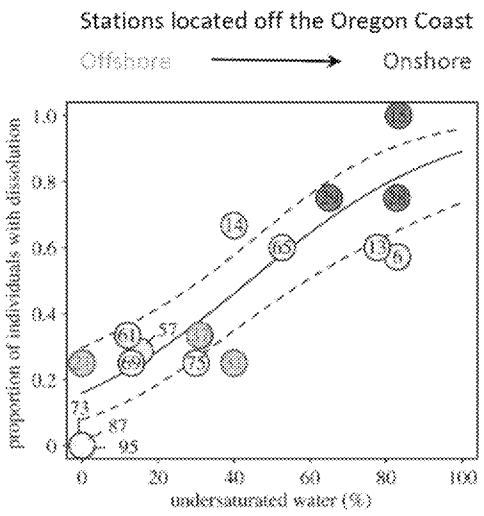
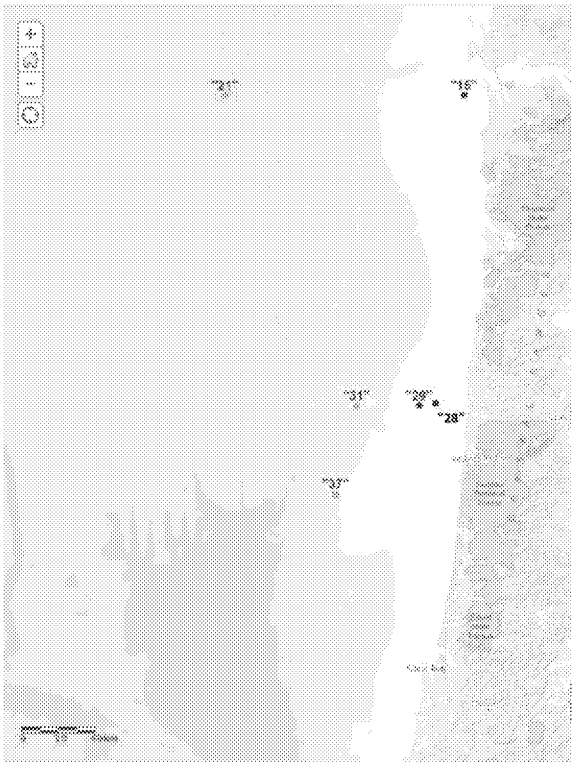

2013 Station 46
Maximum Station Depth = 81 m
Percent of upper 100 m with Ω_{arg} < 1 = 61.4%
$\Omega_{aragonite}$
Pressure (db)


$\Omega_{aragonite}$
Pressure (db)
2013 Station 50
Maximum Station Depth = 653 m
Percent of upper 100 m with Ω_{arg} < 1 = 26.9%


$\Omega_{aragonite}$
Pressure (db)
2013 Station 36 (CTD Station 40)
Maximum Station Depth = 92 m
Percent of upper 100 m with Ω_{arg} < 1 = 90.9%


$\Omega_{aragonite}$
Pressure (db)
2013 Station 37 (CTD Station 38)
Maximum Station Depth = 360 m
Percent of upper 100 m with Ω_{arg} < 1 = 60.8%


$\Omega_{aragonite}$
Pressure (db)
2013 Station 38 (CTD Station 37)
Maximum Station Depth = 1334 m
Percent of upper 100 m with Ω_{arg} < 1 = 10.2%


$\Omega_{aragonite}$
1
2
0
200
400
600
800
1000
Pressure (db)
2013 Station 40 (CTD Station 36)
Maximum Station Depth = 1379 m
Percent of upper 100 m with Ω_{arg} < 1 = 5.9%

Appendix B: Figure 3 from Bednarsek et al (2014) highlighting datapoints offshore of Oregon. Right panel shows 2011 sampling locations offshore of Oregon.