THE EFFECTS OF SUSPENDED AND ACCRETED SEDIMENT ON THE MARINE INVERTEBRATE FOULING COMMUNITY OF HUMBOLDT BAY

By

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ABSTRACT

THE EFFECTS OF SUSPENDED AND ACCRETED SEDIMENT ON THE MARINE INVERTEBRATE FOULING COMMUNITY OF HUMBOLDT BAY

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Humboldt Bay, in far northern California receives a large amount of sediment, predominantly silts and clays from the surrounding watersheds at an estimated 62,532 metric tons/yr. (Barrett 2004). Fine grained sediments such as silts and clays have a high transport rate and remain in suspension longer than coarser sands and gravels, creating periods of high turbidity during winter rainfall events, which can last from a few hours to several weeks due to time lags following the event. While some of this sediment is washed out into the ocean, a large amount accumulates in the bay, which must be dredged annually by the U.S. Army Corps of Engineers to permit large commercial ships to move in and out of the bay. Winter rainfall events and human activity are the main drivers that elevate turbidity above normal background levels (>30 Nephelometric Turbidity Units; Shaughnessy and Williams 2005). We know very little about how the biological communities of Humboldt Bay respond to these extended disturbances of sediment suspension and deposition. Environmental Impact Assessments for dredging and development projects have provided some general information of potential impacts on select communities (U.S. Army Corps of Engineers San Francisco District, 2012), but direct effects of high (> 30 NTU) suspended and accreted sediment have not been rigorously tested. To address some of these gaps, the following study exposed naturally settled communities of sessile marine "fouling" invertebrates to 14-days of suspended or accreted sediment in a controlled laboratory setting, mimicking a high suspension event in Humboldt Bay. The experimental trials compared the effects of constant turbidity, generated by daily sediment addition at three treatment levels; Control (< 2 NTU), Low (20 NTU) and High (130 NTU). The role of surface orientation (vertical versus horizontal) was also explored during the 14-day turbidity trials to study the effect of sedimentation on communities by positioning panels either on the sides (vertical) or bottom (horizontal) of each tank. Average depths of sediment after 14-days of accretion for horizontal panels were ~3mm in the low and ~8mm in the high turbidity treatments. Overall, results showed the highest level of mortality was incurred in the high turbidity, horizontally oriented (~8mm final sediment accumulation) communities by organisms with low-profile (colonial ascidians; *Botryllus spp.*, *Botrylloides spp*.) or encrusting growth forms (*Celleporella hyalina*). Organisms with upright growth forms (*Bugula neritina, Bugula californica, Scrupocellaria diegensis*, *Ciona intestinalis*, and *Mytilus edulis*) within these same communities were largely unaffected by sedimentation and high turbidity. Communities oriented vertically in both the low and high turbidity treatments experienced no statistically significant mortality across all species in comparison with the control treatment. These results suggest that position/orientation and morphology (encrusting versus upright) play important roles in individual survival and overall community response during high turbidity events in Humboldt Bay.

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INTRODUCTION

Coastal bays and estuaries are highly dynamic systems with biological communities that have adapted to constant fluxes in their physical environment. Many of these organisms can tolerate a wide range of abiotic factors (including salinity, temperature, dissolved oxygen, light, and turbidity) however, these variables act strongly on the spatial and temporal distribution of individual species and community assemblages within these systems. The central focus of this study is to understand the impacts of one abiotic factor, sediment (from both suspended and deposited particles) on the sessile "fouling" invertebrate communities (so-called because they attach to the hulls of boats and other hard structures, "fouling" them) represented in the sub-tidal, nearshore environment of Humboldt Bay, California.

Sediment can be suspended and accreted through natural processes (e.g. tidal exchange, wave action, bioturbation and storm surges) and by anthropogenic disturbances (agriculture, development, deforestation, dredging, etc.). Humboldt Bay receives a large amount of sediment (predominantly silts and clays) from the Elk River and Freshwater Creek watersheds, particularly during winter storms, creating periods with a large amount of suspended sediments in the water column. In addition to natural surface erosion, activities associated with timber harvesting (e.g. deforestation, landslides, and roads) have intensified the amount of sediment loads added to Humboldt Bay from the surrounding watershed, estimated at an annual rate of 62,532 metric tons/yr. (Barrett

2004). Real time data loggers in Humboldt Bay have recorded turbidity between 30 and 200 Nephelometric Turbidity Units (NTU) during precipitation events (Shaughnessy and Williamson 2005, Swanson *et al.* 2013). As a result of the incoming sediment, annual dredging of the entrance channel by the U.S. Army Corps of Engineers is essential to maintain the fixed depth of the channel for shipping traffic into and out of Humboldt Bay (U.S. Army Corps of Engineers San Francisco District, 2012).

Annual dredging is usually carried out between April and June with two hopper dredges, *Yaquina* and *Essayons,* the latter fitted with anti-turbidity valves to reduce the environmental impact. In 2005, the Engineer Research and Development Center of the U.S. Army Corps of Engineers conducted a study to assess the overflow plumes created by the *Yaquina* hopper dredge, which lacks anti-turbidity valves. Turbidity levels were recorded at three different depths (< 3.5 m, 7.5 m and 10 m) after dredging in the North Bay Channel and the Samoa Channel within Humboldt Bay, California. Turbidities between 6 – 12 NTU were measured for the North Bay Channel, while turbidities between 100-150 NTU were measured for the Samoa Channel. The large differences in turbidity levels following dredging at these two sites were related to variation in sediment composition (Dickerson *et al.* 2005). Sediment in the North Bay Channel is 96.2% coarse grain sand, which settles quickly, while the Samoa Channel is predominantly fine sand and silt, resulting in longer periods of suspension (Dickerson *et al.* 2005). The most recent Environmental Impact Assessment conducted by the U.S. Army Corps of Engineers (2012-2016) concludes that any resulting turbidity from annual dredging operations will be localized and temporary and will therefore not have a significant impact on planktonic, mobile benthic, or fish communities. The impacts on sessile, sub-tidal communities were, however, not addressed by the current Environmental Impact Assessment and remain unknown.

In addition to annual Bay and Entrance Channel dredging inside Humboldt Bay, various development and restoration projects near the bay can create periods of high turbidity. A recent example includes the large-scale restoration project of the former G&R Metals salvage yard on the Eureka waterfront carried out between July and September 2013. The upland area and adjacent intertidal mudflats were contaminated with PCBs (polychlorinated biphenyls), metals and PAHs (polycyclic aromatic hydrocarbons) and required dredging to remove all contaminated sediments (Humboldt Baykeeper) from this site. During this period of intertidal dredging, the nearby CENCOOS data logger recorded elevated turbidity levels >50 NTU for approximately 10 days (end of July – early August). At this time, experimental panels attached within nearshore, sub-tidal locations under the docks at the Woodley Island marina (directly across from the project site) and at the Eureka Public marina accumulated a large amount of sediment (>2.5 cm thick) over several weeks. These experimental panels were part of a study to examine juvenile colonies of the invasive bryozoan *Waterispora subtorquata,* and following this period of high sediment suspension and accretion all 500 colonies across three separate locations died (personal observations). The extent of invertebrate monitoring for this local restoration project included only two sample locations (one at the dredge site, the other at a control site) before and after dredging, and examined exclusively benthic, infaunal species (personal communication; Dan Berman, Director of Conservation for the Humboldt Bay Harbor District, Dan Berman). Invertebrate species in the water column or attached to hard substrates, which may have been indirectly affected by the suspended, contaminated sediments, were not assessed.

The effect of suspended and accreted sediment on marine invertebrate species can be quite significant as the previous scenario suggests. Past studies from around the world have indicated substantial effects of natural and artificially elevated levels of sediment suspension and deposition on invertebrate species and communities in coastal and estuarine ecosystems (Round *et al.* 1961, Bakus 1968, Moore 1977, Young and Chia 1984, Saiz-Salinas and Urdangarin 1994, Naranjo *et al.* 1996, Slattery and Bockus 1997, Saiz-Salinas and Urkiaga-Alberdi 1999, Maughan 2001, Ellis *et al.* 2002, Hinchey *et al.* 2002, Miller *et al.* 2002, Reid *et al.* 2013, Airoldi 2003, Carballo 2006, Burton and Johnston 2010, Roberts 2012).

Natural, seasonal sedimentation on tropical sponge assemblages in the Bay of Mazaltan, Mexico, reduced diversity and shifted the community from a relatively mature, stable state of large branching sponges to a more unstable, to a less stable, less diverse community of encrusting and boring sponges that were better adapted to disturbances (Carballo 2006).

Naranjo *et al.* (1996) found that sedimentation was a stressor that determined the abundance and distribution of a variety of ascidian species in the Algeciras Bay of Spain, while Young and Chia (1984) discovered that sediment accumulation was closely linked to high levels of post-settlement mortality in six different species inhabiting the San Juan

Islands in Washington State. The authors identify sedimentation as one of the major selective pressures influencing negative phototactic behavior in ascidian larvae.

Reid *et al.* (2013) compared the effects of terrigenous sediment additions on the macrobenthic invertebrate species associated with a stream system and an adjacent estuary in Whangapoua Harbor on the North Island of New Zealand. This study found that estuarine species were more heavily impacted by accumulated sediment, which caused significant declines in invertebrate densities and changes to the community structure 16 days after experimental sediment addition.

The study of re-suspended contaminated sediment on marine invertebrates in the lab and field has expanded in recent years due to the growing concern of human impact on our coastal systems and the advancement of methods and technologies now available in the field of marine biochemistry. Some benthic invertebrates have been identified as useful bio-indicators for the presence or absence of pollutants in aquatic systems. Filter feeders (i.e. sponges and bivalves) that readily accumulate heavy metal contaminants within their tissues are being studied for their use in bio-monitoring programs for water quality management (Oros *et al.* 2005, Negri *et al.* 2006, Knott *et al.* 2009, Edge *et al.* 2015). Contaminated sediments have been linked to lethal and sub-lethal effects in bivalves, marine gastropods and polychaete worms (Roberts 2012). Knott *et al.* (2009) studied the long-term re-suspension of contaminated sediments on sessile invertebrate species in response to a large-scale dredging operation in Port Kembala, Australia. This study found that sessile invertebrate recruitment was inhibited for four months following an extensive dredging event there.

Several studies have compared the effects of sediment burial on marine invertebrate species with different levels of mobility, and have found that sessile invertebrates are the most heavily impacted by accreted sediment (Miller *et al.* 2002, Hinchey *et al.* 2006). Sessile invertebrates are particularly vulnerable to environmental change, as they cannot escape their surroundings. These species have instead adapted to a range of behaviors and morphological features that enable them to feed on plankton and filter out excess solids found within the water column (Riisgard and Larsen 2000). Some species have finer filter-feeding mechanisms (i.e. *Bugula neritina*) relative to other, non-selective filter feeders (i.e. *Ciona intestinalis*), and therefore species are likely to vary in their ability to cope with extra sediment during a high suspension event.

Inorganic particulates in the water column can directly inhibit feeding due to clogging of feeding appendages (Round *et al.* 1961). Bakus (1968) noticed a rapid decline in growth and survivorship of sponge and ascidian species due to burial and clogging of aquiferous canals during several weeks of sediment deposition along the edge of a lagoon on Fanning Island in the central Pacific. Long-term exposures to suspended sediments can shift energy away from growth and reproduction in bivalves due to excess energy spent sorting out inorganic particles (Ellis *et al.* 2002). Suspended sediments can also indirectly inhibit feeding and physiological condition by altering the physical environment: increasing water temperatures, reducing dissolved oxygen and light attenuation (integral for phytoplankton health: see Bilotta and Brazier 2008).

The status of sessile filter-feeding communities can be seen as a direct reflection of local aquatic conditions as the species composition of these communities often fluctuates with changes in the physical environment (Saiz-Salinas and Urdangarin 1994), and filter-feeders create many biological links throughout the food web. These organisms serve a pivotal role in aquatic systems by maintaining water quality (Officer *et al.* 1985), directly regulating primary production (reducing eutrophication), indirectly regulating secondary production and providing complex three-dimensional habitats with heterogeneous flow regimes that cultivate rich, diverse communities. (Gila and Coma 1998).

Despite multiple lines of evidence (above) that suggest that dredging and other human activities can have major impacts on marine communities, the impacts of suspended sediments on the biological community in Humboldt Bay, California, have yet to be explored. A previous multi-year study conducted at the Woodley Island Marina in Humboldt Bay indicated distinct, seasonal fluctuations in the abundance and diversity of the local marine invertebrate community. Results from this study showed dramatic die offs (and concomitant increases in bare space) during winter months which coincided with high sediment loads (Boyle *et al.* 2004). While these results suggest that high levels of suspended sediments may reduce species abundance, this potential causal relationship has not been rigorously tested in a controlled laboratory setting.

In an effort to understand the direct impacts of sediment on marine invertebrate communities I conducted a series of controlled laboratory experiments to examine the effects of sediment as it occurs in suspension and accretion on sessile marine fouling communities from Humboldt Bay, California. Communities (assembled either artificially from collected species or naturally onto settlement plates suspended under docks in Humboldt Bay from May – September 2014) were exposed to daily sediment additions mimicking turbidities that occur in the field during normal tidal exchange (background turbidity) as well as during a high suspension event (turbidity levels comparable to winter precipitation or dredging event) for approximately two weeks. Based on previous studies and limited findings for Humboldt Bay, I tested the following hypotheses:

a) communities exposed to high turbidity will be negatively affected (reduction in weight, survivorship, and elevated partial mortality of species within them) relative to those in the low (background level) or control (no sediment) treatments and b) communities oriented on the bottom (horizontally) will accumulate sediment and be more negatively affected than those held vertically, on the side of lab tanks.

METHODS

Three separate trials were conducted to test the effects of suspended and accreted sediment on sessile marine fouling invertebrate communities at the Telonicher Marine Lab in Trinidad, CA. Species attachment and composition varied between these trials and captures some of the natural seasonality that occurs in Humboldt Bay.

For the first trial, organisms were collected and communities were artificially assembled before the start of the laboratory experiment, which ran from June 10 – July 2, 2014. This trial will herein be referred to as the "Artificial Community Trial". The second trial was conducted from July 14 – 27, 2014 and tested invertebrate communities that settled naturally over the span of two months in the spring (May-June) onto PVC panels deployed under the docks at the Woodley Island Marina in Humboldt Bay. This trial will herein be referred to as the "Spring Community Trial". The third trial conducted in the laboratory from September 19 – 28, 2014 tested naturally settled communities (using similar PVC panels) from late July– Sept and will herein be referred to as the "Summer Community Trial".

Pre-Trial Community Assembly and Assessment

Artificial Community Trial

Communities for the Artificial Community Trial were assembled at the Telonicher Marine Lab from species collected under the docks at the Woodley Island Marina in Eureka, CA on June 1st, 2014. A total of 60 community panels were assembled.

These communities included the following four species, with the number of individuals per panel in bold:

- *Mytilus edulis* (**2** mussels: (1) one 1.5 cm in size and the other (2) 3.5 cm in size),
- *Halichondria spp.*(**1, ~** 2.5 cm in length and 1 cm wide),
- *Watersipora spp.* (**2** colonies, each 1-2 zooids in size),
- *Scrupocellaria diegensis* (**2** colonies, each approximately 1.5 cm in height with 5-10 upright branches).

Organisms were arranged on 10 cm x 10 cm PVC panels in the laboratory with a 2 cm border of free space around the outer edge (see Figure 1). Each individual organism was randomly assigned a 2 cm x 2 cm grid cell in the center of the panel.

The condition of each organism was assessed before attachment. The length of each mussel was measured from the anterior tip of the umbo to posterior edge of the shell to ensure representation of two size classes; 1.5 cm and 3.5 cm. Mussels were individually attached to the experimental PVC panels with a small amount of Super Glue. Shortly after application, these mussels attached themselves by secreting byssal threads to the panel.

Sponges were weighed before the experimental trial. Each individual sponge was patted dry and weighed on a petri dish (wet weight). One sponge was secured to each panel using a small, rectangular belt attached to the panel with hot glue made from 2mm plastic mesh screening.

In order to establish small *Watersipora* spp. colonies on experimental panels, adult colonies were collected from the Woodley Island Marina in Eureka, CA and kept in the dark at the Telonicher Marine Lab. When exposed to intense light, these adult colonies will release free-swimming larvae during their reproductive season (approximately late March – November). To acquire small colonies for this study, light was shined intermittently on two large adult colonies in separate tanks in order to induce larval release. Within 24 hrs. of release the free-swimming larvae settled onto plastic sheets that were placed on the sides of these tanks. Two small (1-2 zooid) colonies were cut out of these plastic sheets and the back of the plastic was adhered with Super Glue to each experimental panel. Macro photographs were taken of each colony before the trial began using an Olympus camera (model DP12) attached to a dissecting microscope.

Two small colonies (~5- 10 branches) of the arborescent bryozoan species, *Scrupocellaria diegensis* were attached to the experimental panels by the bottom stalk of the colony with a small amount of Super Glue. In order to assess whether these colonies were alive on a given sampling date, the first 5 zooids below the growing tips on four randomly selected branches were assessed from each colony for vibracular movement.

Once communities were assembled, panels were submerged in seawater and photographed. Each panel was fitted with Velcro backing so that they could be randomly assigned to the side or bottom of the experimental tanks (Figure 2).

<u>Spring Community Trial</u>

On May 12th, 2015, 60 PVC panels (10 cm x 10 cm) were bolted to two racks (30 per rack) constructed from PVC piping (Figure 3). I attached the racks to the side of a floating dock at the Woodley Island Marina (40.8°N, -124.16°W). Panels were submerged 1 meter below the surface, face down to collect natural settlement of organisms from May to mid-July.

Panels were removed before the start of the laboratory trial and transported in seawater to the Telonicher Marine Lab. Velcro was adhered to the back of each panel. Each panel was then submerged in a small container of seawater and photographed to assess pre-trial species composition and cover. Pre-trial species composition and cover were quantified using a randomly stratified point intercept method to identify species under 50 randomly-generated points on the photograph with the photo analysis program, PhotoGrid. Values for percent cover were calculated by dividing the number of occurrences for a particular species by the total number of points (50). Multiple, 2-way ANOVAs were generated to determine whether the difference in mean values of pre-trial percent cover were significantly different across turbidity treatments and panel orientations (Table 1). No significant differences in initial species composition and cover (including bare space) among treatments were found.

Spring communities were dominated by three different genera of sheet-like, colonial ascidians; *Botrylloides sp., Botryllus schlosseri,* and *Didemnum sp.,* as well as two arborescent bryozoan species; *Bugula neritina* and *Bugula californica* and two encrusting bryozoan species; *Celleporella hyalina* and *Watersipora subtorquata* (Figure 4).

<u>Summer Community Trial</u>

The same methods of field collection for naturally settled invertebrate communities used in the spring trial were again used for the Summer Trial. On July 20th, 2014, 120 (5 cm x 5 cm) PVC panels were attached to the same collection racks and submerged at the same field location for approximately 2 months (Aug – Sept). Note that smaller panels were used for this trial to increase replication within experimental lab tanks.

Panels were transported to the Telonicher Marine Lab on September 17th, 2014 where they were individually photographed. Summer community panels were dominated by three arborescent bryozoan species; (1) *Bugula neritina,* (2) *Bugula californica*, and (3) *Scrupocellaria diegensis*, as well as the encrusting bryozoan, *Celleporella hyalina,* and the solitary tunicate, *Ciona intestinalis* (Figure 5).

Pre-trial assessments were done for the arborescent bryozoan species. I randomly selected four colonies per panel to assess the percentage of living zooids within them. For each colony, 20 random zooids per colony were examined. The numbers of live zooids (indicated by lophophore and/or vibracular movement) out of 20 were recorded, and empty (dead) zooecia were also recorded. The presence or absence of ovicells across the whole colony was recorded to track reproductive status pre and post-trial.

Sediment Collection

Sediment was collected (< 2 cm below surface) from Humboldt Bay at the Woodley Island Marina during low tide before the start of each trial. Sediment was sieved through a 2 mm mesh screen to eliminate any large debris. Sediment was diluted with filtered seawater in a 20-liter carboy and aerated for 24 hours before each trial began. Sediment aeration continued for the duration of each experiment (Figure 6).

Experimental Design

To test the effects of suspended and accreted sediment on sessile invertebrate communities, 8-liter closed-system tanks were set up at the Telonicher Marine Lab in Trinidad, CA with four, 6-inch air stones placed along the bottom perimeter of each tank to keep sediment in suspension during trials. Panels were either attached via Velcro to the side of the tank (vertically) or to the bottom (horizontally). A tube connected to a phytoplankton drip system was placed in each tank for the duration of each experiment to supply these organisms with food during the course of these experiments (See Figures 2 and 6).

The Artificial Community Trial commenced on June 10, 2014 and ran for 22 days. A total of 20, 8-liter tanks were used for this trial and included 5 replicate tanks for each of 4 treatments. The tanks were arranged randomly in the sea tables to account for location effects. Each closed-system tank was randomly assigned to one of four sediment treatments measured in Nephelometric Turbidity Units (NTU): (1) low (20 NTU), (2) mid (70 NTU) and (3) high (200 NTU) or (4) a control (< 2 NTU) which lacked sediment. Sediment treatment levels were chosen to mirror conditions found in Humboldt Bay, from background turbidity levels (experienced during an average tidal cycle) to peak levels reached during a storm event (see Figure 7). Panels were oriented on either the bottom or side of each tank. Two community panels were attached via Velcro to the side of each tank adjacent to one another, and one panel was placed on the bottom of the tank. At the end of 10 days, one side panel was removed from each tank for assessment. The remaining side panel and bottom panel were removed after 22 days to assess whether there was a significant effect of time, treatment and orientation.

Spring (7/14/14-7/27/14) and Summer Community (9/19/14-9/28/14) Trials both ran for 14 days. A total of 30, 8-liter tanks were used for these trials and included 10 replicate tanks of 3 treatments[1]. Each closed-system tank was randomly assigned to either (1) a low (20 NTU) or (2) a high (130 NTU) sediment treatment or (3) a control treatment (< 2 NTU) without sediment. One side panel and one bottom panel were attached inside each tank in the Spring Community Trial and two side and two bottom panels (four total) were attached inside tanks in the Summer Community Trial (to increase replication in the final lab trial).

Phytoplankton Drip System

Two species of phytoplankton (*Tetraselmis sp.* and *Isochrysis sp.*) were cultured at the Telonicher Marine Lab. Two 20-liter carboys were attached to a drip system in the wet lab and these automatically dispensed 150 ml per tank, twice a day (timer set at 5 am and 5 pm) for a total of 300 ml/day of phytoplankton. A Fuchs Rosenthal UltraPlane 1/16 sq. mm/10mm deep slide was used to determine average cell counts which varied

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[1] Note: The “Mid” sediment treatment used in the Artificial Community Trial was discontinued because analysis showed no significant differences of treatment effect between the “Low” and “Mid” treatments or between the “Mid” and “High” treatments. Removing the “Mid” treatment increased tank replication from an n= 5 to n=10 for treatments used in the Spring and Summer Community Trials.

throughout the trials (Table 2). In order to complete these counts, cells were killed with a small amount of Lugo's solution. If low cells counts occurred (< 100 cells per 4x4 square) an average of three large 4x4 squares was recorded.

Daily Monitoring

For all trials I monitored the turbidity, temperature, salinity and dissolved oxygen levels at mid-day before daily sediment additions (Table 2). A Hach 2100Q Turbidimeter was used to measure turbidity from a 20 ml water sample taken from each replicate tank. A handheld Yellow Springs Instrument (YSI) model 85 was used to measure temperature (C°), salinity (ppt) and dissolved oxygen (mg/L). The aerated sediment was manually stirred to re-suspend any settled particles and to create a homogenized slurry before adding it to the experimental tanks. Daily sediment additions were necessary in order to maintain turbidity levels specific to each treatment.

Post-Trial Assessment

After the completion of each trial, all side panels were gently rinsed with filtered seawater, submerged in water and photographed. Bottom panels that had accumulated sediment throughout the trials were photographed twice, once when initially removed from their tank (accumulated sediment intact) and again after panels were rinsed with seawater. The maximum depth of accumulated sediment on each bottom panel was recorded in millimeters.

Individual species within the Artificial Communities were re-assessed at the end of the experiment. Wet weights for *M. edulis* and *Halichondria sp*. were recorded. Macro photographs of *W. subtorquata* colonies were taken post-trial with an Olympus camera, model D12 (attached to a dissecting scope) to quantify survivorship and calculate their size. The ratio of dead/live zooids out of 20 randomly chosen zooids for *Scrupocellaria diegensis.* Was recorded.

Percent cover for species in the Spring Communities were calculated using two different programs for photo analysis: MatLab and PhotoGrid. Methods for each program are described below.

MatLab analysis

The total live areas of colonial ascidians, before and after treatments, were calculated using the program MatLab. The program, according to specific thresholds, assessed each pixel within the panel's image. Thresholds were manually set to include the color spectrum associated with living colonial ascidians (hues of red, yellow and orange). All pixels within this threshold appeared white and everything else, not within the threshold appeared black in a second image generated by this software program. Within the MatLab code, the percent cover of colonial ascidians was calculated from this second image using the following formula:

$$\frac{\text{white area (live zooids)}}{\text{black area (everything else)}} = \text{fractional cover} * 100 = \text{percent cover of colonial ascidians}$$

Images before and after treatment were assessed using this method and the difference in percent cover was calculated. The first ten images were visually assessed to ensure that the threshold was accurately identifying live areas of colonial ascidians when compared to the original photographs. To check the accuracy of the MatLab calculations further, a second program, PhotoGrid was used to determine percent cover of colonial ascidians and the results were compared statistically to test for differences among mean values between the two different methods.

PhotoGrid analysis

PhotoGrid beta 1.0 was used to determine the percent cover of all species on the Spring Community panels. Images were cropped to include only the panel (eliminating the background). The program generated 50 randomly stratified points across each image. An open circle with cross hairs represented a stratified “point”. The species or bare space that was underneath each of these cross hairs was identified. The output from the program was saved to an Excel file to calculate fractional and percent cover. For the purposes of this study, all colonial ascidian species were grouped together because although one species, *Botrylloides spp.* predominated, there were other ascidians as well (including *Botryllus schlosseri,* and *Didemnum spp*). Species that occurred infrequently across panels and made up <2% of the total percent cover were not considered as part of the focal group of species in the community, and were therefore not included in analyses of percent cover.

Summer Communities were dominated by the following species: *Ciona intestinalis* (a solitary tunicate), *Bugula neritina, Bugula californica,* and *Scrupocellaria diegensis* (three arborescent bryozoans) and *Celleporella hyalina* (an encrusting bryozoan).

All *C. intestinalis* were alive before and after the 2-week summer trial, across all sediment treatments and orientations (side and bottom panels). Sub-lethal effects were not quantified for this species.

The arborescent bryozoans were re-assessed post-trial using the same protocol as described in the pre-trial assessment, noting the ratio of live/dead zooids amongst 20 randomly selected zooids, as well as the presence/absence of ovicells (reproductive status).

To assess the effect of each treatment on *C. hyalina*, survivorship was calculated by dividing the number of live colonies post-trial by the total number of pre-trial colonies (Note: All colonies were alive before the trial commenced). The condition of each colony was assessed from macro-photographs taken of each panel before and after the trial using an Olympus PowerShot SX120 IS.

Statistical Analysis

All statistical analyses were conducted using the program R, version 3.1.2. A one-way ANOVA was used to test whether significant differences occurred across treatments for each of the physical parameters measured daily – turbidity, salinity, temperature, and dissolved oxygen. Mussel survivorship in the Artificial Community trial was analyzed using a generalized linear model (GLM) for binomial data using the logit link function, comparing turbidity treatment and orientation with two categories, “Alive” and “Dead”. To compare change in wet weight across treatments for mussels and sponges in the Artificial Community Trial, ANOVA was used for both 10-day (one-way ANOVA) and

22-day panels (two-way ANOVA). The natural log transformation was used to redistribute the data and meet the assumptions of normality for these ANOVAs. Panel orientation (side and bottom) was an independent variable for the 22-day panels in this trial, hence a 2-way ANOVA was run (note: only vertical panel orientation was measured for 10-day panels). For *Watersipora spp.* colonies within the Artificial Community trial one generalized linear model was created to assess the effect of sediment treatment on colony condition (alive, partially dead or dead) for the 10-day side panels and a second model was created to test the effect of sediment treatment and panel orientation on colonies in the 22-day panels. Both models compare the number of live colonies versus dead colonies across treatments. For the purpose of the GLM, partially dead colonies were grouped with the dead colonies.

For the Spring Community trial, two-way ANOVAs were used to compare differences in percent cover across treatments and panel orientations. When p-values indicated a significant difference in means, Tukey’s HSD (honest significant difference) post-hoc test was used to determine where the differences occurred. Paired t-tests with pooled variances were used to determine whether significant differences in percent cover, before and after the Spring Community trial, occurred for individual species within the same treatment group. Survivorship of *C. hyalina* in the Summer Community trial and reproductive status of arborescent bryozoans were compared across turbidity treatments and panel orientations using a generalized linear model.

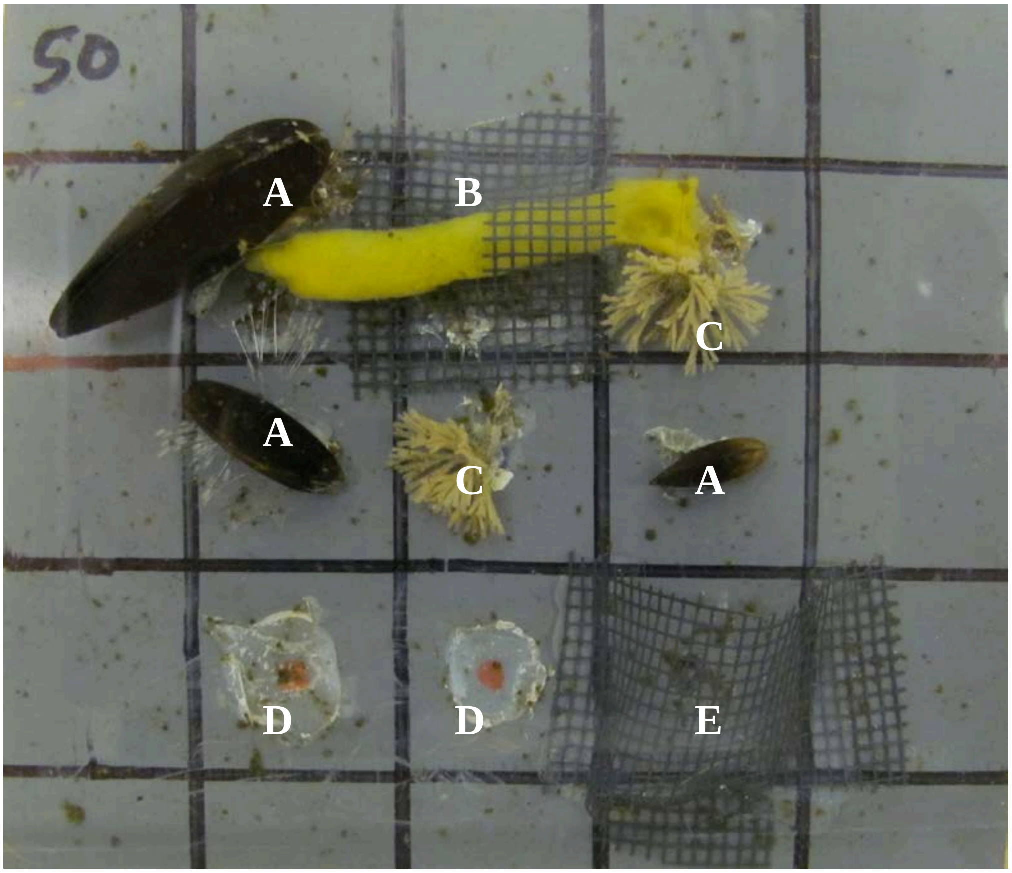


Figure 1 Artificially assembled communities from organisms collected in Humboldt Bay. Species include: (A) *Mytilus edulis*, (B) *Halichondria sp.*, (C) *Scrupocellaria diegensis*, and small (D) *Watersipora spp.* colonies. Note: The black mesh cage on the bottom right was intended for *Ciona intestinalis*, but due to the contractile nature of this species, it would not remain in the cage and had to be eliminated from this trial (E).

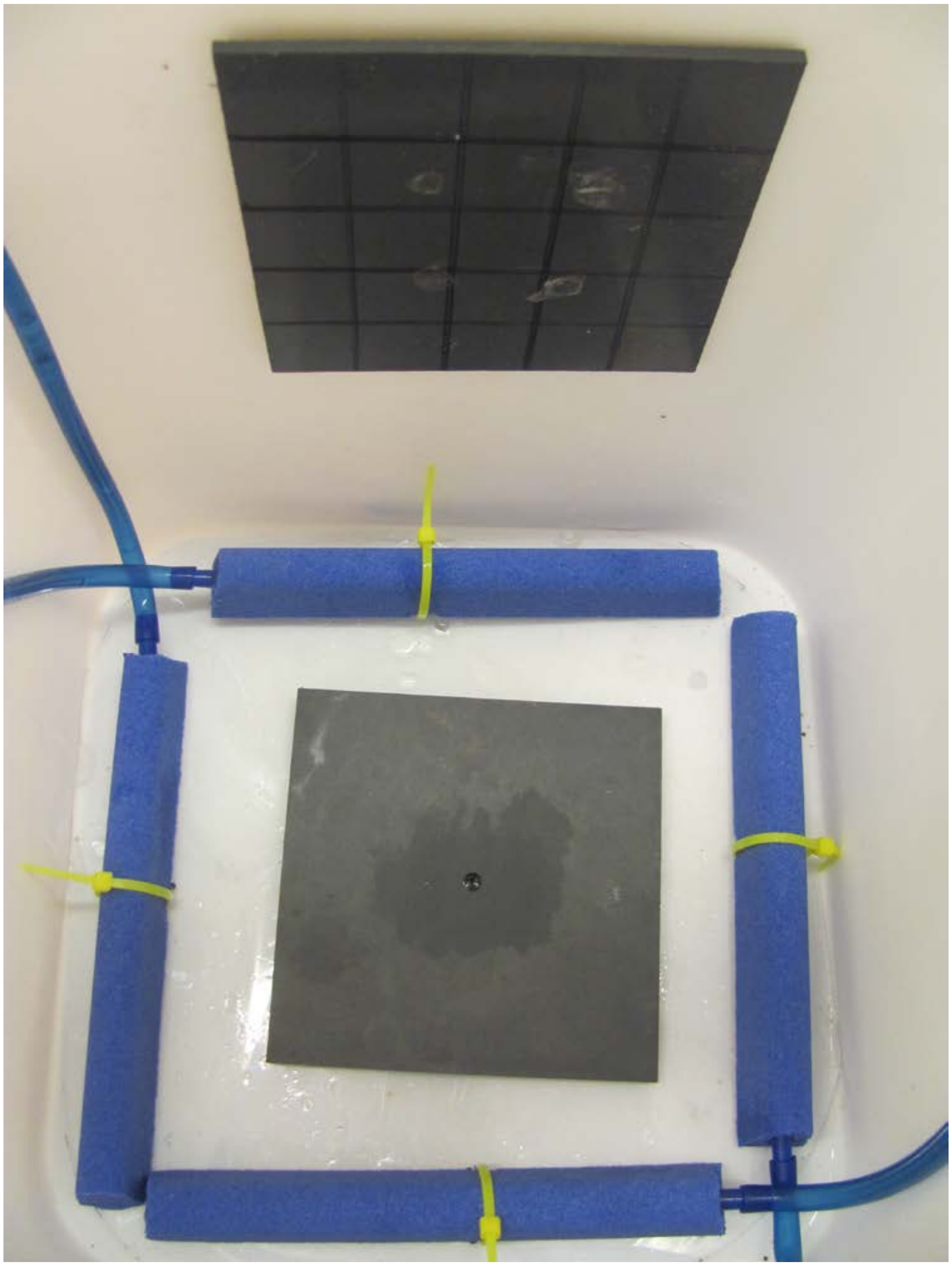


Figure 2 Representation of panel orientations for experimental communities (side and bottom positions) in each replicate tank. Four, 6-inch air stones lined the bottom of each tank to maintain turbidity levels throughout each trial by keeping sediments in suspension.

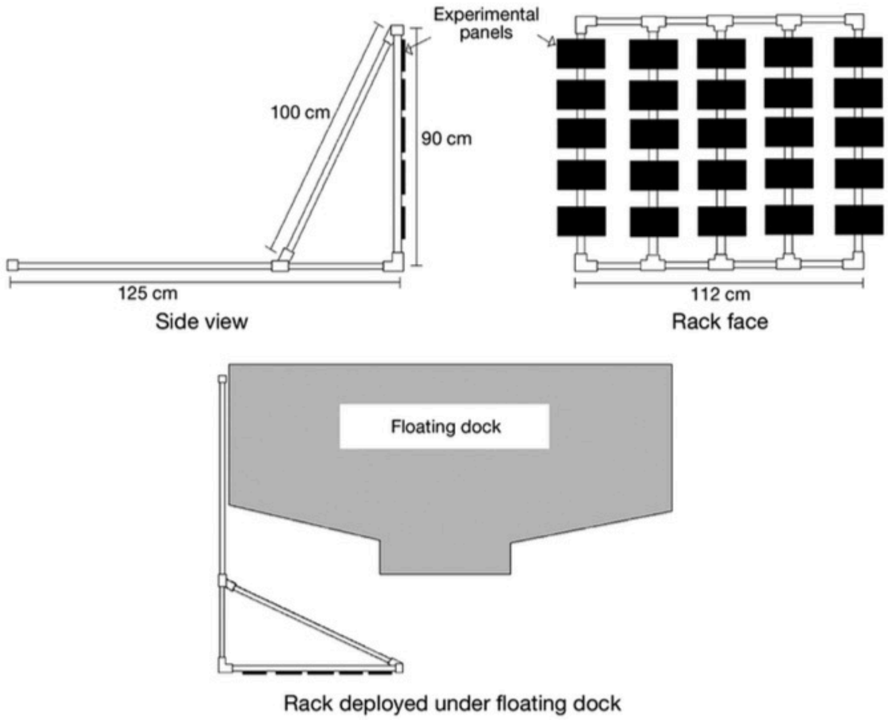


Figure 3 A schematic view of the PVC collection racks used for the Spring and Summer Community Trials. Actual panel sizes and numbers varied for the Spring trial (60, 10cm x 10 cm panels) and the Summer trial (120, 5cm x 5cm panels). Figure accredited to Matt Nelson (Nelson and Craig, 2011).

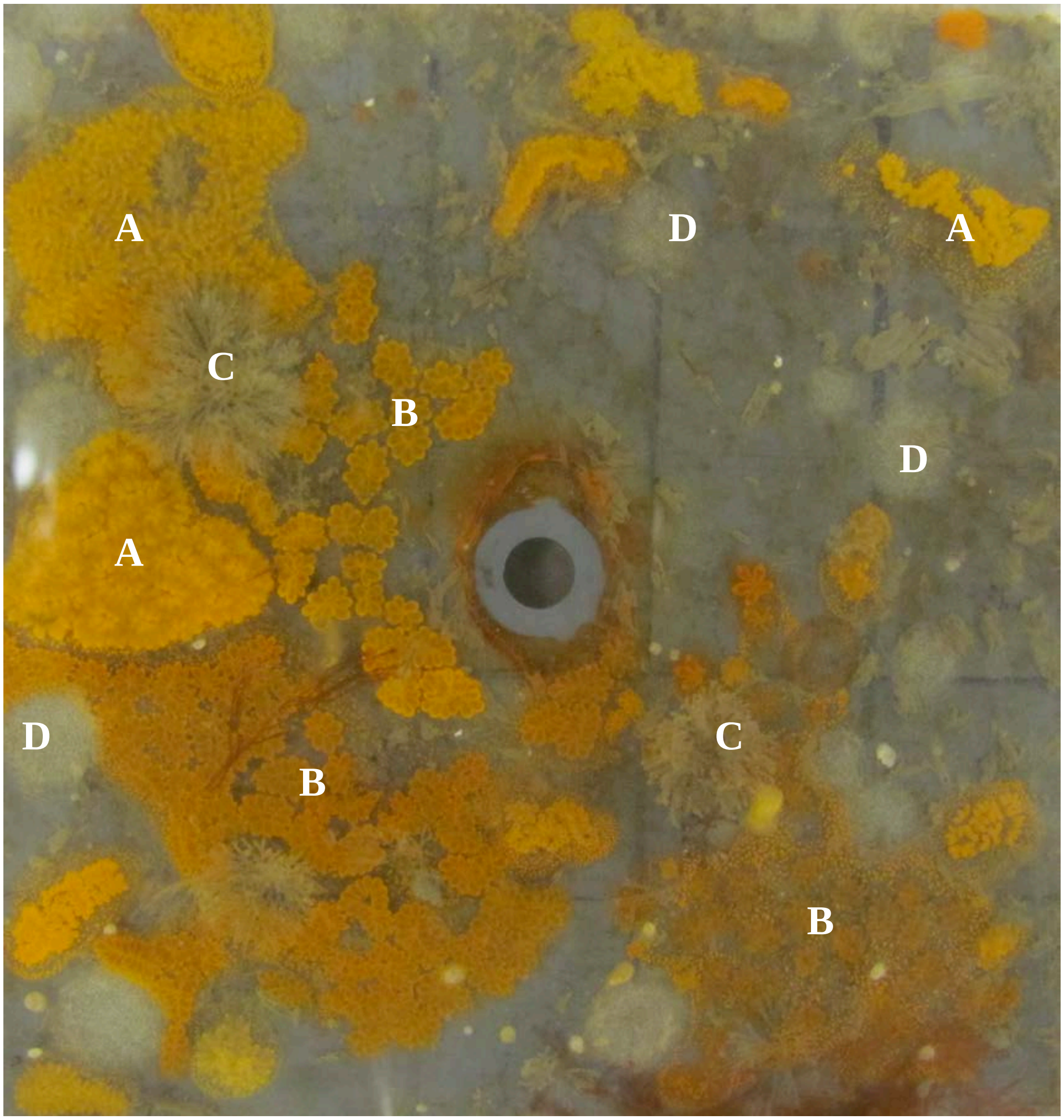


Figure 4 One experimental panel representative of the Spring Community Trial. Panels (60 in total, each 10 cm x 10 cm in size) were attached to PVC racks with stainless steel bolts and submerged ~1m. below the surface of the water in Humboldt Bay at the Woodley Island Marina in Eureka, CA from mid-May to mid-July 2014. These panels received natural recruitment of invertebrates during that time period, prior to the start of lab experiments. The following species are labeled in the above photo: (A) *Botrylloides sp.*, (B) *Botryllus sp*., (C) *Bugula californica*, and (D) *Celleporella hyalina.*

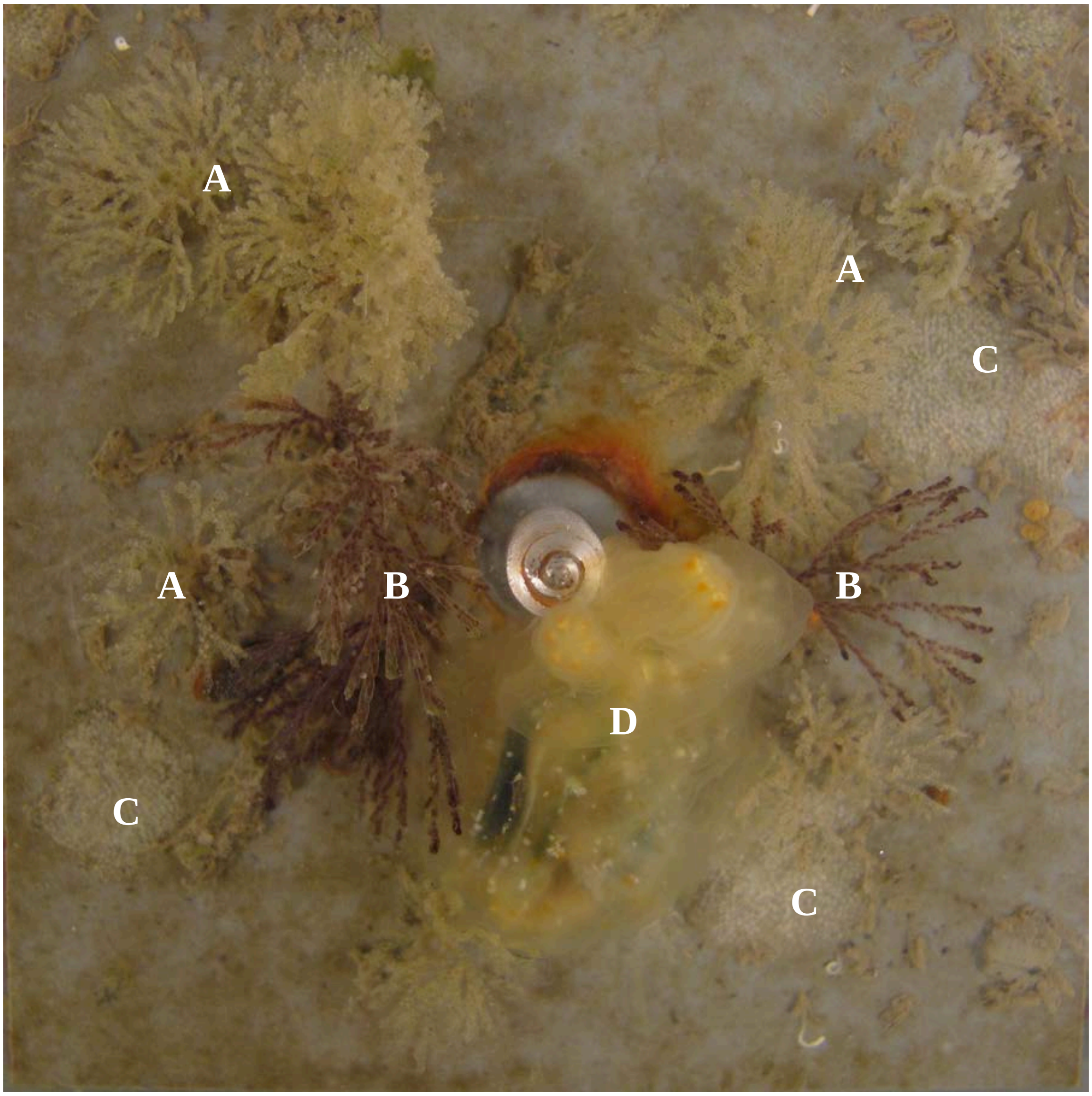


Figure 5 One experimental panel representative of the Summer Community Trial. On July 20th, 2014, 120 (5 cm x 5 cm) PVC panels were attached to the same collection racks as used in the Spring Community Trial, and these were submerged below the docks at the Woodley Island Marina for approximately 2 months. The following species are labeled in the above photo: (A) *Bugula californica,* (B) *Bugula neritina,* (C) *Celleporella hyalina,* (D) *Ciona intestinalis*

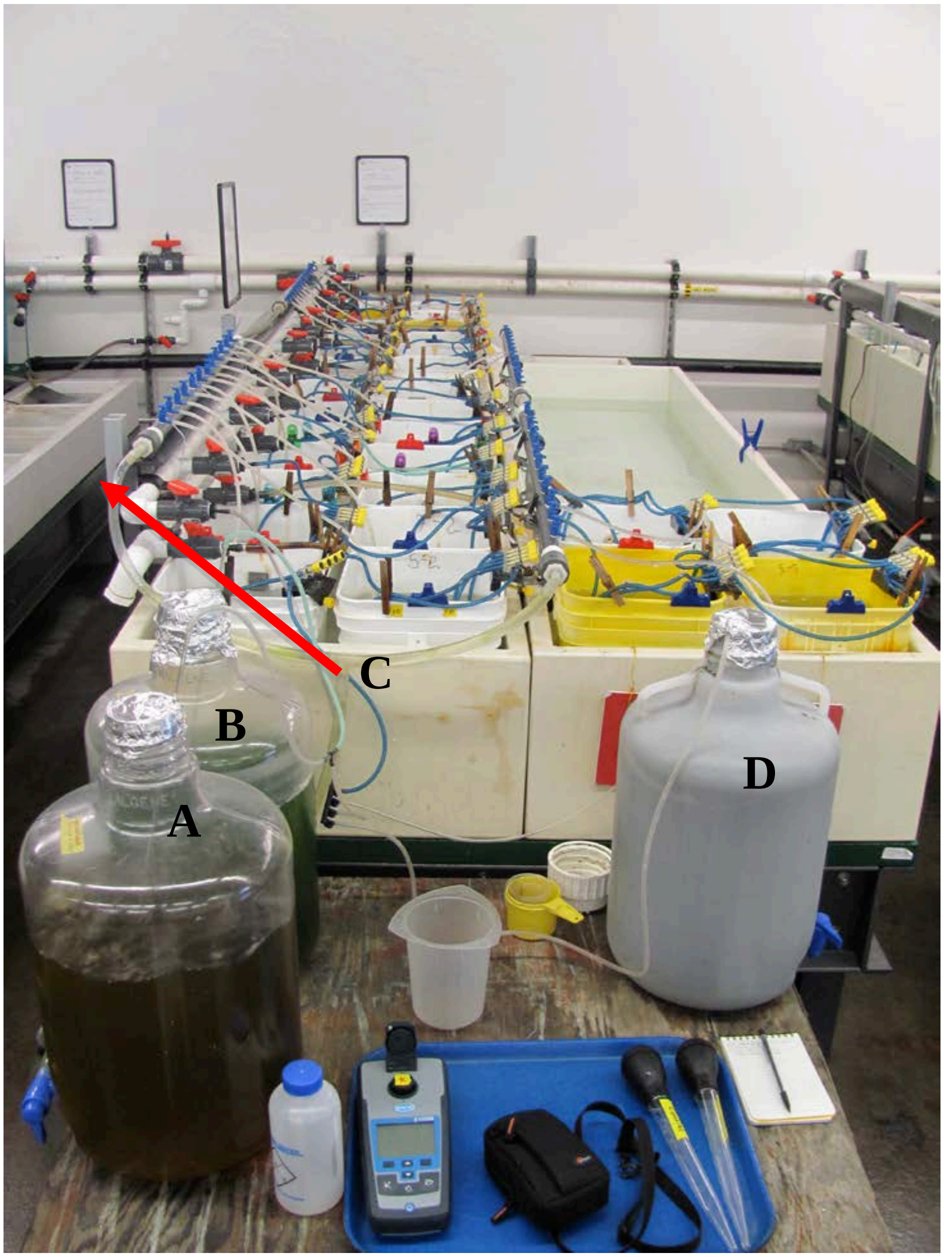


Figure 6 The laboratory setup for all experimental trials. A) *Isochrysis sp.* Cultured in a 20-liter carboy, B) *Tetraselmis sp*. cultured in a 20-liter carboy, C) Phytoplankton drip system delivering food to experimental tanks twice daily D) Aerated sediment which was added to treatment tanks daily.

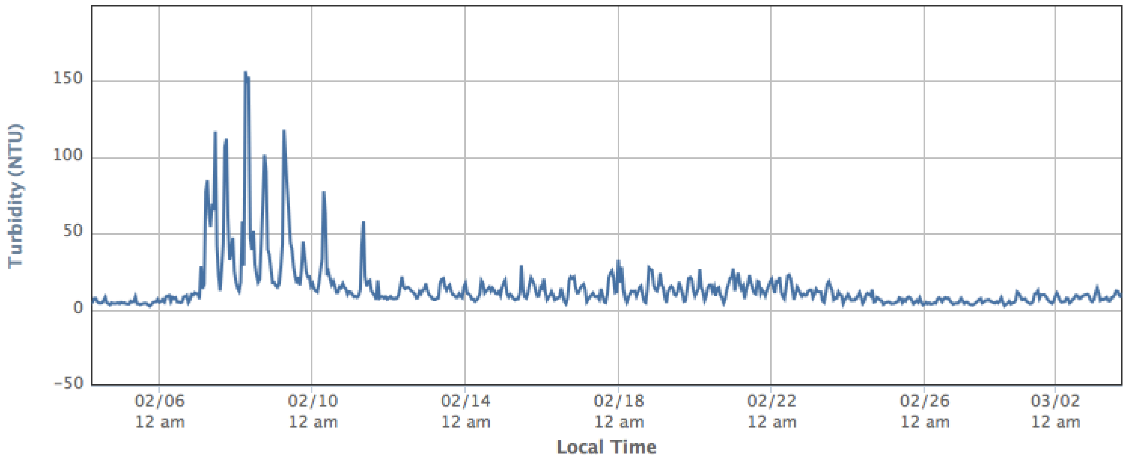


Figure 7 Real time turbidity data for the month of February 2015 from the CeNCOOS sonde at the Chevron dock in Humboldt Bay. The spike between 2/7 – 2/12 indicates elevated levels (maximum at 152 NTU) during a typical winter precipitation event. Turbidity levels fluctuate between 5 and 30 NTU during normal, daily tidal exchange (Shaughnessy and Williamson, 2005). My study reflects these turbidity values, with an average background treatment of 20 NTU as the "Low" treatment and a "High" treatment of 130 NTU.

Table 1

Results of 2-way ANOVAs to determine whether pre-trial percent cover differed among treatments and panel orientations for all species and bare space within the Spring Community trial. Values of percent cover were derived from the PhotoGrid analysis.

Bare Space	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TMT	2	200	99.83	0.828	0.443
ORIENT	1	35	34.57	0.287	0.595
TMT:ORIENT	2	117	58.48	0.485	0.619
B. neritina					
TMT	2	8.65	4.325	1.351	0.268
ORIENT	1	6.15	6.154	1.922	0.171
TMT:ORIENT	2	2.38	1.189	0.371	0.692
B. californica					
TMT	2	6.8	3.38	0.202	0.793
ORIENT	1	0.3	0.27	0.016	0.554
TMT:ORIENT	2	122.9	61.46	3.677	**0.02**
C. hyalina					
TMT	2	178	89.01	1.417	0.252
ORIENT	1	32	31.57	0.503	0.482
TMT:ORIENT	2	159	79.48	1.265	0.291
Colonial ascidians					
TMT	2	261	130.64	0.934	0.4
ORIENT	1	108	107.53	0.768	0.385
TMT:ORIENT	2	47	23.39	0.167	0.847

Table 2
Average values of physical parameters measured daily throughout each trial and corresponding cell counts for phytoplankton.

Trial Name	Trial Dates	TMT	NTU	Sediment Added (ml)	Salinity (ppt)	DO (mg/L)	Temp (C°)	*Tetraselmis sp.* (cells/ml)	*Isochrysis sp.* (cells/ml)	Total cell counts (cells/ml)
Artificial Community	6/10/14-7/2/14	Control	< 2	0	34	8.81	12	367,500	3,823,333	4,1908,333
		Low	20	30	34	8.83	12			
		Mid	70	60	34	8.93	12			
		High	200	100	34	8.90	12			
Spring Community	7/14/14-7/27/14	Control	< 2	0	34	8.74	12	485,555	2,436,666	2,922,222
		Low	20	30	34	8.74	12			
		High	130	70	34	8.74	12			
Summer Community	9/19/14-9/28/14	Control	< 2	0	34	8.17	12	570,000	2,655,000	3,225,000
		Low	20	30	34	8.17	12			
		High	130	70	34	8.17	12			

Note: Phytoplankton cell counts represent the population of each species within each carboy before being dispensed into each replicate tank.

RESULTS

Artificial Community Trial

Mytilus edulis

Wet weights for small mussels (1.5 cm shell length) in the artificial communities were recorded post-trial to quantify effects of sediment treatment, orientation and duration on mussel condition (Table 3). Results of ANOVA showed no significant effect of any sediment treatment on wet weights for small mussels on the 10-day panels ($p = 0.218$) and no significant effect of treatment ($p=0.255$) or panel orientation ($p= 0.609$) for mussels on the 22-day panels (Figure 8a, Table 4). The GLM showed no effect of sediment treatment (Low or High) on mussel survivorship for 10-day panels and also showed no effect of treatment (Low and High) and panel orientation (bottom or side) for the 22-day panels (Table 5). However, orientation of the 22-day panels was nearly significant at the $p < 0.05$ level ($p = 0.0563$; Table 5). See Figure 8b for a graphical representation of values in Table 3.

Halichondria spp.

Sponges in all treatments showed a significant reduction in wet-weight from pre to post-trial (see Table 6 for results of paired t-tests), which implies that these organisms did not do well in laboratory conditions. Panel orientation had a significant effect on sponge wet weight for the 22-day panels (ANOVA: $p = 0.009$ see Table 7), with a greater percent loss in wet weight for sponges on side panels (62% ± 3.8) than bottom panels (76% ± 3.4), but there was no significant interaction of treatment and panel orientation. Excess aeration in each tank was required to maintain turbidity, but may have had damaging effects on these fragile sponges. True wet weights post-trial were difficult to determine because those in the sediment treatments had artificially elevated weights due to particles that had lodged themselves within the body of the sponge. Some individual sponges disintegrated or broke apart and therefore not all pieces were able to be weighed.

The change in wet weights were calculated as a percentage and compared across treatments; results do not indicate an effect of treatment on wet-weight (ANOVA: 10-days side panels $p=0.407$ and 22-day panels $p = 0.078$; Table 7). See Figures 9a-c for a graphical comparison of values.

Watersipora spp.

The exotic, encrusting bryozoan species, *Watersipora spp.* was photographed before and after each trial. Post-assessment, colonies were grouped into three categories; alive, partially dead (referring to colonies with at least one dead zooid) and dead. The mean frequencies of colonies grouped by category are found in Table 8. One generalized linear model was created to assess the effect of sediment treatment on colony condition for the 10-day side panels and a second model was created to test the effect of sediment treatment and panel orientation on colonies in the 22-day side and bottom panels. Both models compare the number of live colonies versus dead colonies across treatments. For the purpose of the GLM, partially dead colonies were grouped with the dead colonies. All colonies were alive in the 10-day control treatment, however the comparison of colony condition among sediment treatments showed no statistically significant effect of treatment. The model for the 22-day panels indicates no effect of sediment treatment or panel orientation on *Watersipora spp.* colony condition (see Table 9 for GLM results).

<u>Scrupocellaria diegensis</u>

All colonies of *Scrupocellaria diegensis* exhibited vibracular movement post-trial and had no visible brown bodies or empty zooecia (dead zooids) across all treatments, trial durations (10 and 22-day) and panel orientations (side and bottom).

Spring Community Trial

<u>MatLab analysis</u>

Percent loss of colonial ascidian cover was calculated using the program MatLab to analyze photographs taken before and after the 2-week Spring Community trial. Overall, statistical results showed a strong effect of gradual sediment accumulation on colonial ascidian cover (Tukey's HSD: $p = <0.0001$ for all combinations: see Table 10 and 11). Of those panels oriented on the bottom, ascidian colonies in the control treatments (no sediment), experienced a mean loss in cover of 9.7%, whereas there was a 60.9% loss in the low treatment (~3 mm sediment depth) and a 93.9% loss in the high treatment (~8 mm sediment depth) (Figure 10).

Treatment effects on colonial ascidians were less pronounced in communities on the side of each tank. Results do not show a significant effect of sediment treatment on percent cover for side panels, however the high sediment treatment was close to significant in the MatLab analysis (Tukey's HSD: H:S-C:S $p = 0.09$, L:S-C:S $p = 0.30$, L:S-H:S $p = 0.96$: see Table 11). Of those panels oriented on the side of each tank, ascidian colonies in the control treatments experienced a mean loss in cover of 7.2%, whereas there was a 19.8% reduction in cover in the low treatment and a 23.7% loss in the high treatments (Figure 10).

<u>PhotoGrid analysis</u>

The change in percent cover of all focal species in the spring communities as well as the amount of bare space on these panels were assessed using the program PhotoGrid. Figure 11 shows the percent cover of each species and bare space before and after the 2-week trial for bottom panels. Similarly, Figure 12 shows these results for side panels. Corresponding values for percent cover in Figures 11 and 12 and results from paired t-tests comparing cover before versus after the Spring Community trial are located in Table 12.

Colonies of *Celleporella hyalina* were most significantly affected by sediment accumulation (bottom panels) in the high treatment ($p < 0.0001$), with a change in percent cover from 19.4% to 5.2% post-trial (Figure 11c). Changes in percent cover of *C. hyalina* in all other treatments for both panel orientations (side and bottom) were not significantly different statistically pre versus post-treatment (Table 12).

Percent cover was significantly reduced in colonial ascidians in the low and high treatments for both the side and bottom panels while no difference was seen in the control treatments (Table 12). Mean change in percent cover for side panels in the control, low and high treatments were; 8.2%, 19.5%, and 21.6% respectively and for bottom panels were 2.4%, 68.8%, and 93.3% (Figures 11 and 12). These results are very similar to those found using the MatLab analysis. A comparison of the mean values of percent cover between these two methods (PhotoGrid vs. MatLab) found no statistically significant differences in the results (Table 13).

Bugula neritina and *Bugula californica* made up the smallest portion of the overall community cover in this experiment and also experienced no significant changes before versus after the two week trial across all treatments and panel orientations. The subsequent Summer Community trial described below was a more thorough assessment of these species with higher replicate numbers.

The percent cover of bare space was calculated in all treatments, and due to significant mortality of colonial ascidians within the high sediment treatment panels on the bottom of the experimental tanks, percent cover of bare space was significantly different pre/post-trial ($p = 0.03$; Table 12).

Summer Community Trial

Celleporella hyalina

The dominant encrusting species in the summer communities was *C. hyalina*. Colony survivorship was quantified from photos taken before and after the trial, and Table 14 shows the mean number of colonies pre-trial and their survivorship. Figure 13 represents survivorship of *C. hyalina* for all treatments and panel orientations. The results showed no mortality of colonies (100% survival) in the side panel communities across all treatments. These results match those from the Spring Community trial.

Colonies on the bottom panels, however, were dramatically affected by sediment accumulation compared to controls (GLM: High, $p < 0.0001$ and Low, $p < 0.0001$). One hundred percent (100%) of colonies survived in the control bottom panel treatments, while 83% survived in the low sediment treatment (~3 mm sediment depth) and only 32% survived in the high sediment treatment (~8 mm sediment depth). *C. hyalina* responded similarly in the Spring Community trial, showing the highest mortality in the high sediment accumulation treatment, as exhibited by a 73% decrease in percent cover.

Arborescent bryozoans

The survival and reproductive status of all arborescent bryozoan species (*Bugula neritina, Bugula californica and Scrupocellaria diegensis*) were quantified for colonies in the Summer Community trial. All colonies of all species were alive (status of 20 zooids per colony) post 2-week trial across all treatments and panel orientations, as was similarly found in the Artificial Community trial for *S. diegensis* and the Spring Community trial for both *B. neritina and B. californica*.

The proportion of colonies that shifted from having ovicells pre-trial to being without ovicells post-trial is shown in Figure 14. A larger proportion of colonies without ovicells occurred in the bottom panels in the low and high treatments than in the control treatment, however only the low treatment had a statistically significant effect (GLM: Low, $p = 0.02$ and High, $p = 0.92$). No significant effects of sediment treatment occurred for the side panels.

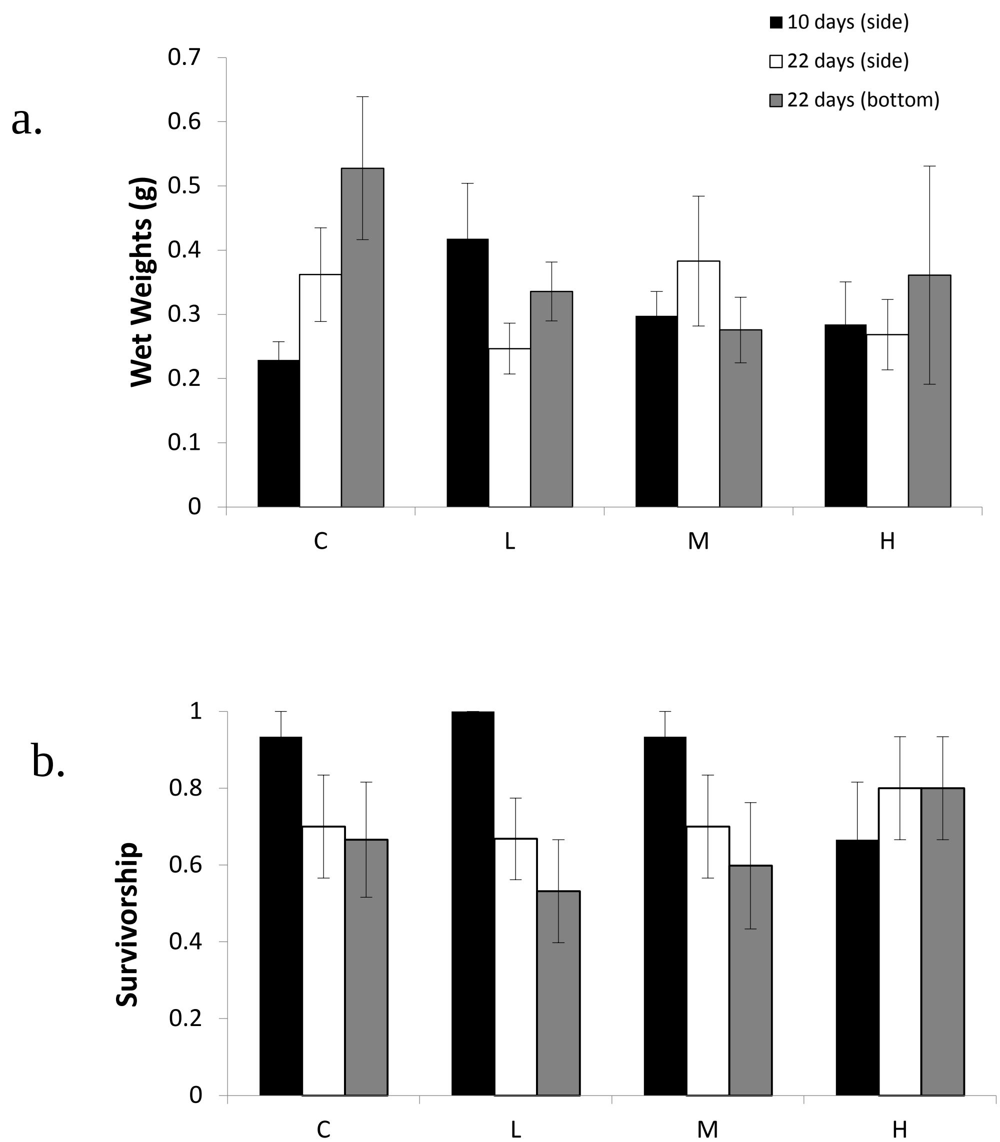


Figure 8 (a) Wet weights post-trial for small mussels in the artificially assembled communities (dead mussels not included). Horizontal axes represent turbidity treatment levels, C = “Control” < 2 NTU, L = “Low” 20 NTU, M = “Mid” 70 NTU and H = “High” 200 NTU. Results show no significant effect of treatment on wet weights for the 10-day panels (p=0.218) and no significant effect of treatment (p=0.255) or panel orientation (p= 0.609) for 22-day panels (Table 4) (b) Mussel survivorship (includes both size classes, 1.5 cm and 3.5 cm). Results show no effect of sediment treatment on mussel survivorship for 10-day panels or sediment treatment and panel orientation for 22-day panels (GLM results; see Table 5). Error bars represent ± standard errors of the mean value.

Table 3
Mean survivorship of all mussels in the Artificial Community Trial and mean wet weights (± 1 standard error) for mussels in the smallest class size (1.5 cm).

Exposure Time (Panel orientation)	TMT	Survivorship	Wet weights (g)
10-Days (side)	Control	0.934	0.229 (± 0.03)
	Low	1	0.418 (± 0.09)
	Mid	0.934	0.298 (± 0.04)
	High	0.666	0.284 (± 0.07)
22-Days (side)	Control	0.7	0.362 (± 0.07)
	Low	0.668	0.247 (± 0.04)
	Mid	0.7	0.383 (± 0.10)
	High	0.8	0.269 (± 0.05)
22-Days (bottom)	Control	0.666	0.528 (± 0.11)
	Low	0.532	0.336 (± 0.05)
	Mid	0.598	0.276 (± 0.05)
	High	0.8	0.361 (± 0.17)

Table 4
ANOVA results for *Mytilus edulis* wet weights post-trial. Treatment (TMT: Control, Low, Mid, High) and panel orientation (ORIENT: Bottom and Side).

Species	Trial Duration	Dependent Variables	Independent Variables	d.f.	F value	Pr(>F)
Mytilus edulis	10-days	Final wet weights	TMT		1.986	0.163
	22-days	Final wet weights	TMT	3	1.036	0.391
			ORIENT	1	0.671	0.419
			TMT:ORIENT	3	0.778	0.516

Table 5
Results of the GLM for mussel condition (“Alive”, “Dead”) in the Artificial Community trial. Trial duration (10-day or 22-day), treatment and orientation are indicated below. Sediment treatments did not have a significant effect on mussel condition.

Trial Duration	Treatment	Estimate	Std. Error	z value	Pr(>|z|)
10-days	(Intercept)	2.64E+00	1.04E+00	2.55	0.0108
	TMTL	1.75E+01	3.74E+03	0.005	0.9963
	TMTM	6.50E-16	1.46E+00	0	1
	TMTH	-1.95E+00	1.17E+00	-1.662	0.0966
22-days	(Intercept)	0.8109	0.6009	1.349	0.1772
	TMTL	-0.1178	0.8131	-0.145	0.8848
	TMTM	0.4884	0.8862	0.551	0.5816
	TMTH	0.4884	0.8862	0.551	0.5816
	ORIENTS	-1.6219	0.8498	-1.908	**0.0563**
	TMTH:ORIENTS	-0.9767	1.2533	-0.779	0.4358
	TMTL:ORIENTS	0.2356	1.1499	0.205	0.8377
	TMTM:ORIENTS	-0.5937	1.2233	-0.485	0.6274

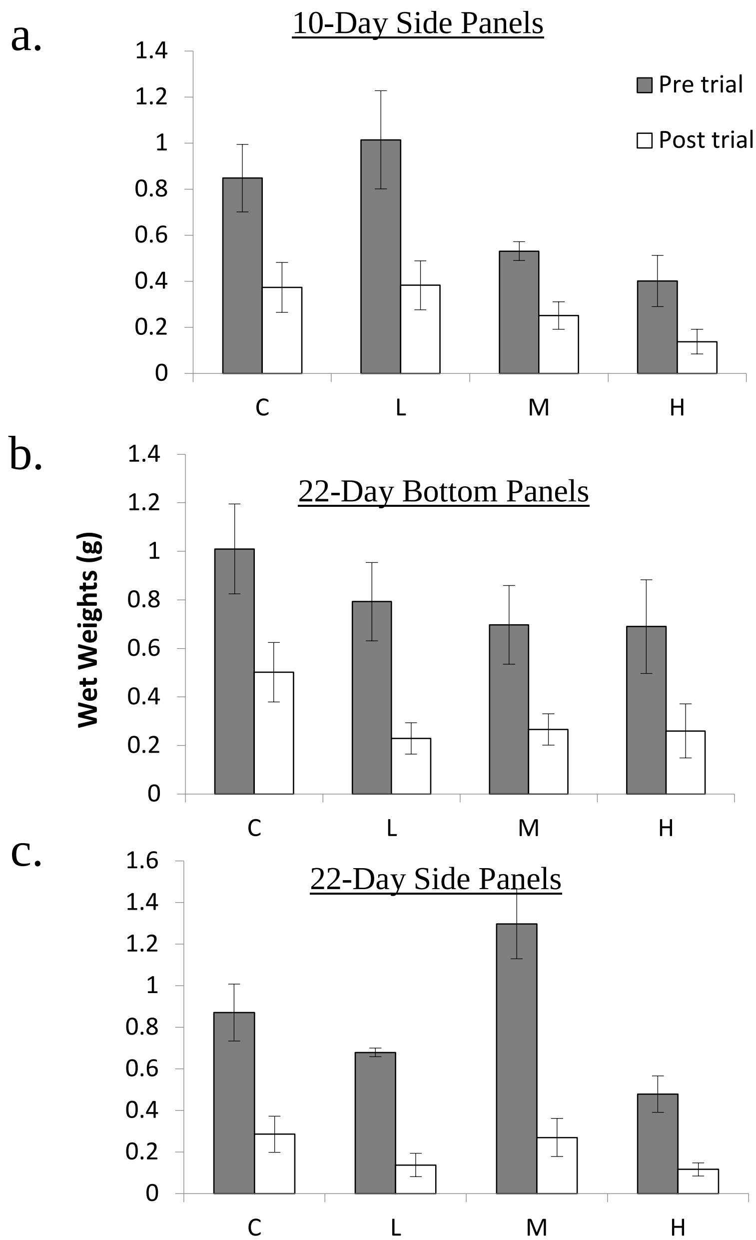


Figure 9 Wet weights for *Halichondria spp*., pre and post-trial. Horizontal axes represent turbidity treatment levels, C = “Control” < 2 NTU, L = “Low” 20 NTU, M = “Mid” 70 NTU and H = “High” 200 NTU. Sponges in all treatments showed a reduction in wet weight. The change in wet weights were calculated as a percent and compared across treatments using ANOVA. Results do not indicate an effect of sediment treatment on wet weight for 10-day panels ($p=0.407$) or 22-day panels ($p = 0.078$), however panel orientation (bottom versus side) had a significant effect ($p = 0.009$) for 22-day panels, but there was no interaction with sediment treatments ($p=0.849$) (Table 7) (a) 10-days side panels (b) 22-days bottom panels (c) 22-days side panels. Error bars represent ± standard errors of the mean value (Table 6).

Table 6

Results of paired t-tests for *Halichondria spp.* wet weights (g) before and after the Artificial Community trial. Exposure time and panel orientation are indicated below. Values represent mean wet weights (± standard errors).

Exposure Time (Panel orientation)	TMT	Pre-trial Wet weights (g)	Post-trial Wet weights (g)	t- value	d.f.	p-values
10-Days (side)	C	0.848 (±0.15)	0.373 (±0.11)	-9.0565	4	**0.0008**
	L	1.014 (±0.21)	0.383 (±0.11)	-3.6127	4	**0.0225**
	M	0.531 (±0.04)	0.251 (±0.06)	-11.0759	4	**0.0004**
	H	0.401 (±0.11)	0.138 (±0.05)	-3.9056	4	**0.0175**
22-Days (side)	C	0.871 (±0.14)	0.286 (±0.09)	-4.6999	4	**0.0093**
	L	0.679 (±0.02)	0.138 (±0.06)	-11.0362	4	**0.0003**
	M	1.297 (±0.17)	0.27 (±0.09)	-6.3462	4	**0.0032**
	H	0.479 (±0.08)	0.116 (±0.3)	-6.2268	4	**0.0034**
22-Days (bottom)	C	1.010 (±0.19)	0.502 (±0.12)	-5.4591	4	**0.0054**
	L	0.793 (±0.16)	0.229 (±0.06)	-5.0652	4	**0.0071**
	M	0.697 (±0.16)	0.266 (±0.06)	-3.6486	4	**0.0355**
	H	0.689 (±0.19)	0.259 (±0.11)	-4.9203	4	**0.0161**

Table 7
ANOVA results for *Halichondria spp.* wet weights post-trial. Treatment (TMT: Control, Low, Mid, High) and panel orientation (ORIENT: Bottom and Side). Significant p-values are in bold.

Species	Trial Duration	Dependent Variables	Independent Variables	d.f.	F value	Pr(>F)
Halichondria spp.	10-days	Change in wet weight	TMT	3	1.027	0.407
	22-days	Change in wet weight	TMT	3	2.508	0.0778
			ORIENT	1	7.68	**0.0095**
			TMT:ORIENT	3	0.267	0.8486

Table 8
Assessment of *Watersipora spp*. colonies in the artificial communities post-trial (2 colonies per panel). Values are the mean frequency of colonies per category. Colonies with at least one dead zooid were categorized as "Partially Dead".

Exposure Time (panel orientation)	TMT	d.f.	Alive	Partially Dead	Dead
10-days (side)	C	4	1	0	0
	L	4	0.6	0.2	0.2
	M	4	0.6	0.3	0.1
	H	4	0.6	0.4	0
22-days (side)	C	4	0.8	0.1	0.1
	L	4	0.7	0.1	0.2
	M	4	0.8	0.2	0
	H	4	0.6	0.4	0
22-days (bottom)	C	4	0.6	0.2	0.2
	L	4	0.4	0.1	0.4
	M	4	0.5	0.1	0.4
	H	4	0.3	0.2	0.5

Table 9

Results of the GLMs for colony condition of *Watersipora spp.* (“Alive”, “Dead + Partially Dead”) in the Artificial Community trial. All colonies were alive in the 10-day control treatment, however colony condition did not vary among the different sediment treatments. Sediment treatment nor panel orientation had a significant effect on colony condition for the 22-day duration.

Trial Duration	Treatment	Estimate	Std. Error	z value	Pr(>|z|)
10-days	TMTL	-3.14E-16	0.913	0.00	1.00
	TMTM	-1.01E-16	0.913	0.00	1.00
	TMTH	0.406	0.646	0.628	0.53
22-days	(Intercept)	0.405	0.646	0.628	0.530
	TMTL	-1.253	0.945	-1.326	0.185
	TMTM	-0.629	0.931	-0.675	0.500
	TMTH	-0.405	0.904	-0.449	0.654
	ORIENTS	0.981	1.021	0.961	0.337
	TMTH:ORIENTS	0.272	1.391	0.196	0.845
	TMTL:ORIENTS	0.090	1.403	0.064	0.949
	TMTM:ORIENTS	0.405	1.438	0.282	0.778

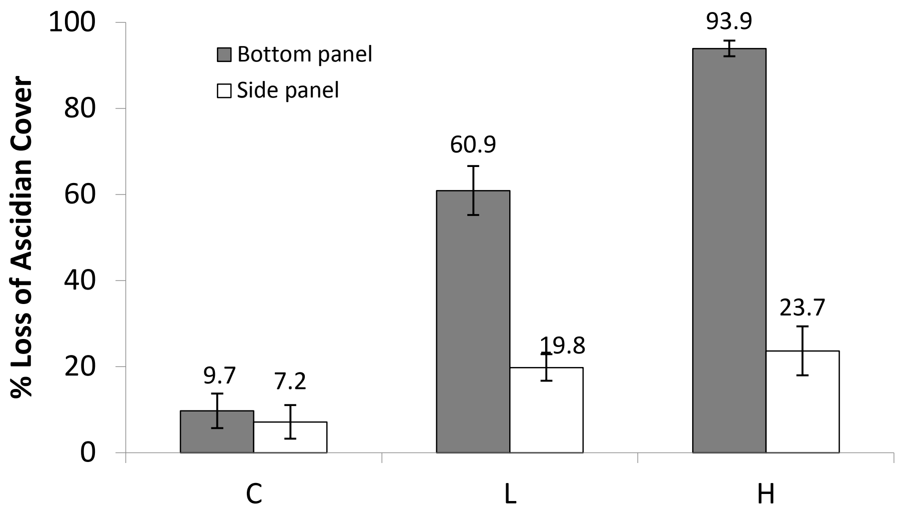


Figure 10 Percent loss of colonial ascidian cover at the end of the 2-week Spring Community Trial. Ascidians in community panels oriented on the bottom of each tank gradually accumulated sediment for the duration of the trial. Mean accumulated sediment depth for low and high treatments were 3 mm and 8 mm, respectively, for these bottom panels. Horizontal axis indicates turbidity treatment level, C = "Control" < 2 NTU, L = "Low" 20 NTU and H = "High" 130 NTU. Results from Tukey's HSD test show a strong effect of sediment burial on colonial ascidian cover (p = <0.0001 for all combinations; see Table 11). Treatment effects on colonial ascidians were less pronounced in communities on the side of each tank. Tukey's HSD test does not show a significant effect of treatment on percent cover, however the high sediment treatment is close to significant (H:S-C:S p = 0.09, L:S-C:S p = 0.30, L:S-H:S p = 0.99; Table 11). Ascidian percent cover was calculated using MatLab (see Methods). Error bars represent ± 1 standard error of the mean.

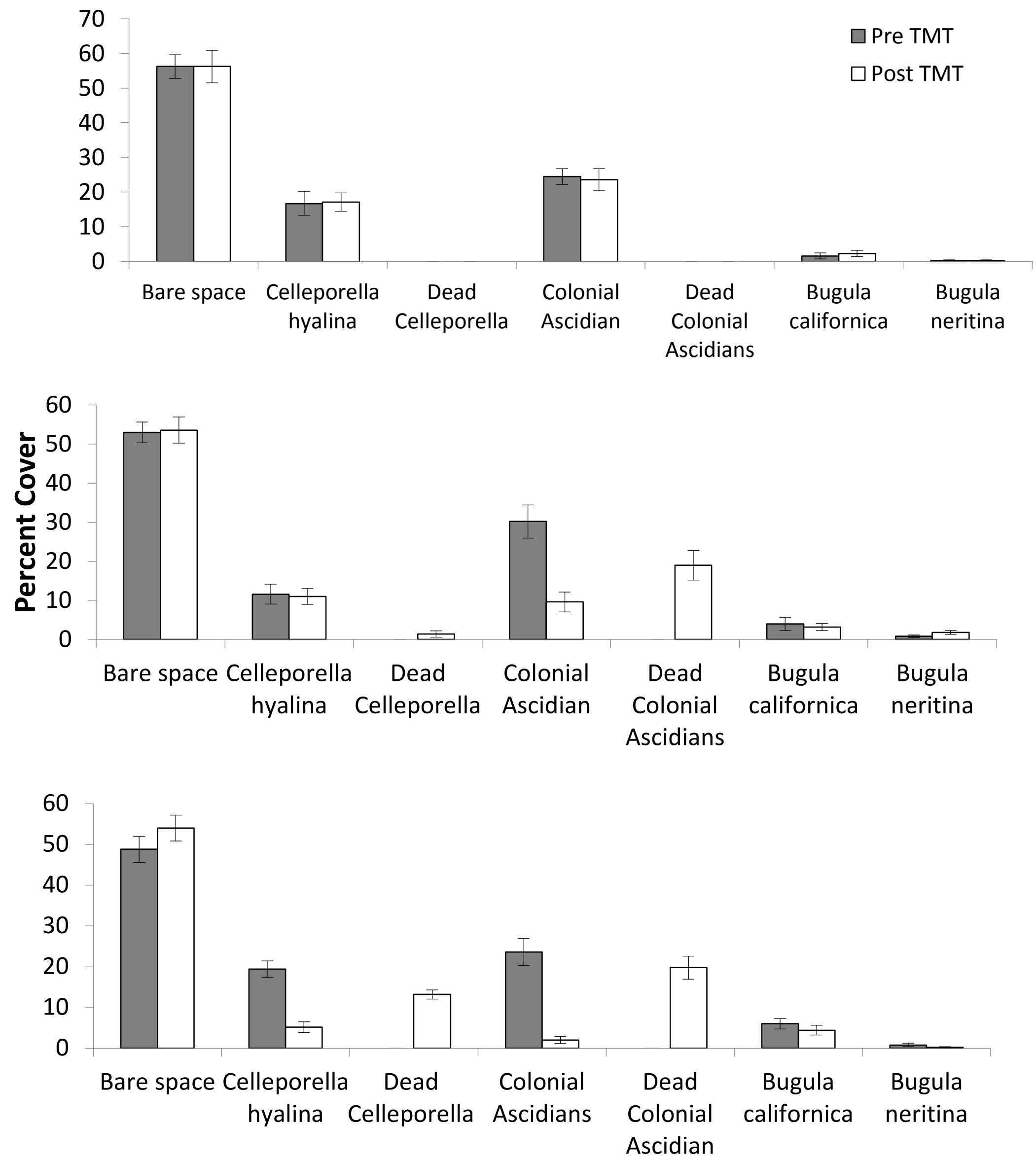
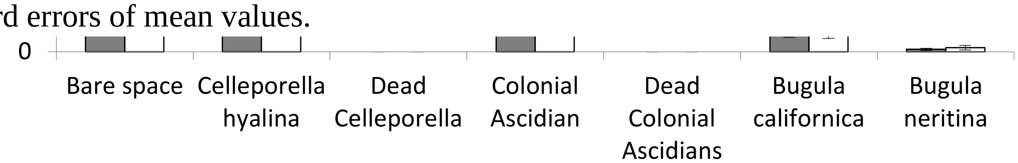


Figure 11 Percent cover of focal species within naturally settled communities, before and after the 2-week Spring Community. Community panels with the above species were oriented on the bottom of each tank. To compare percent cover before and after the trial, paired t-tests with pooled variances were used for each species and bare space (Table 12). (a) Controls, no sediment added (b) Low sediment treatment (20 NTU) (c) High sediment treatments (130 NTU). Percent cover was calculated using the program PhotoGrid beta 1.0. Error bars represent ± standard errors of mean values.

d.



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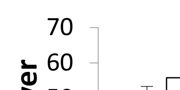

Table 10
ANOVA results comparing change in percent cover of colonial ascidians in the Spring Community trial across turbidity treatments and panel orientations for two photo analysis methods, MatLab and PhotoGrid.

Change in Percent Cover	Variables	Df	Sum Sq.	Mean Sq.	F value	Pr(>F)
MatLab	TMT	2	24282	12141	68.42	**< 0.0001**
	ORIENT	1	22682	22682	127.83	**< 0.0001**
	TMT:ORIENT	2	10883	5441	30.67	**< 0.0001**
PhotoGrid	TMT	2	27194	13597	20.83	**< 0.0001**
	ORIENT	1	23710	23710	36.32	**< 0.0001**
	TMT:ORIENT	2	14915	7458	11.43	**< 0.0001**

Table 11
Results of Tukey's HSD post-hoc test for percent loss in colonial ascidian cover determined by the two-way ANOVA tests in Table 10. PhotoGrid data was square root transformed before analysis. Significant values are in bold.

	MatLab				PhotoGrid			
Comparisons	diff	lwr	upr	p adj	diff	lwr	upr	p adj
H:B-C:B	-84.20	-102.29	-66.10	**<0.0001**	-90.91	-125.62	-56.20	**<0.0001**
L:B-C:B	-51.19	-69.28	-33.09	**<0.0001**	-66.41	-101.12	-31.70	**<0.0001**
L:B-H:B	33.01	15.40	50.62	**<0.0001**	24.50	-9.28	58.28	**0.001**
H:S-C:S	-16.50	-34.60	1.59	0.093	-13.40	-48.11	21.30	0.862
L:S-C:S	-12.62	-30.32	5.09	0.300	-11.34	-45.30	22.61	0.920
L:S-H:S	3.89	-13.32	21.10	0.985	2.06	-30.94	35.06	1.000
C:S-C:B	2.56	-16.01	21.12	0.998	-5.76	-41.36	29.85	0.997
H:S-C:B	-13.95	-32.04	4.15	0.221	-19.16	-53.87	15.55	0.772
L:S-C:B	-10.06	-27.76	7.64	0.551	-17.10	-51.05	16.85	0.852
C:S-L:B	53.74	35.65	71.84	**<0.0001**	60.65	25.95	95.36	**<0.0001**
H:S-L:B	37.24	19.63	54.85	**<0.0001**	47.25	13.47	81.03	**0.002**
L:S-L:B	41.13	23.92	58.34	**<0.0001**	49.31	16.31	82.31	**0.001**
C:S-H:B	86.75	68.66	104.85	**<0.0001**	85.15	50.45	119.86	**<0.0001**
H:S-H:B	70.25	52.64	87.86	**<0.0001**	71.75	37.97	105.53	**<0.0001**
L:S-H:B	74.14	56.93	91.35	**<0.0001**	73.81	40.81	106.81	**<0.0001**

Table 12
The results of paired t-tests comparing the effect of each treatment on percent cover before and after the Spring Community trial for all species as well as bare space. Values represent mean percent cover calculated with PhotoGrid beta 1.0 (± 1 standard error).

Species	TMT	Panel Orientation	Pre-trial cover	Post-trial cover	t –value	d.f.	p –value
C. hyalina	C	Bottom	16.7 (±3.42)	17.1 (±2.65)	0.1657	8	0.8725
	L		11.6 (±2.56)	11 (±2.01)	-0.2278	9	0.8249
	H		19.4 (±2.09)	5.2 (±1.34)	-7.4887	9	**<0.0001**
	C	Side	13.1 (±2.65)	12 (±2.85)	-0.4336	8	0.6761
	L		14.5 (±1.91)	11.6 (±1.94)	-1.5353	10	0.1157
	H		15.2 (±2.53)	13.6 (±2.65)	-0.8109	9	0.4383
Ascidians	C	Bottom	24.4 (±2.28)	23.6 (±3.19)	-0.4015	8	0.6991
	L		30.2 (±4.23)	9.6 (±2.56)	-5.496	9	**0.0003**
	H		23.6 (±3.36)	2 (±0.84)	-8.0104	9	**<0.0001**
	C	Side	28 (±3.16)	25.6 (±3.99)	-0.7454	8	0.4773
	L		30.5 (±4.76)	22.9 (±2.87)	-2.908	10	**0.0156**
	H		28 (±3.53)	20.6 (±2.4)	-3.5084	9	**0.0066**
B. californica	C	Bottom	1.6 (±0.87)	2.2 (±0.91)	0.8165	8	0.4379
	L		4 (±1.67)	3.2 (±0.95)	-0.6882	9	0.5086
	H		6 (±1.26)	4 (±1.2)	-0.8847	9	0.3994
	C	Side	5.6 (±1.54)	5.3 (±1.61)	-0.2857	8	0.7824
	L		4 (±1.14)	4 (±1.5)	0	10	1
	H		2.8 (±1.04)	3.4 (±1.15)	0.8182	9	0.4344
B. neritina	C	Bottom	0.2 (±0.22)	0.2 (±0.22)	0	8	1
	L		0.8 (±0.33)	1.8 (±0.47)	1.8605	9	0.0957
	H		0.8 (±0.44)	0.2 (±0.2)	-1.964	9	0.0811
	C	Side	0.7 (±0.31)	1.1 (±0.64)	0.686	8	0.5121
	L		1.1 (±0.49)	1.1 (±0.56)	0	10	1
	H		2 (±1.07)	2.8 (±1.2)	0.937	9	0.3732
Bare space	C	Bottom	56.2 (±3.42)	56.2 (±4.67)	0	8	1
	L		53 (±2.70)	53.6 (±3.36)	2.195	9	0.8311
	H		48.8 (±3.24)	54 (±3.15)	2.594	9	**0.029**
	C	Side	57.7 (±4.34)	55.8 (±4.59)	0.952	8	0.369
	L		49.5 (±3.83)	55.8 (±3.61)	2.1206	10	0.06
	H		51.2 (±3.03)	56.2 (±2.76)	1.431	9	0.1861

Table 13
Comparison of the percent change in colonial ascidian cover in the spring communities using two different photo analysis programs; Matlab and PhotoGrid beta 1.0. Paired t-tests indicate no significant differences in the calculation of percent change in cover between the two programs for all three treatments and panel orientations. Negative values indicate a loss in percent cover ± 1 standard error.

Panel Orientation	TMT	MatLab: Mean % Change of Cover	PhotoGrid: Mean % Change of Cover	t-value	d.f.	p-value
Side	C	-7.2 (±3.87)	-8.2 (±12.7)	0.091	8	0.929
	L	-19.8 (±3.09)	-19.5 (±6.5)	0.039	10	0.969
	H	-23.7 (±5.69)	-21.6 (±8.05)	-0.235	9	0.819
Bottom	C	-9.7 (±4.03)	-2.4 (±10.9)	-0.586	8	0.574
	L	-60.9 (±5.67)	-68.8 (±6.15)	1.474	9	0.176
	H	-93.9 (±1.81)	-93.3 (±2.46)	-0.232	9	0.822

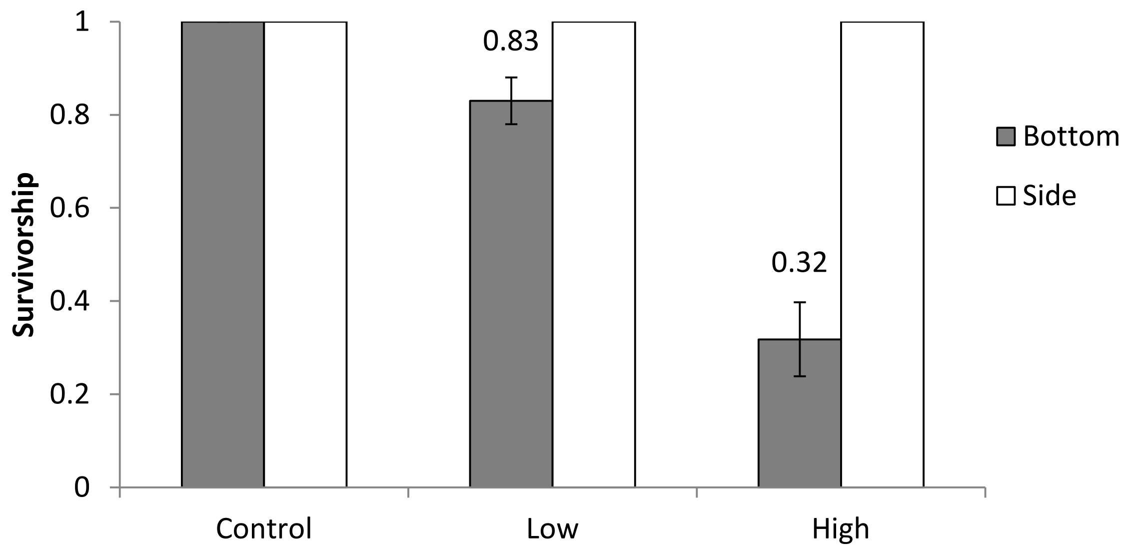

Figure 13 Results from the Summer Community trial show colony survivorship of *C. hyalina* within naturally settled communities after a 2-week exposure to suspended and accreted sediment. Panels with *C. hyalina* colonies were either oriented on the bottom or side of each tank in three treatments; control (no sediment), low (20 NTU) or high (130 NTU) sediment treatment. Average depths of sediment accumulation at the end of the trial were 3mm (low) and 8mm (high) on bottom panels. All colonies oriented on the side of the tank survived the 2-week trial across all treatments. A decrease in survivorship with increasing turbidity and sediment accumulation occurred for colonies on the bottom of each tank. A generalized linear model comparing the number of live versus dead colonies for each sediment treatment indicates a significant effect of both the low ($p < 0.0001$) and high ($p < 0.0001$) treatments on colony condition in bottom panels. See Table 14 for total colony number per tank and survivorship.

Table 14
Survivorship of *Celleporella hyalina* on horizontally oriented panels after the 2-wk Summer Community trial. A generalized linear model was used to compare the number of live versus dead colonies across sediment treatments. All colonies on two replicate panels nested within each experimental tank were represented in the total number assessed.

TMT	Total	Dead	Alive	Survivorship
C	3	0	3	1
C	4	0	4	1
C	3	0	3	1
C	2	0	2	1
C	2	0	2	1
C	6	0	6	1
C	3	0	3	1
C	5	0	5	1
C	3	0	3	1
C	1	0	1	1
C	5	0	5	1
C	2	0	2	1
C	1	0	1	1
C	1	0	1	1
C	4	0	4	1
C	5	0	5	1
L	2	1	1	0.5
L	4	1	3	0.750
L	5	0	5	1
L	6	2	4	0.667
L	4	0	4	1
L	4	1	3	0.750
L	2	0	2	1
L	2	1	1	0.50
L	1	0	1	1
L	7	4	3	0.429
L	3	1	2	0.667
L	3	0	3	1
L	1	0	1	1
L	8	4	4	0.5
L	3	0	3	1
L	3	0	3	1
L	1	0	1	1
L	2	0	2	1
L	2	0	2	1
H	8	7	1	0.125

Table 14 continued

TMT	Total	Dead	Alive	Survivorship
H	6	6	0	0
H	1	1	0	0
H	7	2	5	0.714
H	4	3	1	0.250
H	1	0	1	1
H	3	1	2	0.667
H	4	4	0	0
H	8	8	0	0
H	3	3	0	0
H	7	3	4	0.571
H	10	8	2	0.2
H	3	1	2	0.667
H	6	4	2	0.333
H	4	4	0	0
H	4	1	3	0.750
H	4	4	0	0
H	4	1	3	0.750
H	4	4	0	0
H	8	8	0	0

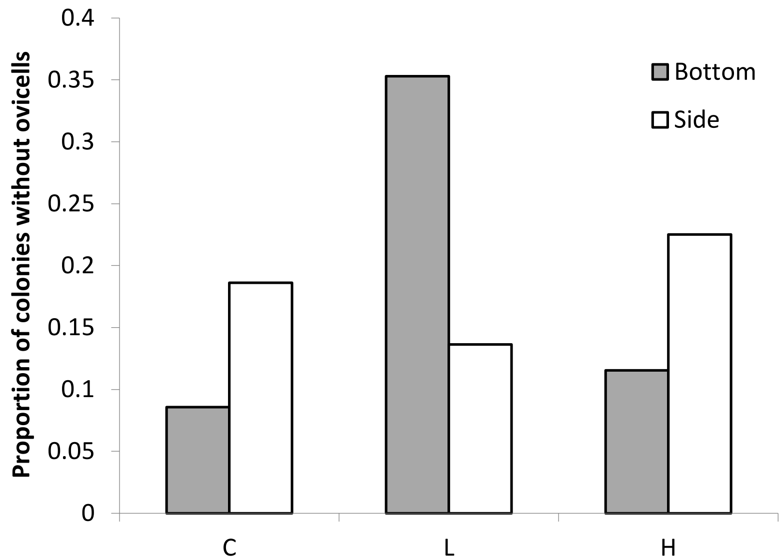

Figure 14 The proportion of colonies among arborescent bryozoan species within the Summer Community trial that shifted reproductive status (ovicells present before trial to ovicells absent post-trial). A larger proportion of colonies without ovicells occurred in the bottom panels in the low and high treatments than in the control treatment, however only the low treatment had a statistically significant effect (GLM: **$p = 0.02$**, $p = 0.92$). No significant effects of treatment occurred in the side panels. The GLM analysis indicated no tank effect, therefore the total number of colonies with ovicells pre-trial were included in this analysis.

Table 15
GLM results of the change in reproductive status in arborescent bryozoan species in the Summer Community trial. Only colonies that had ovicells before treatment were analyzed. The GLM indicated no tank effect ($p > 0.10$ for all tanks), therefore the total number of colonies among treatment groups were included in the analysis.

Variables	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.3671	0.6036	-3.922	8.79E-05
TMTH	0.3302	0.7435	0.444	0.6569
TMTL	1.761	0.7022	2.508	**0.0122**
ORIENTS	0.8912	0.7197	1.238	0.2156
TMTH:ORIENTS	-0.0911	0.9218	-0.099	0.9213
TMTL:ORIENTS	-2.1309	0.9163	-2.325	**0.02**

DISCUSSION

The purpose of this study was to test the effects (lethal or sub-lethal) of suspended and accreted sediment on sessile invertebrate communities that may occur during high suspension event in Humboldt Bay, California. The results of this study address individual species responses within naturally occurring communities to different levels of turbidity for communities in two orientations, vertical and horizontal.

Sediment accumulation (horizontal orientation) on communities in the high turbidity treatment (130 NTU, 8mm accumulation) had the greatest impact, followed by the low turbidity treatment (20 NTU, 3 mm accumulation). The highest levels of mortality were seen in organisms with an encrusting morphology (colonial ascidians: *Botrylloides sp.*, *Botryllus schlosseri*, and *Didemnum sp.* and the bryozoan, *C. hyalina.*). Species that are upright and partially above the level of accumulated sediment (arborescent bryozoans: *B. neritina*, *B. californica*, *S. diegensis*, the mussel, *M. edulis* and the solitary ascidian, *Ciona intestinalis*) did not experience any significant mortality and there was no effect detected in variables quantified for sub-lethal effects in these taxa (reproductive status pre/post-trial in arborescent bryozoans and post-trial wet weight in *M. edulis*). All species within communities oriented vertically in the tanks (little to no sediment accumulation) showed no significant negative effects regardless of turbidity treatment.

Sedimentation on top of ascidians can cue the down regulation of aerobic metabolism during hypoxic conditions and may also create excess squirting (functional hypoxia) in some species (Torre *et al.* 2014). It’s likely that the colonial ascidians in this study died from suffocation, or environmental hypoxia due to clogging of their pharyngeal baskets which are used for gas exchange. Previous studies have linked sedimentation with mortality in various ascidian species (Bakus 1968, Young and Chia 1984, Robbins 1985, Svane and Young 1989, Torre *et al.* 2012 and 2014). Torre *et al.* (2014) identifies the importance of morphology (erect versus flat forms) on physiological response of ascidians to sedimentation in the West Antarctic Peninsula. Their study shows a more passive response in the ascidian species with a flat, encrusting form, as opposed to erect forms when exposed to high levels of sediment in the lab. The encrusting forms significantly reduced its oxygen intake, while the erect forms used excess squirting to expel sediment (Torre *et al.* 2014).

Overall the results from this study indicate that species within sessile fouling invertebrate communities are differentially affected by suspended/accreted sediment. These community assemblages includes taxa that are tolerant of sedimentation and others that are more sensitive. Previous studies have found similar results within coastal and estuarine systems (Saiz-Salinas and Urdangarin 1994, Naranjo *et al* 1996). Saiz-Salinas and Urdangarin (1994) identified a sediment gradient along the mouth of the Nervion River in Northern Spain toward the open ocean in Bilbao Harbor that acted as the main determinant of survival in hard-substrate invertebrates (salinity had a negligible effect in this system), creating assemblages ranging from “tolerant” with few, highly abundant species in the most perturbed areas (high sedimentation, closer to the mouth of the estuary) to highly diverse communities (near the outer bay with higher flow velocity and less sediment). Many "sensitive" species were not represented in the transition zone or high disturbance areas along their sediment gradient. Naranjo *et al*. 1996 found similar results in Southern Spain in Algeciras Bay from groups of ascidian species sampled at 11 coastal, hard-bottom habitat stations from the mouth of the Palmones River to the opening of the bay. In their study, five variables related to sediment were specifically quantified for each site (including suspended solids and siltation). They found that ascidian species partitioned out into two general group responses to disturbance caused by excess sediment; a highly tolerant group (including *Ciona intestinalis*) and a group of highly sensitive species. Species richness was highest in locations with faster flow and less disturbance from sediment (closer to the open ocean) and lowest near the mouth of the river where sediment disturbance was greatest.

Adaptations to Excess Sediment

In general, sessile invertebrate species within coastal marine and estuarine systems have adapted to a wide range of environmental stressors, as these systems are highly dynamic, with physical conditions fluctuating daily from natural and anthropogenic perturbations. Why then are some species more tolerant than others? What adaptations do sessile invertebrate species have to combat the effects of sedimentation?

The following themes appear in the literature when discussing the interaction of sediment and adaptive capability of marine sessile invertebrate species: (a) habitat selection by free-swimming larval stages, (b) morphology as it relates to form (erect versus encrusting) and function (specialized structures to prevent sedimentation) and finally, (c) feeding behavior.

Habitat Selection

The threat of sedimentation is considered a strong selective pressure influencing habitat selection by marine invertebrate larvae. Hodgson (1990) and Perez *et al.* (2014) showed in the laboratory that thin layers of silt on surfaces of potential habitat significantly inhibited settlement of planulae larvae in corals. Young and Chia (1984) and Svane and Young (1989) identified negative phototactic behavior in ascidian larvae as a response to sediment accumulation. This behavior increases the frequency of larvae settled under shaded surfaces (e.g. floating docks, buoys, and rocky overhangs) thus minimizing the potential for sediment to accumulate on top of these organisms. In addition to negative phototactic behavior, habitat preference for settling on neighboring upright organisms, living an epibiotic lifestyle, has been identified for some sessile marine invertebrates as a mechanism to minimize exposure to sediment (Saiz-Salinas and Urdangarin 1994). One of the most sensitive focal species within this study, *C. hyalina* often utilizes this strategy. *C. hyalina* is commonly found growing on macroalgal species that are constantly in motion, which could minimize the potential for sediment to accumulate and suffocate this species (Cancino and Hughes 1987).

Morphology

Form

In this study, sedimentation (especially on horizontally-oriented bottom panels) and increasing turbidity seemed to have more lethal effects on encrusting, low-profile species than those with an upright morphology. Previous studies have found similar results when comparing species morphology and orientation (vertical versus horizontal) in the field and lab. Maughan (2001) studied encrusting communities in Ireland by manipulating light and sediment exposure on artificial settlement plates. Maughan found encrusting species of coralline algae and most bryozoan species to prefer all treatments without sediment with the exception of an erect bryozoan, *Aetea spp*., which settled on all panels, including those with accumulated sediment. This suggested that the upright form of *Aetea spp.* with elongate zooids, prevents this species from becoming clogged with sediment. Irving and Connell (2002) studied the interaction of light and sediment and the effect of orientation (vertical versus horizontal) on rocky intertidal communities. The authors found that survivorship of tube building polychaetes was related to morphology. The growth and abundance of polychaete species with horizontal growth forms were significantly reduced under natural sedimentation rates whereas polychaete species with erect tubes, elevated above the sediment, were not affected. Flores *et al.* (2012) studied the lethal and sub-lethal effects of fine sediment on tropical coral species, exposing organisms to a range of turbidities and sedimentation for 12 weeks. This study found that sedimentation had the most negative impacts, including high rates of mortality, on the species with a horizontal growth form (*Montipora aequituberculata*) in comparison to coral species with an upright, branching morphology (*Acropora millepora*). The authors inferred that intense sediment accumulation on top of both coral species over time exceeded their ability to remove particles, resulting in mortality due to suffocation and anoxia.

Specialized Structures to Prevent Sedimentation

Fluctuations in ambient turbidity and sediment deposition are common in coastal marine and estuarine systems. Many species that inhabit these systems have specialized structures (polymorphic individuals within colonies) that help the organisms remove settled debris. However, as the previous study indicates (Flores *et al.* 2012), intense sediment loads may exceed the adaptive capacity of these mechanisms. Examples of species from this study that contain specialized polymorphic individuals include the arborescent bryozoan species, *S. diegensis* and *B. californica.* These species have specialized zooids, including the long setae-like vibracula seen in *S. diegensis* and the smaller pincher-like avicularia in *B. californica,* that act to remove settled debris from the colony, and which may assist these species during times of high sediment suspension and accumulation.

Feeding Behavior

A wide range of filter-feeding mechanisms exist within zoobenthic invertebrate communities, ranging from highly selective particle sorting (e.g. *M. edulis* and *B. neritina*) to non-selective filter-feeding (e.g. *Ciona intestinalis*) (Riisgard and Larsen 2000). These different feeding mechanisms may relate to the energetic efficiency of an organism's ability to acquire the most nutritive value from ingested particles while simultaneously handling high sediment loads. Species that can actively sort through particles may be at the greatest advantage during times of high suspended sediment and thus more tolerant to sediment disturbances as they are able to reject inorganic particulates before they are digested.

The suspension feeding behavior of *M. edulis* has been studied extensively and reveals that it is particularly efficient at selectively ingesting organic particles and sorting them out of suspended sediments (Kiorboe *et al.* 1980, Kiorboe and Flemming 1981, Bayne *et al.* 1987, Riisgard and Larsen 2000). Kiorboe and Flemming (1981) found that *M. edulis* assimilated between 20-30% of organic matter from re-suspended bottom sediment and may actually require this material to reach its full clearance rate potential in the field. Bayne *et al.* (1987) also found that the presence of silt in the water column (depending on particle size and organic content) may enhance growth in *M. edulis*.

The arborescent bryozoan species within communities tested in this study (*B. neritina*, *B. californica* and *S. diegensis*) are active filter-feeders that use rows of cilia to generate currents around their specialized feeding structure, the lophophore, to move fine particles into their mouth or flick rejected particles away. I presumed that the fine cilia of the lophophore would be easily clogged by increasing turbidity and accreted sediment, however all representative colonies of these species were alive and actively feeding after exposure to all levels of turbidity and sedimentation in my experiments.

A Special Note on *Watersipora spp.*

Watersipora spp. was included in this study and in previous pilot studies due to its dramatic die-off in August 2013 during the intertidal dredging that occurred as part of the G&R Metals restoration project on the waterfront in Eureka, CA. In contrast to the high mortality observed in the field, the results of my laboratory studies did not indicate a significant effect of sediment treatment or orientation on survivorship. The survival of *Watersipora spp.* colonies in my experiments, which included 22 days of gradual sediment accumulation (~8mm in depth) in high turbidity (200 NTU) would infer a fairly high level of tolerance to sediment exposure. Theses contrasting findings may be due to the mechanism of sediment suspension in the lab being aeration, which created a more oxygen rich environment than would likely occur in a low-flow environment during a high suspension event.

Bryozoans that belong to the genus *Watersipora* are known to be highly adaptable to changing environmental conditions and have successfully invaded coastal ecosystems around the world, nevertheless, specialized adaptations in *Watersipora spp.* to prevent the buildup of excess sediment are limited. This genus does not have any specialized zooids (e.g. vibracula, avicularia) for removing settled particles like those found on the other bryozoan species in this study. However, each zooecium has a black operculum which can seal tightly over the orifice of each zooid, protecting the soft, internal organs of this animal from being damaged. If this organism can seal its operculum shut when environmental conditions are stressful (e.g. sediment burial) and survive within its calcareous zooecium until external conditions improve, it may be able to survive intermittent periods of sediment deposition.

The mass mortality of *Watersipora spp*. in the field during the summer of 2013 may not have been due to the sole factor of sediment burial. Many factors go hand in hand during high suspension events such as, increasing temperature, lower salinity from freshwater inputs, a reduction in dissolved oxygen, light attenuation, phytoplankton availability, and the potential for contaminants to be re-suspended (Bilotta and Brazier 2008). Other factors at play may include changes in flow patterns, tidal exchange, microhabitat (neighboring species, substrate, etc.), sediment origin and grain size (Rivero *et al*. 2013). It's possible that the interaction of some (if not all) of these factors contributed to the rapid decline of *Watersipora spp.* in the field, however a more thorough investigation is required.

Studying the effects of sediment, independent of other variables encountered in the field may only be producing a "snap-shot" of real conditions. Understanding the strength of each interacting variable and the additive effects of different factors associated with high turbidity events on biological communities is necessary to capture the whole picture. Few studies have attempted to address these complex interactions within a multivariate context. One notable recent study published by Edge *et al.* (2015), used biomarkers to differentiate between the effects of contaminants found within re-suspended sediments and total suspended solids (TSS) on oyster stress. This study exemplifies the types of tools and innovative approaches necessary to advance our understanding in this field.

CONCLUSIONS

My study is the first of its kind conducted for Humboldt Bay and to my knowledge, is the first to specifically test the direct effects of sediment on naturally settled communities of sessile fouling invertebrate species. The results of this study fills a significant gap in the literature, as we know very little about the effects of sediment on marine invertebrate communities (Miller *et al.* 2002, Arioldi 2003, Burton and Johnston 2010, Roberts 2012) and even less about their effects on sessile, filter-feeding organisms. Most of what is already known has simply been inferred and not rigorously tested in the field or lab. My study sets a foundation for future studies to be built upon to examine the effects of sediment in Humboldt Bay and other similarly sediment-impacted bays. The methods employed by this study are easy to replicate and can accommodate multiple treatments if one wanted to test the interactions of sediment with other variables (e.g. salinity) in a lab setting. Sediment from multiple sites and compositions could be examined, as well as varied trial durations to test the effect of exposure time on species response. The experimental design could also be used to initiate a controlled disturbance in the lab before transporting communities to the field to examine the effects of a high-sediment event on competition and community organization, for example. Bear in mind that the mechanism used to maintain sediment suspension was aeration, which minimized the growth of anaerobes and increased the level of dissolved oxygen beyond what may actually occur in a low-flow, high-sediment environment in Humboldt Bay. Therefore, alternative methods of sediment suspension may need to be explored.

This study concludes that sediment, in the absence of other physical and biological disturbances can have significant, lethal effects on specific groups of species within the sessile, filter-feeding marine invertebrate fouling community. Orientation of these communities in the field, along with species morphology, feeding and respiratory behavior may play a critical role in survival during high suspension events (130 NTU) in Humboldt Bay. Taxa inhabiting near-shore, low-flow environments may be more vulnerable to sediment accretion during a high suspension event, and particularly those with low-profile growth forms are likely to be more adversely affected relative to taxa with upright morphologies.

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