San Francisco Bay Living Shorelines Project
Physical Properties Report, November 2014

Environmental Science Associates (ESA)

Table of Contents

1 Introduction

This report summarizes the methods and results of the physical processes studies as part of the San Francisco Bay Living Shorelines: Near-Shore Linkages Project.

The project has two sites: The Nature Conservancy (TNC) site in San Rafael Bay and the Eden Landing Ecological Reserve (ELER) site in southern San Francisco Bay, near Hayward. These sites vary in size and complexity. The TNC "large-scale" experiment has four treatment plots in a line parallel to the shore, approximately 250 m from shore (Figure 1). These treatment plots consist of native oyster substrate alone; eelgrass alone; both oyster and eelgrass together; and a control of the same size. The plots are 32m x 10m and are large enough scale to compare their effects on physical processes such as accretion and wave attenuation as well as effects on biological properties such as bird and fish utilization and water quality interactions of oysters and eelgrass.

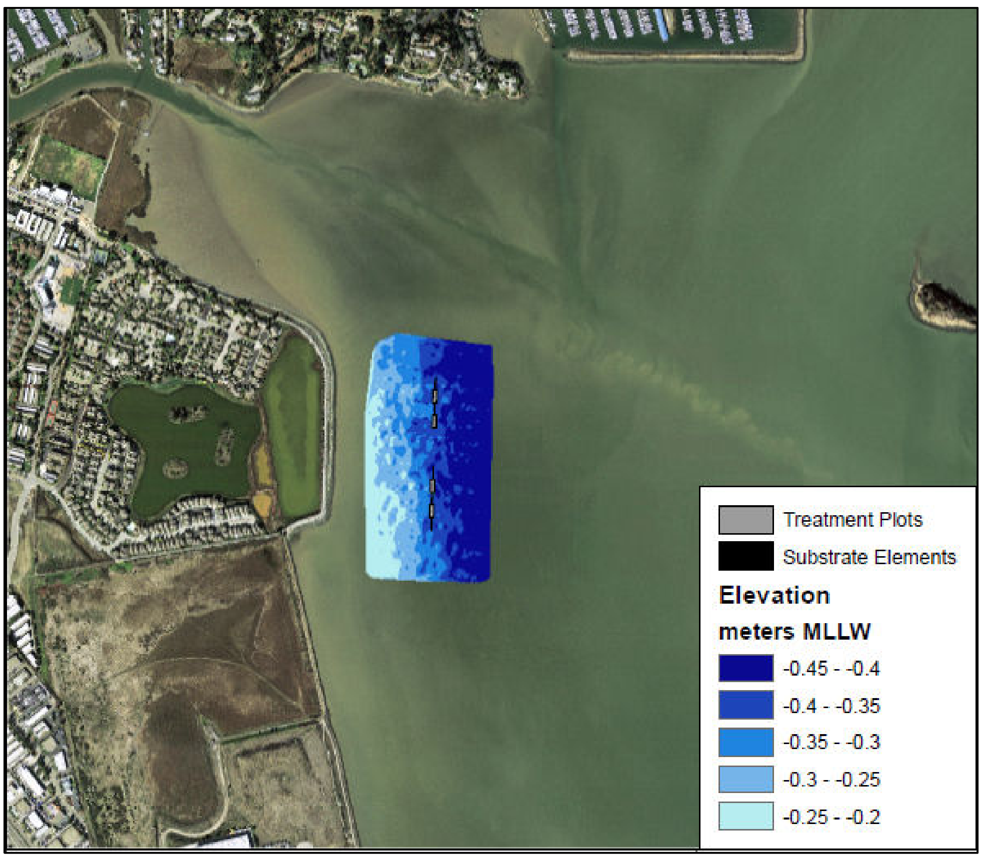


Figure 1. TNC site at San Rafael showing the location of the treatment plots and the limits of the bathymetric survey.

The TNC experimental design was strongly influenced by the considerable prior experience of oyster and eelgrass establishment in the area with the emphasis on investigating the effects of increasing the scale of restoration. By contrast, there had been no previous experience with either oysters or eelgrass at the ELER site and so the emphasis was on understanding the establishment of oysters and eelgrass. This site is smaller in scale, consisting of replicate 1x1 m elements of different substrate types at 30m spacing placed parallel to the shore. The layout is intended to compare native oyster recruitment and growth parameters to inform the feasibility future restoration projects (Figure 2). To provide a comparison, a similar small scale "substrate element" experiment was also setup at the TNC site. A detailed description of the experimental design and construction for the TNC and ELER sites is given elsewhere in this report.

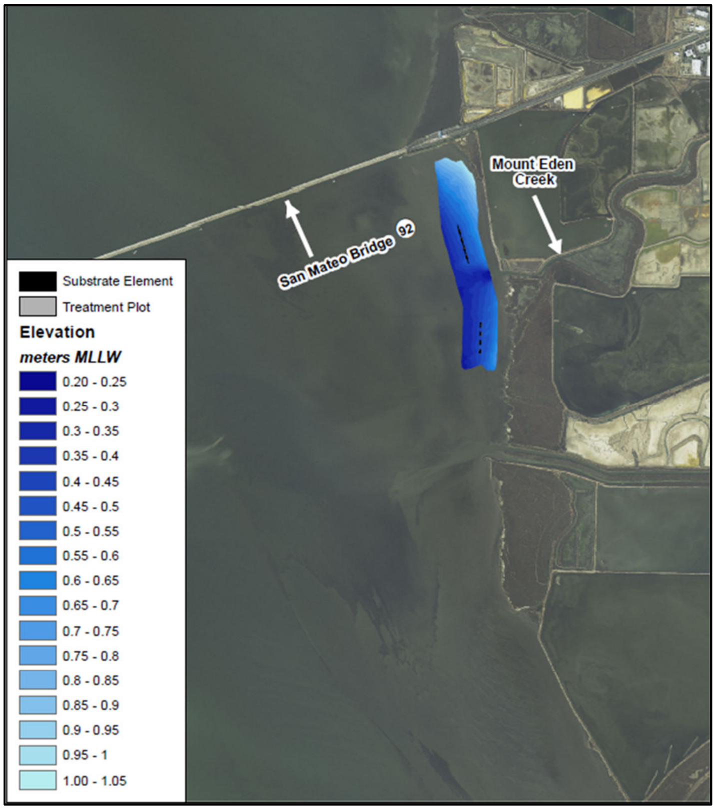


Figure 2. ELER site at Eden Landing showing the location of the substrate elements and the limits of the bathymetric survey.

Following site assessment, project design and construction, ESA began monitoring the two sites in the summer of 2012. The monitoring has consisted of two main elements:

- Measurements in the water column to record water quality parameters for the oyster and eelgrass teams and to identify impacts of the experiments on the water column.
- Measurements of the sediment surface to determine changes in sedimentation and erosion in response to the different treatments and to measure the stability of the oyster reef elements.

Most of the measurements have been focused on the TNC site as it contains the large scale treatment plots. At ELER, measurements have been confined to oyster reef element stability to help understand how a larger treatment plot may perform in the future.

2 Methods

2.1 Water Column Measurements

2.1.1 Water Quality (TNC)

ESA deployed a multi-parameter sonde at the TNC site to collect ambient water properties of temperature, salinity, dissolved oxygen (DO), pH, and turbidity. An In-Situ Troll 9500 sonde was used with sensor ranges and accuracies reported by the manufacturer as:

	Accuracy	Range
pH	±0.1 pH units	0 to 12 pH units
Dissolved oxygen, DO	±0.1 mg/L from 0 to 8 mg/L ±0.2mg/L from 8 to 20 mg/L	
Conductivity	±0.5% or 2 µS/cm	150 to 112,000 µS/cm
Turbidity	±5% or 2 NTU/FNU	0 to 2000 NTU/FNU

Table 1. Sonde measurement parameters reported by In-Situ.

The sonde was located at the bay side of the reef structures and continually submerged in roughly 2m of water (Figure 3). A 3m pole was driven into the mudflat and the sonde attached to the pole. Measurements were made 0.25m above the bed at 15 minute intervals.

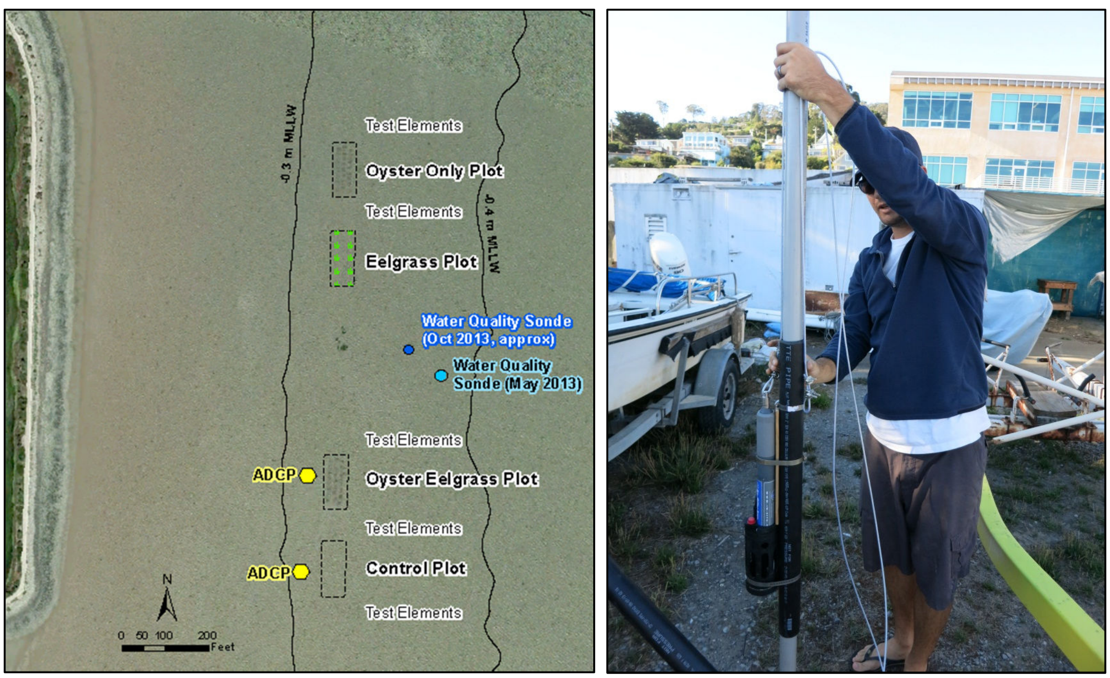


Figure 3a,b. Water quality sonde location at the TNC site in San Rafael and general arrangement of the mounting.

Data collection was impeded by biofouling and sensor damage; the sonde had to be removed, repaired and redeployed on a number of occasions. In all there have been four deployments which are listed in Table 2.

Deployment	Start Date	End Date
1	05/16/13	06/03/13
2	10/04/13	10/29/13
3	04/30/14	08/06/14
4	09/14/14	present (10/30/14)

Table 2. Deployment dates of the water quality sonde at the TNC site.

For comparative purposes, data from the San Francisco Bay National Estuarine Research Reserve (NERR) water quality sonde located at China Camp was downloaded for the four periods shown in Table 2 (NERR 2014). Both the TNC and China Camp data have been shared with the other project teams, who are collecting water property data within the oyster reefs and eelgrass plots.

2.1.2 Waves (TNC)

Wave height, wave period, wave direction, current speeds, and current directions have been measured on both landward and bayward of the TNC reef structures. Two RDO Workhorse bottom-mounted Acoustic Doppler Current Profilers (ADCPs) were deployed at the TNC site inshore of the reefs to measure waves transmitted across the oyster-eelgrass reef and at the control site (Figure 4). They were located 0.15m and 0.21 m above the bed respectively.

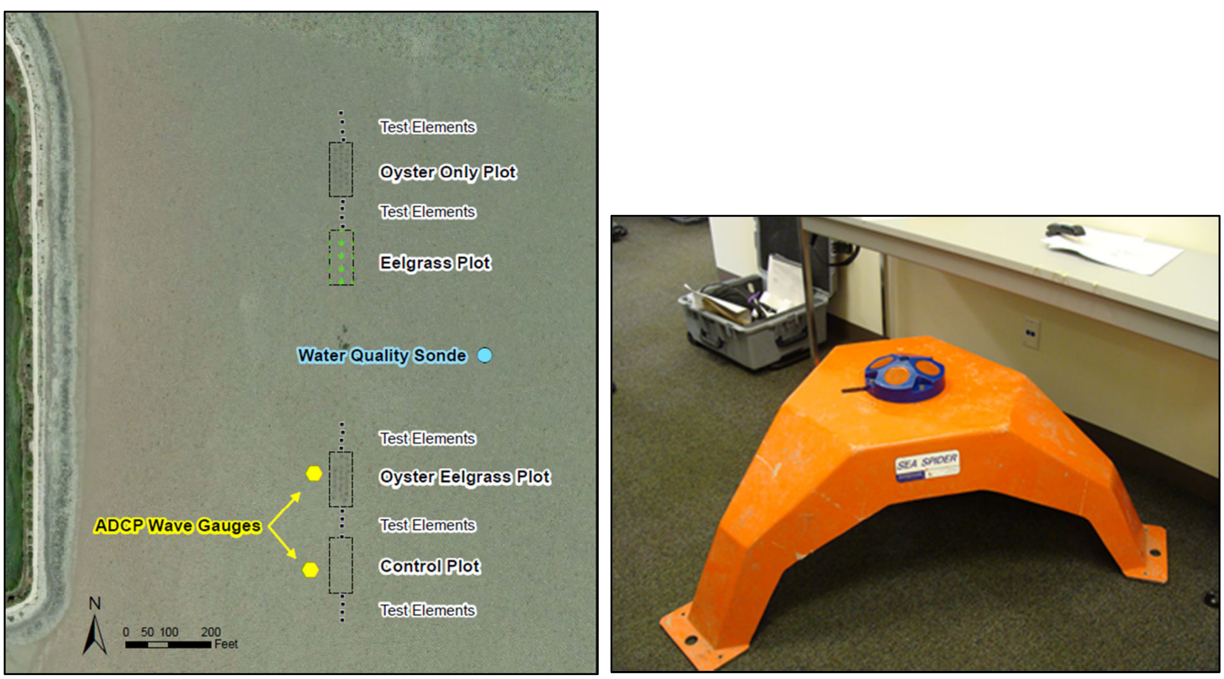


Figure 4a,b. ADCPs at the TNC site at San Rafael showing the location and general arrangement of the mounting.

The ADCPs were deployed for two months between February and April 2013 when waves would be expected to occur (Table 3). Three large wind events occurred during this period. A significant proportion of these waves were propagating offshore, away from the site, due to the local wind direction during the events. Periods of onshore waves were identified and this subset was analyzed.

Deployment	Start Date	End Date
1	02/22/13	04/16/13

Table 3. Deployment dates of the ADCPs at the TNC site.

2.2 Sediment Response Measurements

Bathymetric surveys were undertaken to establish mudflat bed elevations and far-field patterns of erosion and accretion around the TNC treatment plots and around the ELER substrate elements. Separate surveys were undertaken on a more regular basis to monitor the movement of the individual oyster reef elements and to record local sedimentation and scour within the treatment plots. All the survey data was measured in meters NAVD88 and reduced to MLLW for reporting.

2.2.1 Bathymetric Survey (TNC, ELER)

ESA PWA subcontracted Environmental Data Solutions to conduct a single-beam bathymetric survey prior to construction at the TNC site (Figure 1) and ELER site (Figure 2). The surveys, completed in May 2012, utilized Class 1 methods and accuracies as outlined in the USACE Hydrographic Surveying Manual (USACE 2002). Bathymetric data were collected using an Odom CVM survey grade fathometer with a 3-degree, 200-kHz transducer. The transducer was mounted in a fathometer well (housing a mineral oil bath) located mid-ship through the hull in the keel. Fathometer readings were oriented in space via communications with a Leica Viva Real-Time Kinematic GPS (RTK-GPS) system receiving corrections from the Leica SmartNet base station network. The survey was completed in horizontal coordinate system NAD83 State Plane Zone 3 Feet, and the vertical datum NAVD 88 Feet. The data was then provided to ESA PWA in point format. ESA PWA created a TIN surface from the point file in order to check for any survey irregularities, and then converted to a raster using the natural neighbor function. The raster was then converted to meters MLLW.

ESA conducted a second single-beam bathymetric survey in June 2014 at the TNC site (Figure 1). Bathymetric data were collected using a Seafloor Systems Hydrolite survey grade fathometer with a 4-degree, 200 kHz transducer. The transducer was mounted to a kayak transom mount that is located on the stern of the boat. Fathometer readings were oriented in space via communications with a Leica Viva RTK-GPS system receiving corrections from the Leica SmartNet base station network. The survey was completed in horizontal coordinate system NAD83 State Plane Zone 3 Feet, and the vertical datum NAVD 88 Feet. After an initial TIN creation to check for survey irregularities, the data was despiked using a moving average function before being converted to a raster using the natural neighbor function. The raster was then converted to meters MLLW.

Once both the 2012 and 2014 digital elevation models (DEM) were completed, a DEM of difference map (Wheaton *et al*. 2010) was completed in order to map out morphological changes to the mudflat during the course of the project thus far. The difference between the two surface s gives an approximate accretion/erosion rate between the surveys (Table 4).

Survey	Start Date
ELER	05/14/12
TNC	05/15/12
TNC	06/13/14

Table 4. Bathymetric survey dates for the TNC and ELER site.

2.2.2 Elevation of Individual Units (TNC, ELER)

Prior projects that installed reef elements near the TNC site in San Rafael observed significant subsidence into the bed due to the muddy substrate; some settling of the individual oyster reef units would be expected as a result. To quantify this, the top elevation of selected elements at the TNC and ELER sites were measured at regular intervals to determine the rates of subsidence. An initial elevation of every element in the test plots and at least one element per shell bag unit in the larger plots was collected beginning in October 2012. A combined RTK-GPS and total station topographic survey was completed to measure the element elevation relative to a local temporary benchmark (Figure 5). The same element within a shell bag unit was tagged and surveyed each time to maintain consistency. Monthly surveys were continued until the subsidence appeared to level off, at which point collection shifted to bi-monthly and then semi-annual frequency (Table 5).

Figure 5. RTK-GPS survey of element elevation

Survey	TNC	ELER
1	10/15/12	09/29/12
2	11/12/12	11/13/12
3	12/10/12	12/11/12
4	01/23/13	01/22/13
5	03/07/13	04/26/13
6	04/16/13	05/28/13
7	07/11/13	07/10/13
8	05/20/14	06/02/14
9	11/03/14	11/14/14

Table 5. Element survey dates for the TNC and ELER site.

2.2.3 Sediment Accretion and Erosion (TNC)

Two approaches were used to track sedimentation at the San Rafael site for the project. The first approach was to measure accretion and scour using sedimentation plate in and around the reefs; the second involved topographic surveys of the bed in and around the units.

As part of the monitoring plan for sediment accretion, ESA installed 14 sediment plates immediately after the construction of the treatment plots at the San Rafael site. Sediment plates are flat disks buried in the substrate and held in place laterally by a threaded pole through the center of the plate (Figure 6). The plates were held vertically by galvanized brackets above and below the disk. Half of the plate surface was sanded to enhance sediment trapping of finer particles on a rougher surface. The sediment accretion/scour was measured monthly by taking four repeat measurements of the sediment thickness on the plate surface and averaging (Table 6). Biofouling and bed scouring became challenges for using sediment plates to the point that their use had to be discontinued after December 2012.

Figure 6. Sediment plate

Survey	Start Date
1	08/31/12
2	10/15/12
3	11/12/12
4	12/10/12

Table 6. Sediment plate survey dates for the TNC and ELER site.

As an alternative to the sediment plates, the depth of sediment accumulating within the treatment plots was measured using topographic surveys of the mudflat surface. Those depth measurements were then used to calculate a rough volume of sediment accumulation inside the units. The pre-project bathymetric survey (May 2012) and subsequent yearly substrate and sediment surveys were used to calculate sedimentation rates. The post-project surveys were undertaken with a total station. Four transects per plot were measured within the oyster-only, oyster-eelgrass, and control treatment plots: two in the N-S orientation and two in the E-W orientation (Figure 7).

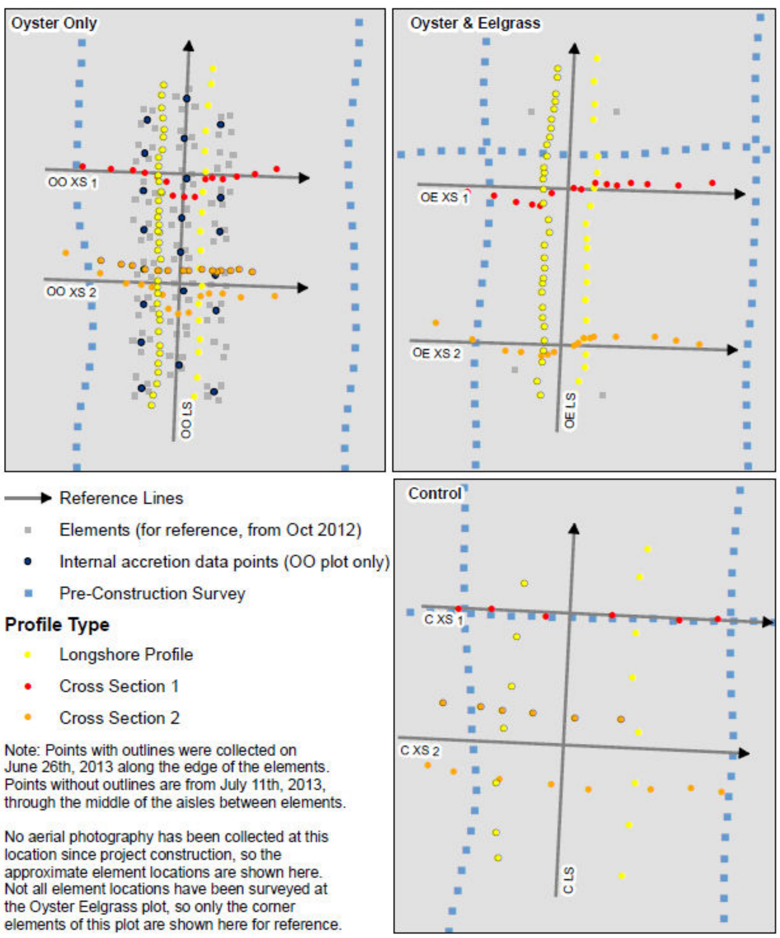
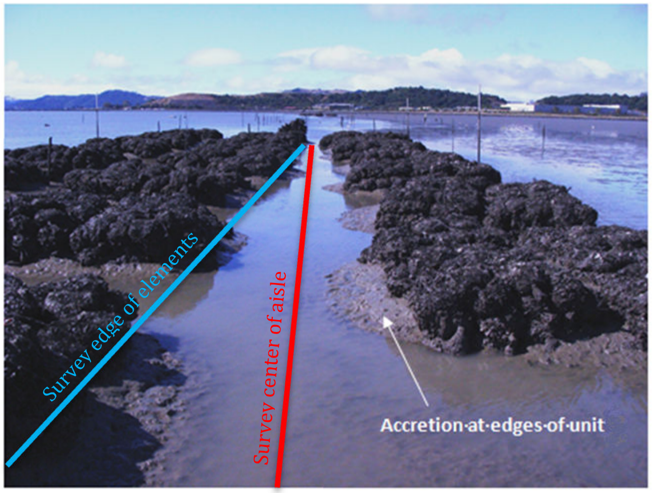
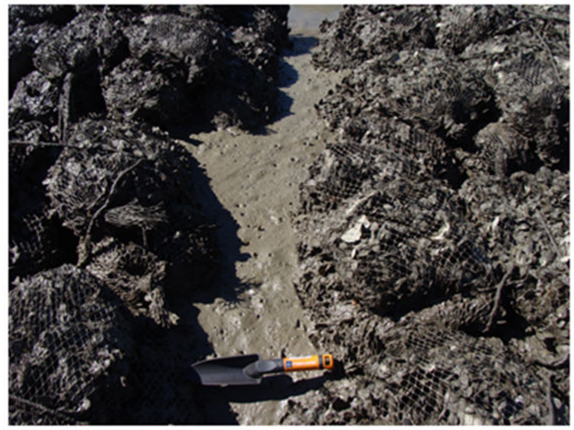


Figure 7. Treatment plot sediment bed surveys at TNC.

For the oyster-only and oyster-eelgrass treatment plots, one transect was collected through the middle of the aisles between elements while the second was collected close to the edge of the elements to capture the undulations in bed topography that occur close to the individual elements (Figure 8). In the oyster-only treatment plot, data points were also collected between the shell bags in the middle of the units, where sediment has been accumulating rapidly (Figure 8).



Oyster-Only plot at San Rafael, facing south



Deposition in between oyster elements, view from above

Figure 8. Sediment bed survey types and methods for the TNC site.

Survey	Start Date
1	06/26/13
2	07/11/13
3	05/20/14

Table 7. Sediment bed survey dates for the TNC site.

2.2.4 Photographic Documentation

Semiannual repeat photography of the plots and elements at both sites began in May 2014 in order to document long term scour and accretion around the elements. Photos are taken on opposite sides of each plot or element and compared over time. Repeat photography dates are presented in Table 7.

Survey	TNC	ELER
1	05/20/14	06/02/14
2	Nov 2014	Nov 2014

Table 7. Repeat photograph dates for TNC and ELER site.

3 Results

3.1 Water Column

3.1.1 Water Quality (TNC)

The results of the water quality monitoring are shown in Figures 9, 10, 11 and 12 for 2013 and 2014. Data from the nearby China Camp NERR station are presented alongside the ESA data for comparison. Temperature, pH, and DO show close agreement between sondes; turbidity and salinity show distinct differences. Turbidity at the TNC site is more sensitive to wind events due to its shallow depth and soft bed, and the turbidity spikes around June 2, 2013, October 4, 2013, and May 17, 2014 are all concurrent with high wind events recorded by the CIMIS weather station located at Point San Pedro (CIMIS 2014). Despite the drought, the influence of freshwater input from San Rafael Creek can clearly be seen in the lower salinity readings collected at the TNC site by ESA when compared with data collected at China Camp by NERR.

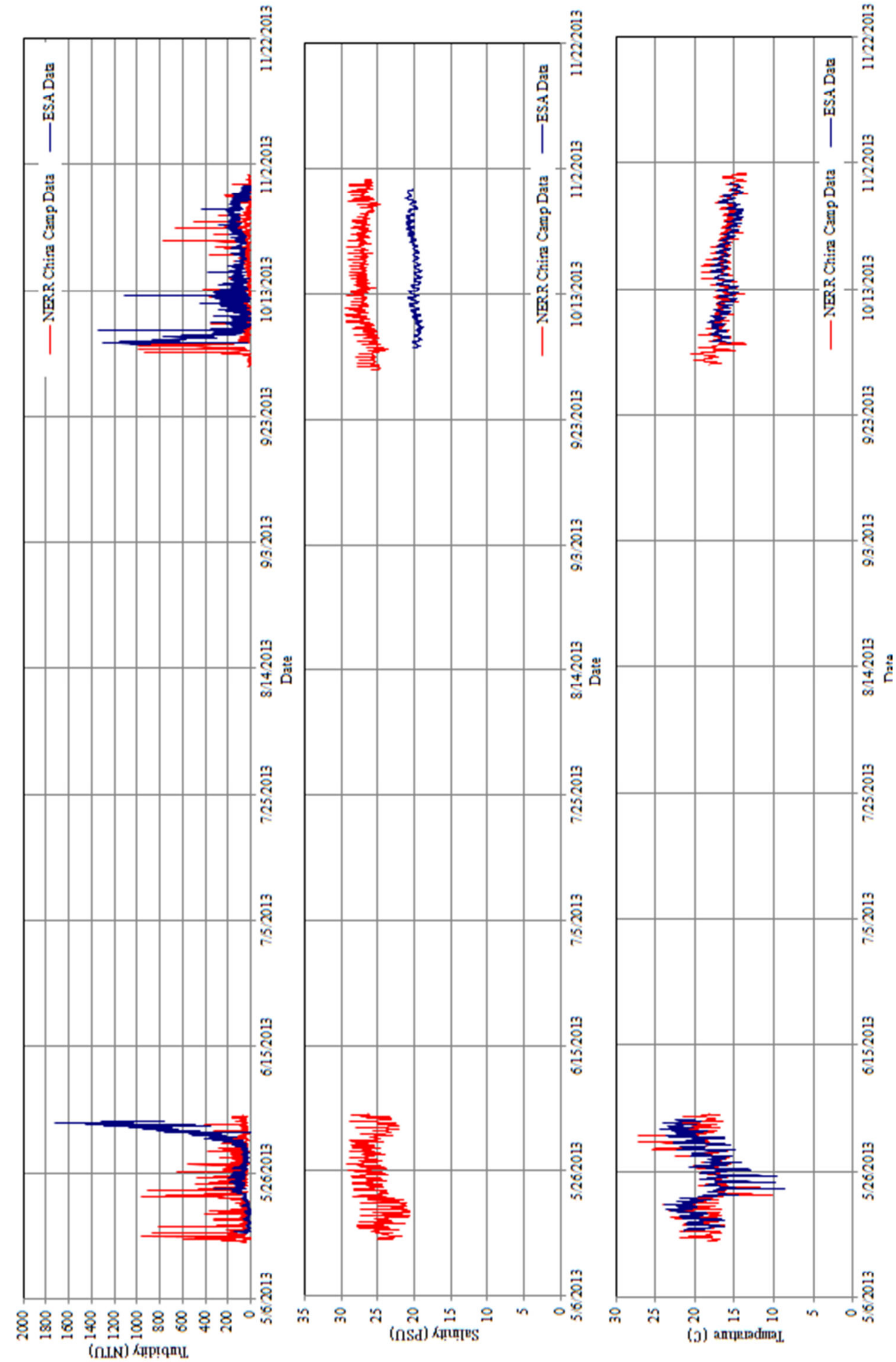


Figure 9. Temperature, salinity and turbidity measured at TNC and China Camp in 2013.

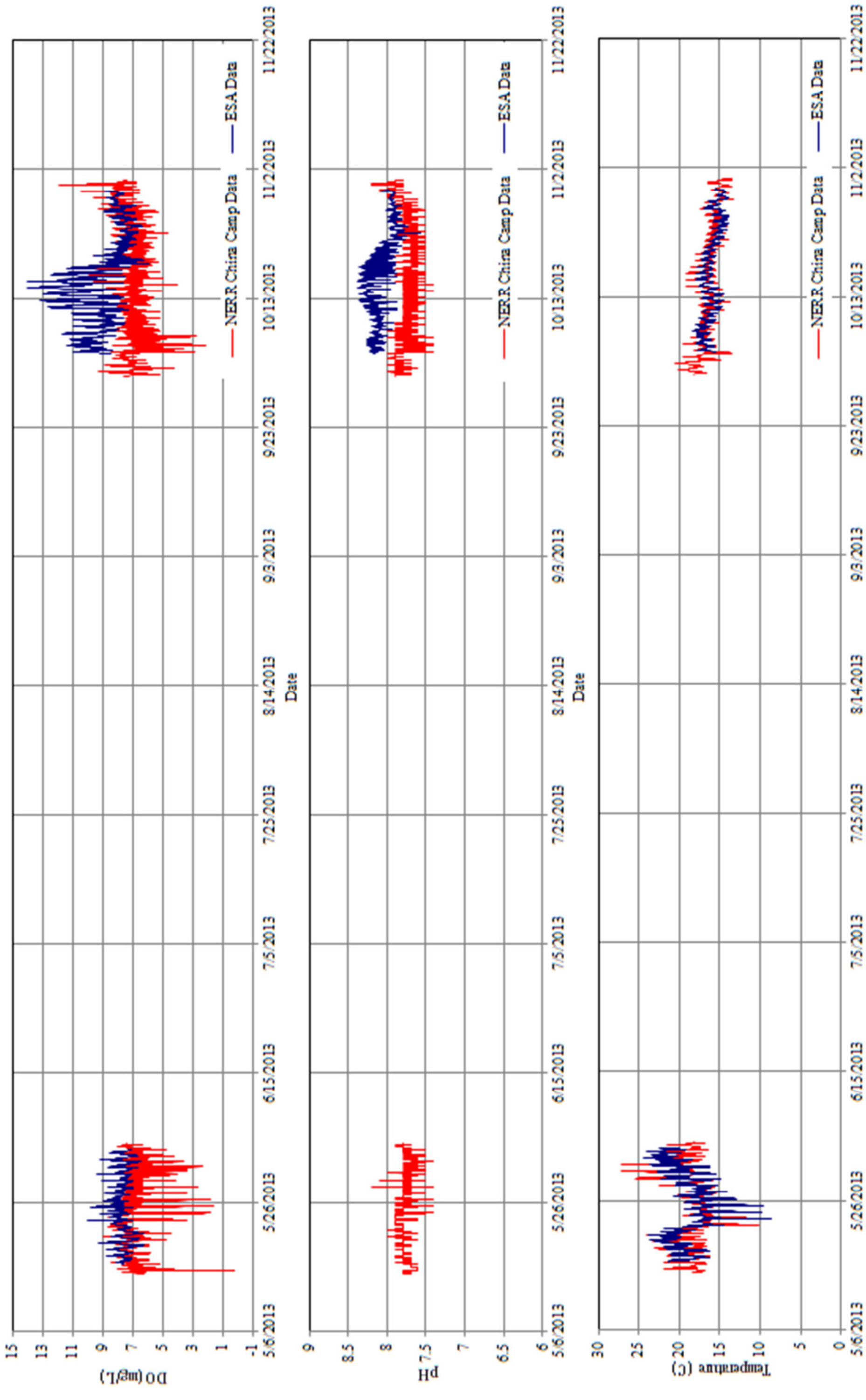


Figure 10. Temperature, pH and dissolved oxygen measured at TNC and China Camp in 2013.

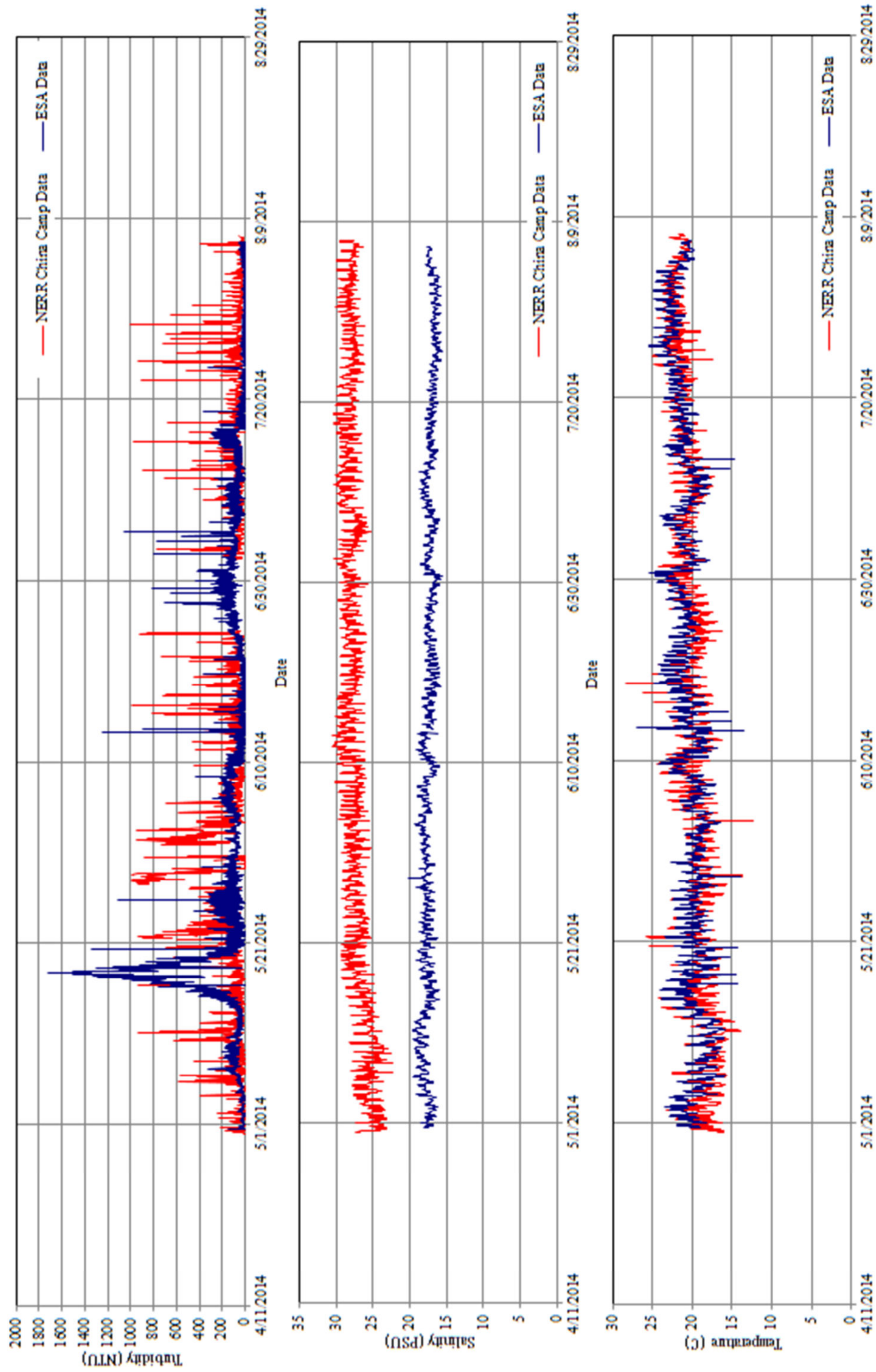


Figure 11. Temperature, salinity and turbidity measured at TNC and China Camp in 2014.

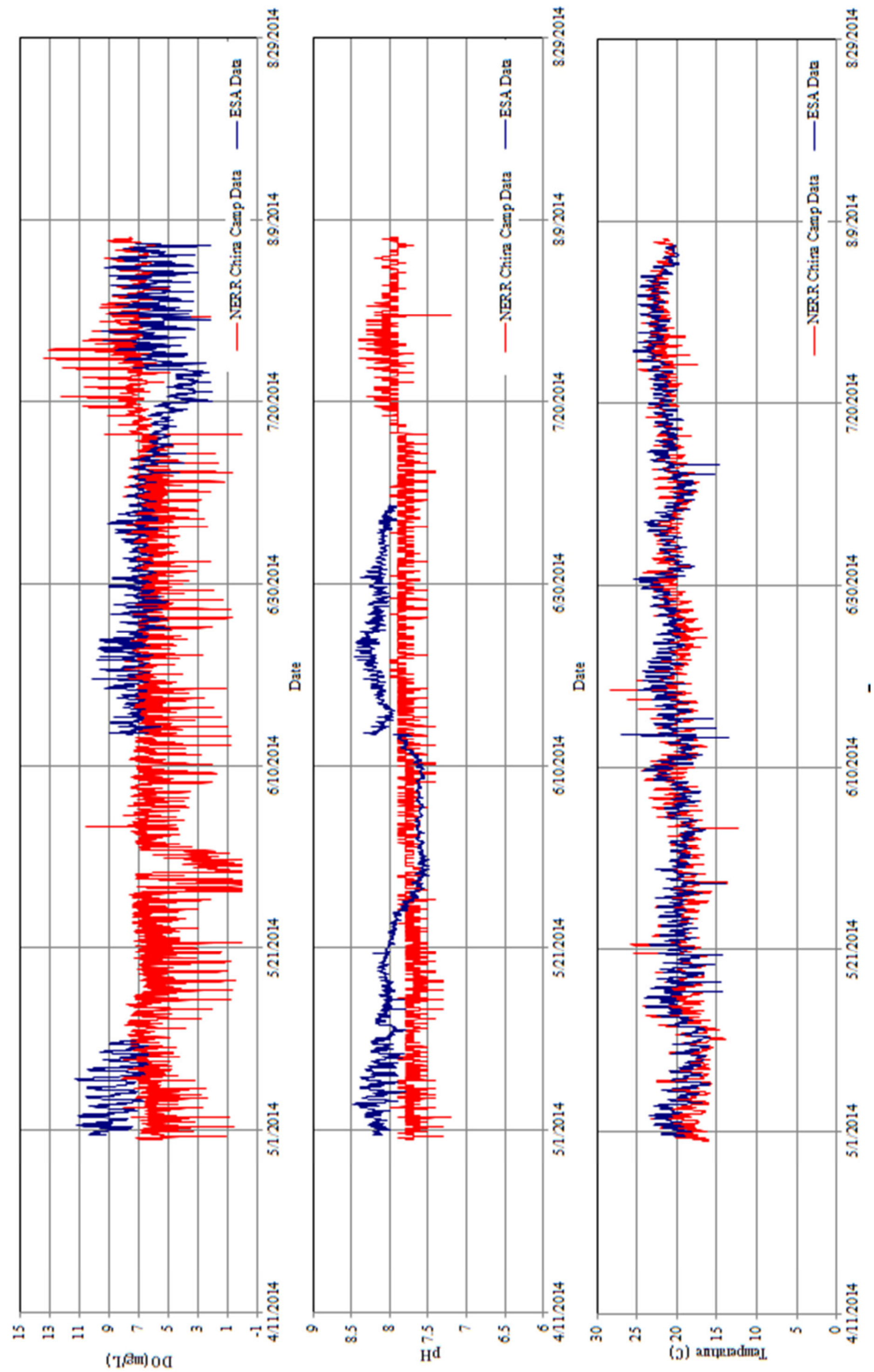


Figure 12. Temperature, pH and dissolved oxygen measured at TNC and China Camp in 2014.

3.1.2 Waves and Currents (TNC)

Wave height show different patterns between the lee of the oyster-eelgrass plot and the control plot. Wave heights ranged 0.06- 0.26 m for both although the waves behind the oyster-eelgrass tended to be smaller (Figure 13). This illustrates the influence of the structure on transmitted wave heights although the conditions under which these were measured was limited. To increase the range of conditions the wave measurements were used to calibrate a numerical model.

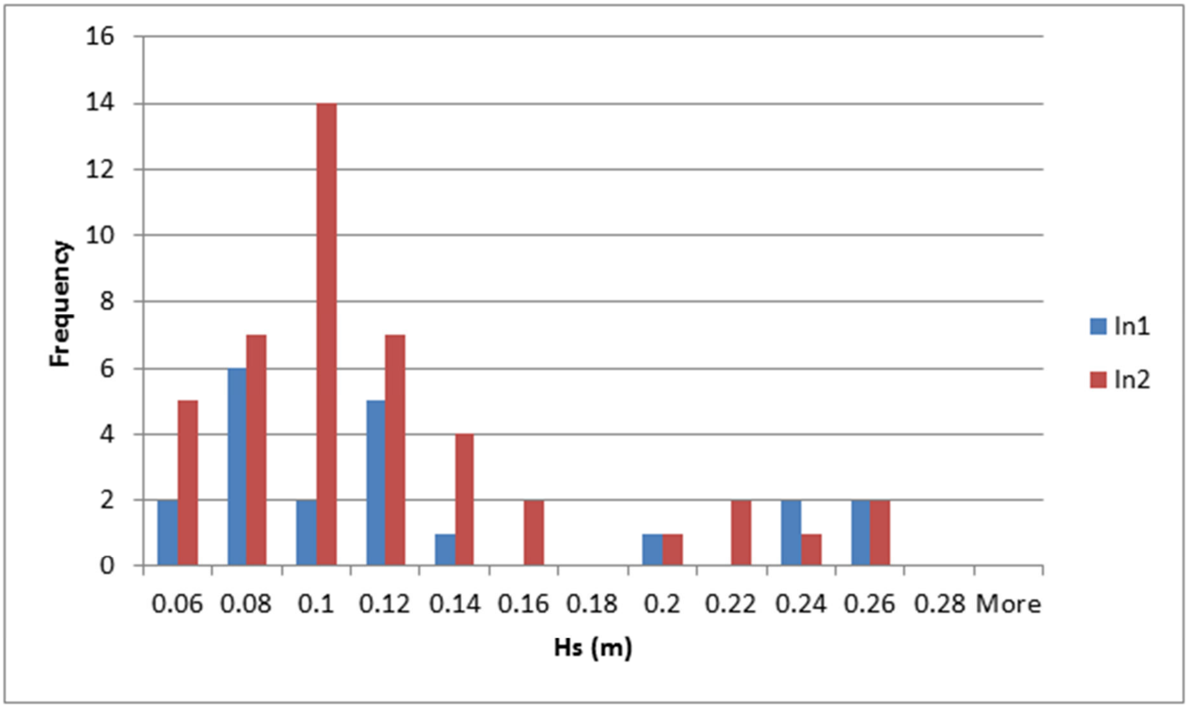


Figure 13. Wave Height measured at TNC 02/26/13 to 04/15/13. In1 ADCP is located on the shore side of the Oyster-Eelgrass reef, and In2 is located on the shore side of the control plot.

A Boussinesq wave model was developed for the TNC San Rafael site. This wave model allows the evaluation of wave and current interaction with the oyster reef for a larger combination of wave height, period and water depths. The model results have been validated with the field data. Preliminary results testing the wave height and wave energy reduction of the reefs for different wave and water level conditions show a 30% reduction of wave energy at the reef for regular tidal elevations.

Differences were also seen in the currents in the lee of the reef. Velocities were observed to be faster and flood-dominated, with negligible ebb tide velocities. This contrasts with the current data for the control plot that shows a symmetrical distribution for the flood and ebb tides (NW-SE angle) but with lower velocity (Figure 14). This may be related to the proximity of the site to the mouth of San Rafael Creek.

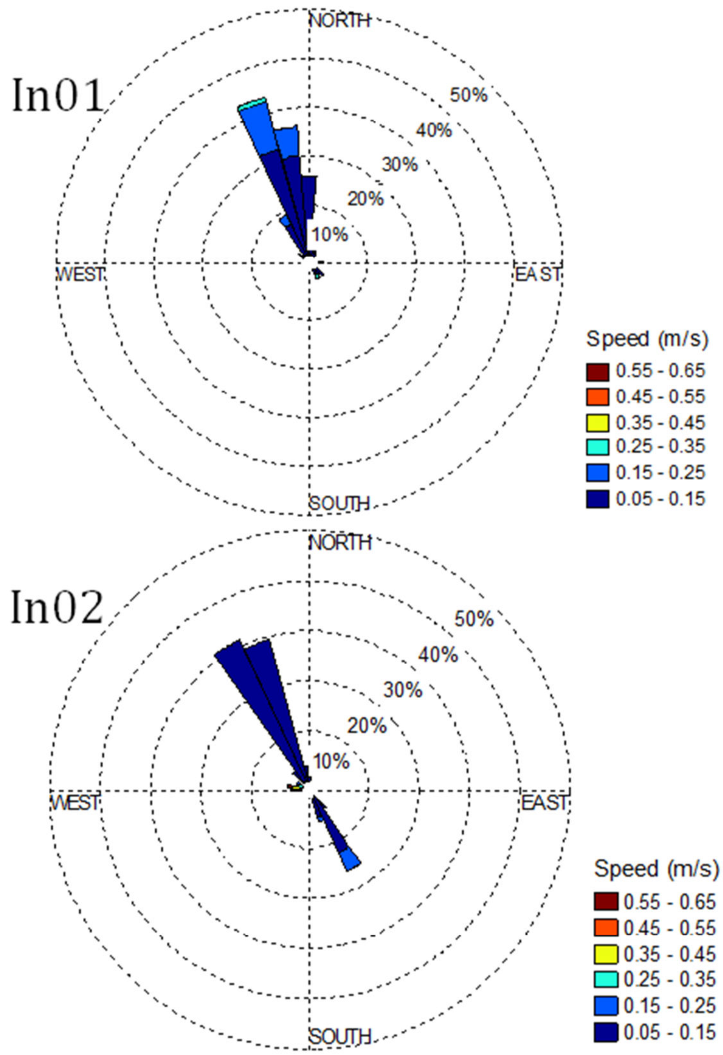


Figure 14. Current roses for TNC site 02/26/13 to 04/15/13.

3.2 Sediment Response

3.2.1 Bathymetric Survey (TNC, ELER)

Figures 15a and 15b show the TNC bathymetry in 2012 and 2014 respectively together with the difference between the two surveys (Figure 15c). The difference map appears to indicate sedimentation of about 0.07m in the lee of the treatment plots and erosion of about 0.09m offshore and to the north. The north-south difference may be related to the proximity of San Rafael Creek. The east-west difference may be related to the treatment elements but the same pattern can be seen in relation to the control plot which should not have an impact.

From the two surveys it appears that the treatment plots have little impact on the overall pattern of erosion and sedimentation in the area. This is the result of only one repeat survey and it would be necessary to undertake another survey in the future to see if the pattern of erosion and accretion was an ongoing trend. Unfortunately we know little about the seasonality of mudflat elevations in this area and we may be observing a cyclical process.

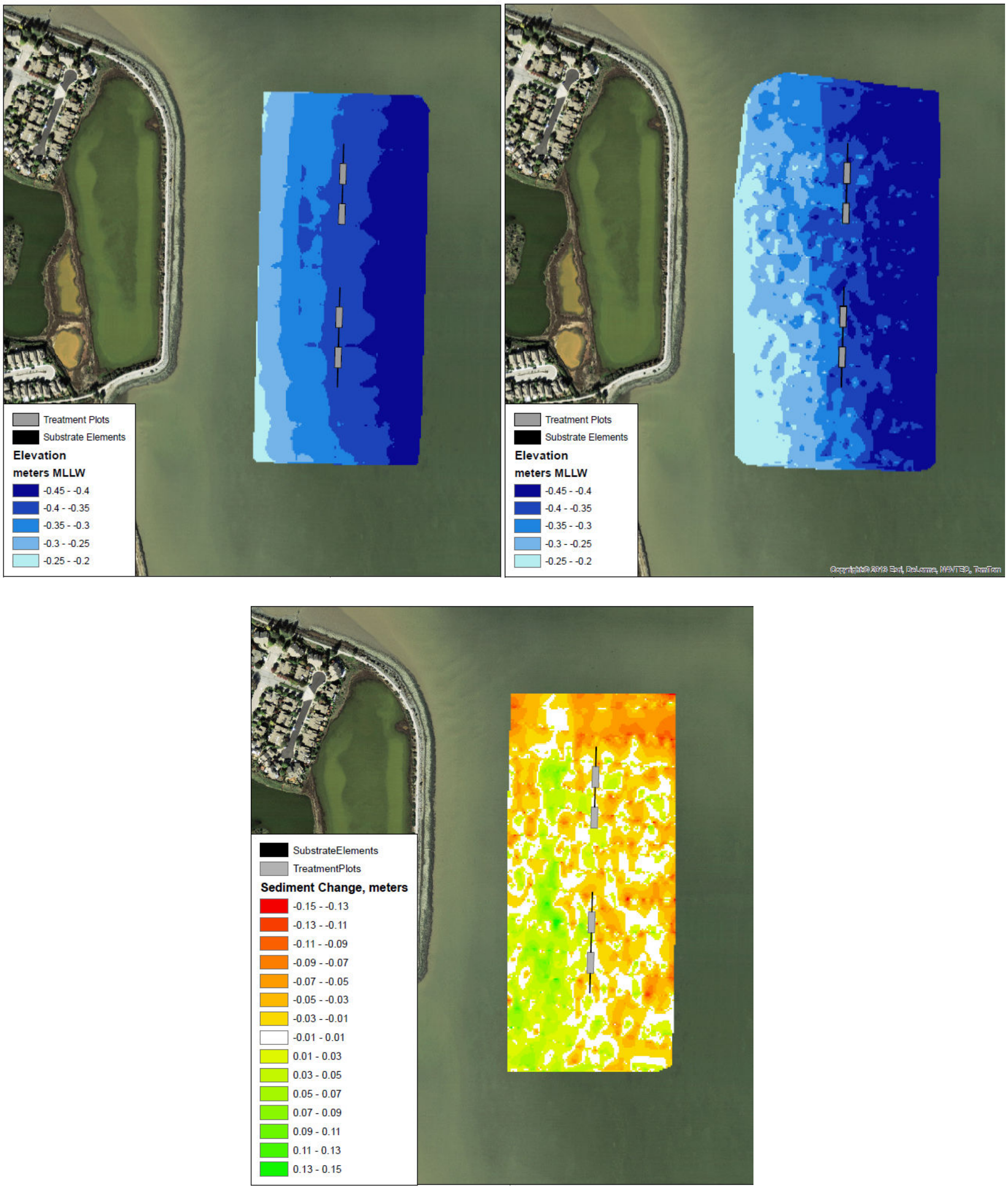


Figure 15a, b, c. TNC site at San Rafael showing 2012, 2014 elevations and difference in elevations.

3.2.2 Elevation of Individual Units (TNC, ELER)

To date, approximately 0.1m of element subsidence has been observed across the TNC site but the rate has not been constant. The average rate of subsidence from October 2012 to January 2013 was 0.02 ± 0.018 m/month for the layer cake, oyster ball, oyster block, and reef ball elements and 0.017 ± 0.016 m/month for the shell bag elements (Figure 16). The different types of elements subsided at fairly consistent rates into March 2013. After April 2013, the rates of change for all the elements stabilized around zero and within the estimated error of the observations (±0.03 m), indicating subsidence had mostly ceased. This stability has continued through May 2014.

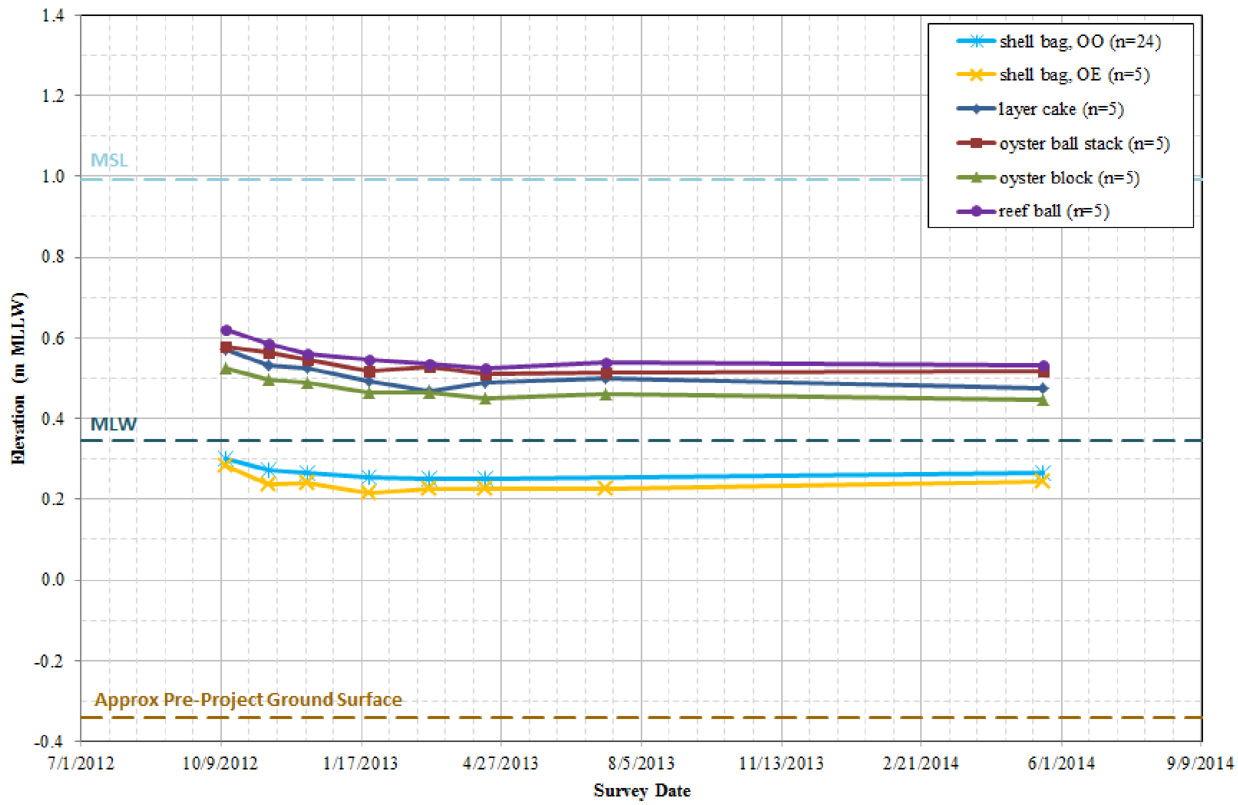


Figure 16. Element elevations over time at TNC. Note: the shell bag mounds are lower than the other four types of elements by approximately 0.25m

Since September 2012, approximately 0.08m of subsidence has been observed across the ELER site but, similar to TNC, the rate has not been constant (Figure 17). The average rate of subsidence at the site for the test elements from September 2012 to January 2013 was 0.02 ± 0.013 m/month. After January 2013, the rates of change decreased effectively to zero, similar to the TNC site.

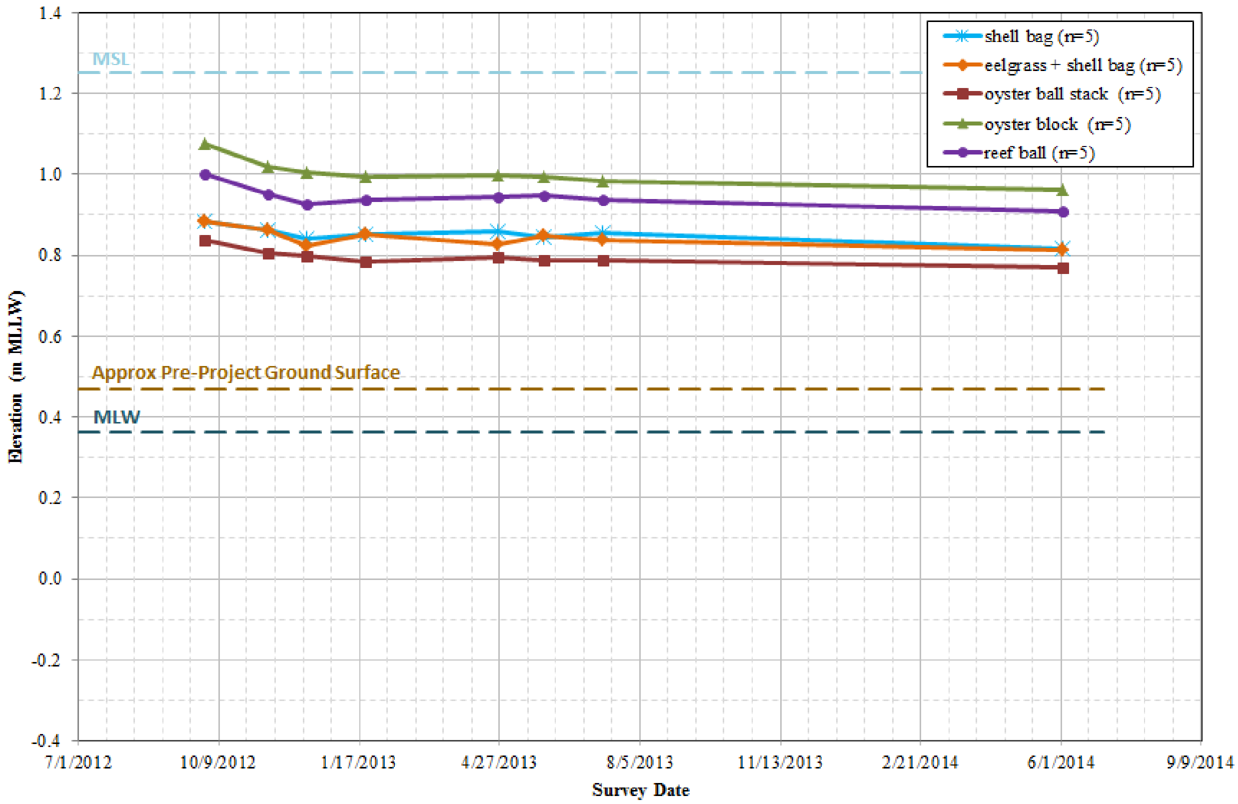


Figure 17. Element elevations over time at ELER.

3.2.3 Sediment Accretion and Erosion (TNC)

Sediment accretion and erosion monitoring results at the TNC site are presented in Figures 18, 19 and 20. The control plot had remarkably consistent sedimentation rates (Figure 18). An average of 0.044 m/yr of sedimentation occurred in the first year post-construction, and continued through the second year with an average of 0.042 m/yr of sedimentation.

The majority of the sedimentation within the treatment plots occurred during the first year, with rates slowing down considerably in the second year. During the monitoring period, the treatment plots have experienced more sedimentation than the control plot along the outside edges, but less sedimentation in the aisles between the elements. A significantly higher average of 0.170 m/yr of sedimentation occurred along the edge of the elements in the first year, but since then has slowed to 0.010 m/yr in the second year. This decrease similarly occurred in the center of the shellbag aisles, with an average of 0.034 m/yr in the first year, and 0.010 m/yr in the second.

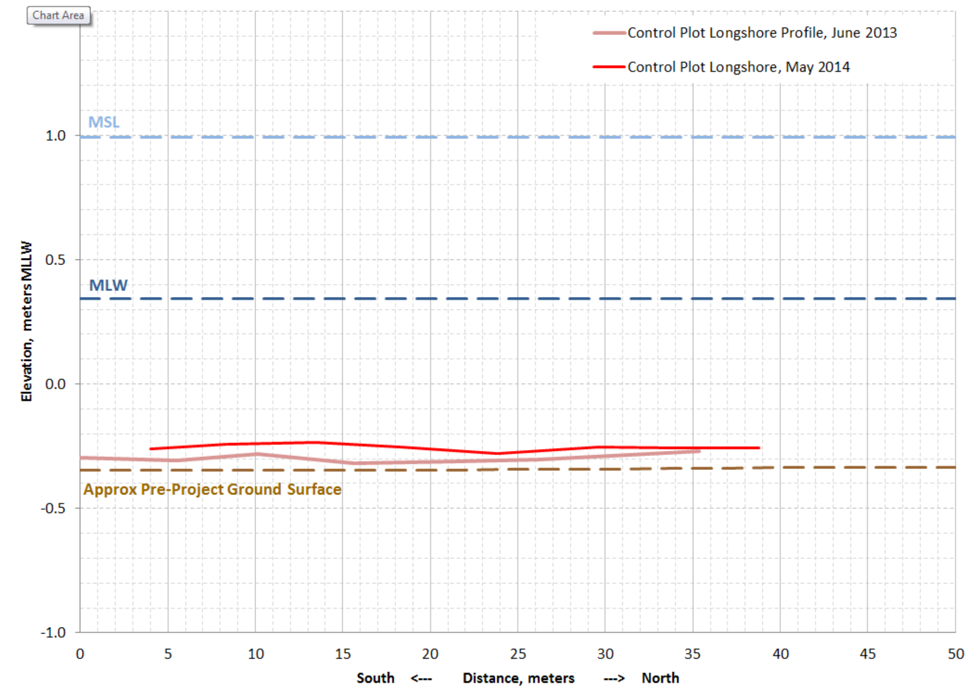


Figure 18. TNC control plot longshore profile.

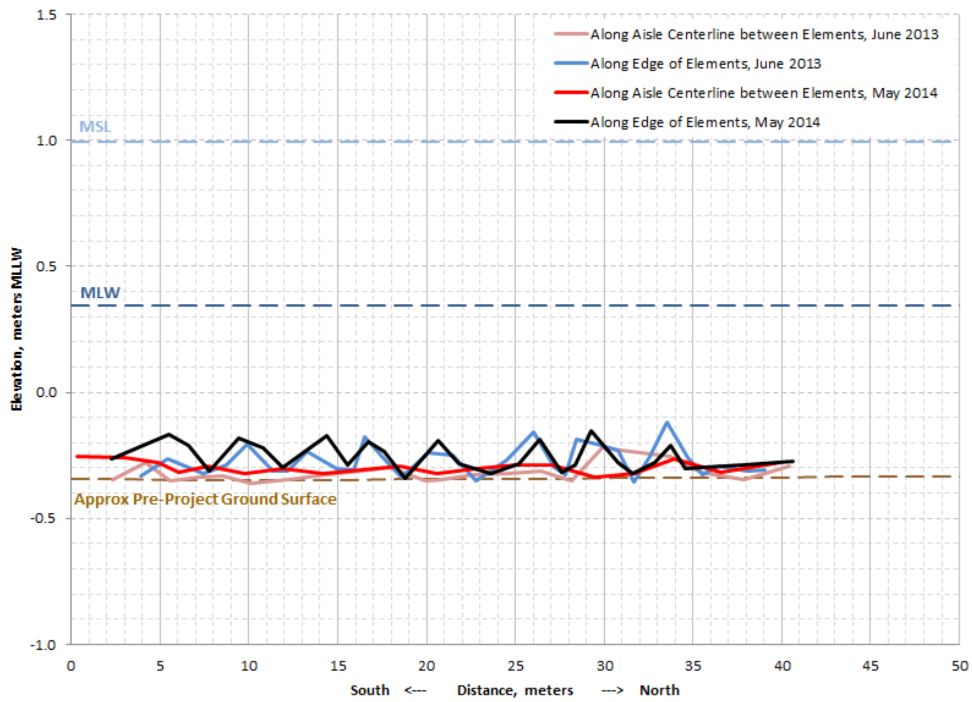


Figure 19. TNC oyster-eelgrass plot interior sediment profiles.

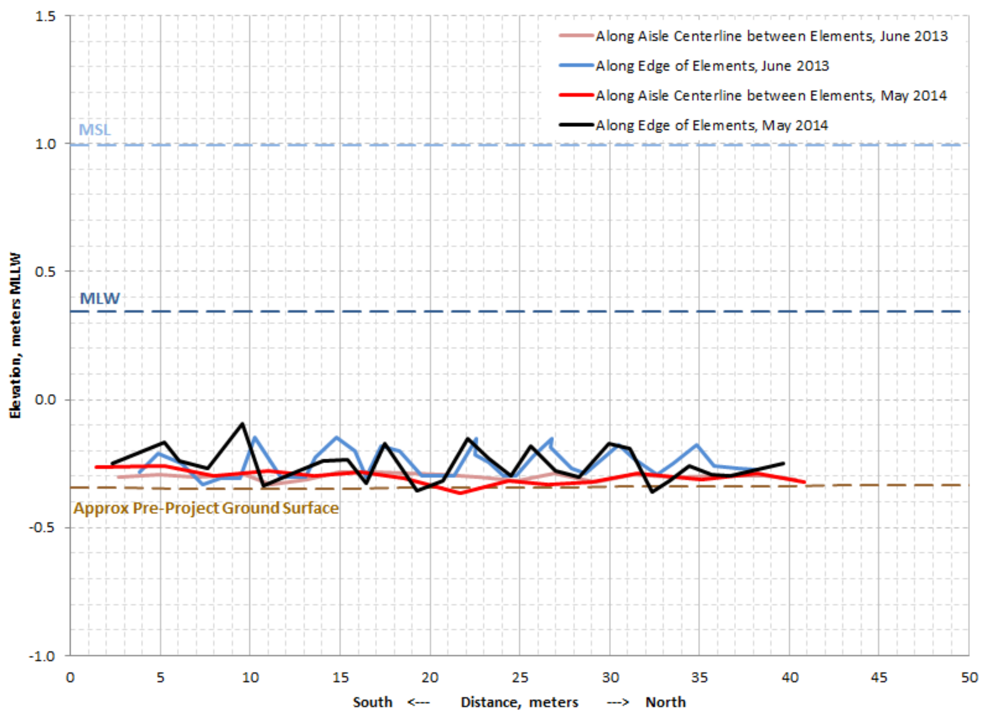


Figure 20. TNC oyster only plot interior sediment profiles.

3.2.4 Sedimentation and Oyster Availability (TNC)

The space available on each element for oyster settlement and growth was examined by combining the average shell bag elevation and sediment accumulation. Combining the subsidence measurement for shell bags from section 3.2.2 with the sedimentation measurements in section 3.2.3 allows an assessment to be made of the change of available space for oysters on each element (the distance between the sediment surface and the top of the element) (Figure 21). This space has decreased through time due to subsidence of the elements into the mudflat and accumulation of sediment adjacent to and inside the reef structure. Initially the tops of the shell bags were about 0.65 m above the surface in November 2012. By July 2013 this reduced to about 0.30m inside the reef and 0.40m outside the reef due to a combination of settling and accretion. After July 2013 subsidence had reduced significantly; the available space for the outer reef remained the same at about 0.40m and the elements on the inner reef increased slightly reflecting some adjustment in sedimentation.

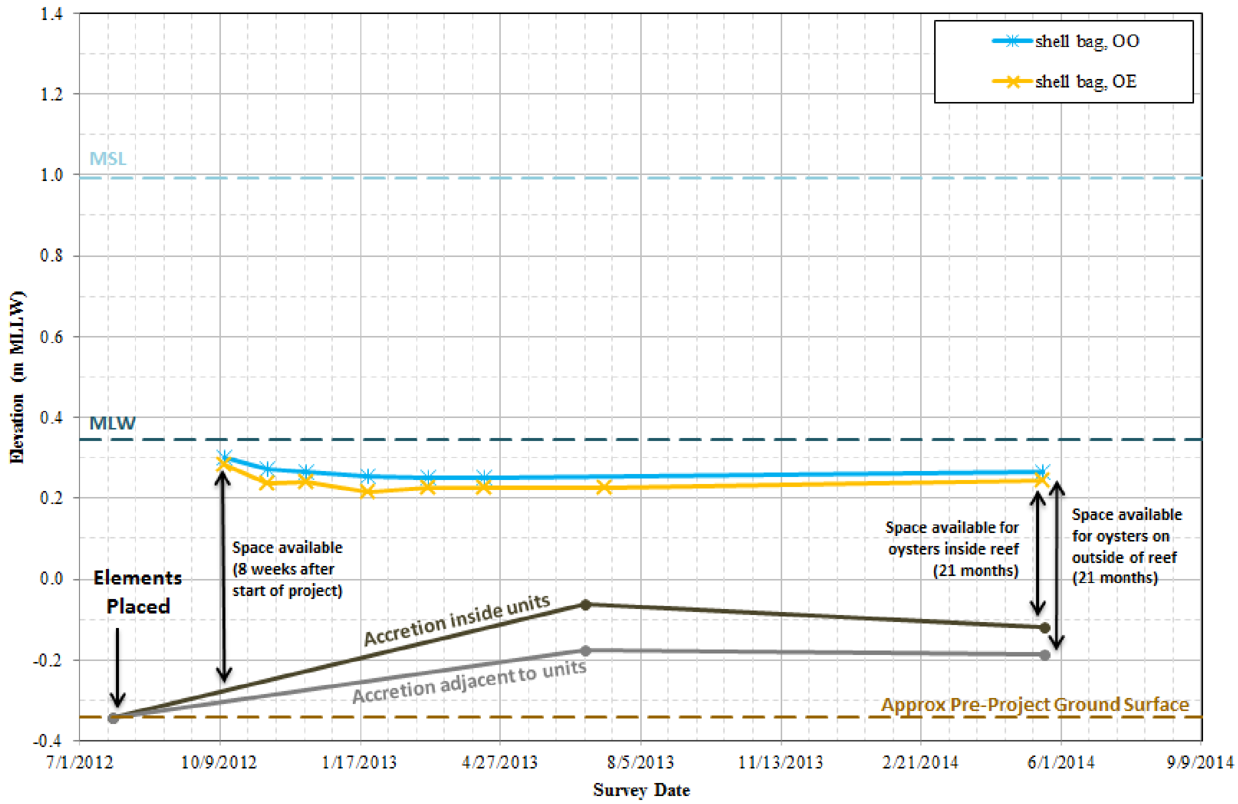


Figure 21. Sedimentation and oyster availability at TNC.

3.2.5 Photographic Documentation

There is currently only one set of photos, thus comparison between photo sets is not possible. In lieu of repeat photographs, photos of interest from May 2015 are presented in Figure 22.

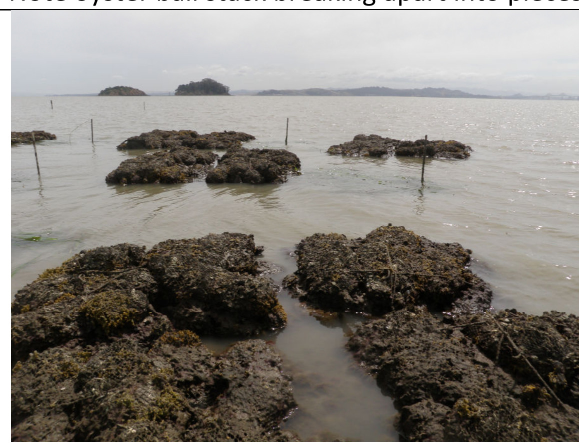
ELER Site	**TNC Site**
 Minor scour around shell bag.	 Note oyster ball stack breaking apart into pieces.
 Minor sedimentation around element in foreground.	 Note sediment level inside shell bags under thin layer of water. Oyster-eelgrass plot.

Figure 22. May 2014 photographic documentation.

4 List of Preparers

Damien Kunz, Project Manager
Jeremy Lowe, Project Director

5 References

In Situ (2013) http://www.in-situ.com/products/water-quality/troll-9500-instruments. In-Situ Inc, Fort Collins, CO.

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Wheaton, J.M., J. Brassington, S.E Darby and D.A. Sear. 2010. Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets. *Earth Surface Processes and Landforms,* **35**, 136-156.

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