Acute Turbidity Exposures with Port of Miami Sediments Impact *Orbicella faveolata* Tissue Regeneration

Lisa A. May[1], Carl V. Miller[1], Zachary J. Moffitt[1], Len Balthis[2], Jocelyn Karazsia[3], Pace Wilber[4] and Cheryl M. Woodley[5*]*

[1]Consolidated Safety Services, Inc. contractor for National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, Hollings Marine Laboratory, 331 Ft. Johnson Rd., Charleston, SC, 29412

[2]National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, 219 Ft. Johnson Rd., Charleston, SC 29412 (*retired*)

[3]National Oceanic and Atmospheric Administration, National Marine Fisheries Service Southeast Regional Office, Habitat Conservation Division, 400 North Congress Ave, Suite 270, West Palm Beach, FL 33401

[4]National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Regional Office, Habitat Conservation Division, 219 Ft Johnson Road, Charleston, SC 29412

[5]National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, Hollings Marine Laboratory, 331 Fort Johnson Rd., Charleston, SC 29412

* corresponding authors: lisa.may@noaa.gov; cheryl.woodley@noaa.gov

Abstract

We evaluated acute turbidity effects on a threatened coral species (*Orbicella faveolata*) under three challenge scenarios. A Port of Miami sediment homogenate was used to simulate turbid conditions during dredging. We observed that low turbidity levels (≤ 4 NTU) have negative effects on *O. faveolata* tissue regeneration following a 96-h exposure. A 48-h turbidity exposure (maximum 30 NTU) followed by placement in fresh seawater had no effect on *O. faveolata* tissue regeneration, demonstrating that short term turbidity exposures may not be detrimental to coral health. In a 13-day test, treated coral fragments (maximum 30 NTU) exhibited significant delays in tissue regeneration. *Lytechinus variegatus* embryos were used in a standard toxicity test. No toxic effects were observed indicating pollutants in the sediment were not a factor inhibiting coral tissue regrowth. The results presented here can be used to inform management decisions for proposed dredging activities proximal to coral reef habitats.

Keywords: turbidity, dredging, *Orbicella faveolata*, tissue regeneration, coral health, sea urchin embryo development toxicity test

Introduction

Increased turbidity occurs in coastal zones and nearby watersheds due to natural events (e.g., runoff from rainfall, wave action) and anthropogenic activities (e.g., agriculture, coastal development, dredging). Florida's seaports are some of the largest in the world and generate $117.6 billion in revenue (13.3 % of the state gross domestic product) with marine cargo and vessel activity. (Florida Ports Council, 2016). Dredging in ports along the U.S. Florida coast is necessary for maintenance or expansion of shipping channels; however, negative impacts to benthic fauna can occur from increased turbidity or sediment accumulation. Elevated turbidity and increased sedimentation from dredging near coral reefs may result in adverse health effects in corals due to reduced light levels (Dallmeyer et al., 1982; Telesnicki and Goldberg, 1995), potential toxicity and/or tissue loss with surface accumulation of sediments (which creates an anoxic environment), particularly if the sediment harbors significant amounts of pollutants (metals, organohalide compounds, etc.) (Erftemeijer et al., 2012, review). Reduced light levels negatively impact the ability of symbiotic algae to fix carbon, a significant source of energy for the coral host (Muscatine and Porter, 1977). Considering both the reduction in light and the excess mucus production that corals use to remove any accumulated sediment particles, it is reasonable to expect that scleractinian corals under turbid conditions likely will have a reduced energy budget for activities such as growth and reproduction.

While there have been many scientific reports on the effects of turbidity on corals, there are few controlled laboratory studies linking discrete health effects from increased turbidity as measured in nephelometric turbidity units, NTU (Fourney and

Figueiredo, 2017; Telesnicki and Goldberg, 1995). The Florida turbidity threshold (50 Jackson turbidity units) was established in 1962 and was converted to nephelometric turbidity units (29 NTU) in 1983 (US Environmental Protection Agency, 1988). Since the criterion was established prior to turbidity studies on shallow-water corals, it is unknown whether it is sufficient for protection of ESA-listed corals such as *Orbicella faveolata*. As part of a triennial review, the Florida Department of Environmental Protection is proposing the addition of a subpart (b) to the current criterion language, specifically for the protection of coral reefs and hardbottom communities. Since this addition is currently being evaluated, there is a crucial need for scientific data linking turbidity effects to coral health. The NOAA National Marine Fisheries Service (NMFS) is also responsible for implementing the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery and Conservation Act and Section 7 of the ESA, requiring the evaluation of routes of effects from dredging activities to corals, including ESA-listed corals. Through these mandates, NMFS identifies measures to reduce impacts to corals from dredge operations, such as development of acute and chronic water quality thresholds protective of corals.

Growth rates (e. g., buoyant density, linear extension, etc.) have been used for decades to determine effects of turbidity on the coral animal (Bak, 1978; Dodge and Vaisnys, 1977; Goh and Chou, 1995; Hennige et al., 2008; Jokiel et al., 2014; Manzello et al., 2021; Rice and Hunter, 1992), however it is difficult to capture meaningful differences in short-term exposures (days), particularly for slower-growing coral species such as *O. faveolata*. Tissue regeneration has been used historically as an effective research tool to evaluate coral health *in situ,* with slower regeneration rates associated

with increased exposure to stressors (Dustan et al., 2008; Fisher et al., 2007; Kramarsky-Winter and Loya, 2000; Meesters and Bak, 1993; Moses and Hallock, 2016; Rodriguez-Villalobos et al., 2016; Traylor-Knowles, 2016). Recently we have demonstrated its sensitivity as a laboratory method to determine acute ecotoxicological effects to an oil-exposed, branching Pacific coral (May et al., 2020).

The mountainous star coral, *Orbicella faveolata* (formerly *Montastraea faveolata*, Ellis and Solander, 1786) is a massive bouldering stony coral native to the Gulf of Mexico, western Atlantic Ocean and Caribbean Sea (Hoeksema and Cairns, 2020). The relatively slow growth rate of *O. faveolata* coupled with increased loss of colonies due to disease, habitat degradation, land-based sources of pollution, and other factors has resulted in its protection as a threatened species under the U. S. Endangered Species Act (Federal Register, 2014). *Orbicella faveolata* is present in nearshore waters, ranging from 0.5-40 m depths and is co-located with high-latitude corals offshore from Port Everglades and Port of Miami, FL. Extensive mortality and habitat loss for *O. faveolata* and other coral species have been associated with dredging projects (Cunning et al., 2019; Miller et al., 2016).

The purpose of this study was to investigate how short-term (2-13 d) turbidity exposures using a simulated dredge sediment might affect tissue regeneration in *O. faveolata*. Additionally, the sea urchin embryo development assay (SUETOX), a standard method used to gauge toxicity of sediment interstitial waters to early life stages (ASTM, 2006; Chapman et al., 1995; Carr and Chapman, 1992; Carr et al., 1996), was employed to estimate potential toxicity of the sediment mixture. This assay was slightly

modified by using sediment mixed with artificial seawater at the same concentrations as the coral exposures to gauge toxicity.

Methods

Husbandry

Colonies (>30 cm) of *O. faveolata*, are long-term holdings of the NOAA National Centers for Coastal Ocean Science, Charleston Laboratory (NCCOS CHS) and held under the Florida Keys National Marine Sanctuary, permit #FKNMS-2016-021 and South Carolina Department of Natural Resources non-indigenous species permit #NI17-0401. One colony of *O. faveolata* was used to generate approximately 100 nubbins (1 cm long x 1 cm wide). Each nubbin was attached with cyanoacrylate gel to a custom Teflon mounting peg. During the 12 weeks of healing, nubbins were maintained in a recirculating custom glass and Teflon aquarium system (570 L) in artificial seawater (ASW, Tropic Marin, Wartemburg, Germany, 36 ppt). Biological filtration was provided by a refugium compartment in the sump with a 5-inch-deep sand bed and approximately 80 lb of seeded live rock. A constant seawater temperature of 26 ± 1 °C was maintained using a 300 W submersible glass heater (Jager TruTemp, Eheim, Deizisau, Germany). Two LED light fixtures (Radion XR30 G4 Pro, Ecotech Marine, Lehigh County, Pennsylvania) provided an average irradiance of 150 µmol photons m^{-2} s^{-1} with a 10 h:14 h light:dark cycle. Lighting was programmed to increase or decrease slowly (over 1.5 h) on each end of the light cycle. Water circulation was provided by a Teflon (ETFE) lined pump (MD-55Y, Iwaki America, Inc., Holliston, MA) and 1-inch Teflon (PTFE) piping. Calcium, alkalinity and trace element levels (e.g., Mg, K, Sr, Mo) were

138 regulated with custom glass calcium reactors (Greatglas, Inc., Wilmington, DE) via a
139 manual drip system (total alkalinity range = 143-161 mg/L $CaCO_3$; pH = 8.1-8.3).

140 Sediment source and particle size analysis

141 Port of Miami sediment samples were collected at 20 discrete sites in April 2016
142 by the NOAA National Marine Fisheries Service, and used for mineralogy and stable
143 isotope analysis (organic C, organic N and inorganic C and O) (Swart, 2016).
144 Approximately two years after analysis (samples held at room temperature), the
145 remaining samples were transferred to NCCOS CHS, for use in coral turbidity challenge
146 experiments. Sample subsets were pooled and mixed thoroughly by hand for the
147 preliminary tests. Subsequently the sediment mixture was cryomilled (SPEX Certi-Prep,
148 Metuchen, NJ) at 10 cycles per second for 9 min and dried (105 °C) for 72 h. A wet
149 sediment treatment sample in ASW (collected directly from a treatment vessel) was
150 used for particle size analysis. Samples were placed in a Malvern Mastersizer 3000
151 (Malvern, United Kingdom), which uses laser diffraction to determine particle size
152 (range: 0.01 – 3500 µm). Samples were circulated to ensure equal distribution in the
153 measurement cell. Data are reported as the average of 10 measurement runs.

154 Sea urchin embryo development toxicity assay

155 To understand potential intrinsic toxicity of the Port of Miami sediment sample,
156 we performed a sea urchin embryo development toxicity test with *Lytechinus variegatus*
157 (green sea urchin) using a modified standard protocol (ASTM, 2006). Sea urchin
158 embryos were exposed to 50, 100 and 150 mg/L concentrations of the cryomilled, dried
159 sediment homogenate mixed in artificial seawater in a static test. These were the same
160 sediment concentrations used in the coral turbidity exposures. Assays were performed

161 in 20 mL pre-cleaned glass vials in a total volume of 5 mL, with approximately 200
162 embryos per vial. An assay negative (ASW) control was included in the experiment (4
163 replicate vials per treatment). Following a 48-h incubation (26 °C, no continuous
164 mixing), sea urchin development was halted with the addition of an equal volume of 2X
165 zinc-formalin fixative (Z-fix, Anatech, Poughkeepsie, NY) and embryo developmental
166 stage was scored and imaged (n = 100 embryos/vial).

167 Coral challenge experiments

168 *Optimization of turbidity dosing system*

169 There are several reports documenting the effect of turbid conditions on shallow
170 water coral species (Jones et al., 2016; Fourney and Figueiredo, 2017; Bessell-Browne
171 et al., 2017), however there are no cost-effective, standardized laboratory methods to
172 test turbidity effects on benthic marine organisms. Thus, we performed extensive
173 system validation tests to address this knowledge gap. In our tests, we included three
174 methods for sediment agitation (aquarium pump, 250 rpm stir plate, 300 rpm stir plate),
175 three methods for suspending coral in the treatment beakers (custom-manufactured
176 polypropylene sheeting with silicone support, egg crate louver with silicone support and
177 egg crate louver without support) and three methods for preparing sediment (wet
178 homogenate, wet cryomilled homogenate and dry cryomilled homogenate). A complete
179 list of materials used is detailed in Supplement 1.

180 *96-h dose response experiment*

181 Port of Miami sediment loads (50, 100 and 150 mg/L) were chosen based on
182 preliminary tests to target peak turbidity measurements of approximately 5, 20 and 30
183 nephelometric turbidity units (NTU), respectively. These values were chosen to better

understand turbidity effects on *O. faveolata* within a broad range, not to exceed the current Florida turbidity criterion (29 NTU above background) (US Environmental Protection Agency, 1988), with background averaging ~1 NTU on the southeast Florida coastal shelf; (Gramer and Hendee, 2018; Whitall, et al., 2019). Glass dosing beakers (2.0 L) for controls and treatments (n = 4) were randomly arranged on two 15-position stir plates in a temperature-controlled room (26.5 °C). The appropriate amount of dried sediment homogenate was added to beakers filled with 2 L of ASW while stirring with a 2-inch Teflon stir bar (300 rpm). Control beakers contained no added sediment. Sediment was mixed for 15 min prior to placing coral fragments in the center of the treatment vessels (Supplement 2). Beakers were covered with 1/8-inch glass plates (which allow passage of broad spectrum light wavelengths) to reduce evaporation. Lighting was provided by a single Ecotech Radion LED source (PAR = 133-168 µmol photons m^{-2} s^{-1}) on a 10 h:14 h light:dark cycle. Turbidity and temperature measurements were collected every 4 h during the course of the experiment beginning at 10:30 am, except for the 2:30 am time point. Turbidity was measured using a Hach model 2100P turbidimeter, calibrated with Hach StablCal® formazine standards once daily. Salinity and pH were measured every 24 h. Total ammonia nitrogen was measured in preliminary 96 h sediment tests as previously described (May et al., 2022) to ensure no toxicity occurred from that source. Measurements were below 0.07 mg/L (< 8 µg/L ammonia) for all samples.

48-h turbidity exposure with recovery period

A pulse-chase experiment was devised to determine effects of an acute short-term (48-h) exposure of coral to turbidity (100 mg/L sediment load) and to evaluate coral

recovery following the exposure. The appropriate amount of dried anthropogenic sediment mixture was added to each test beaker as detailed for the dose response experiment. Coral fragments were placed in the beakers 15 min following the addition of sediment. Water quality measurements (turbidity, temperature, pH and salinity) were performed as in the 96-h challenge experiment. Corals (controls and treatments) were dosed for 48 h, then transferred to fresh ASW. Accumulated sediment was removed from treated fragments with gentle agitation in treatment water prior to transfer, since wounds could not be imaged without sediment removal. Water changes (100 %) were performed every 96 h thereafter, to maintain salinity. Lighting was as detailed above for the 96-h dose response experiment. Corals were imaged (see tissue regeneration analysis section) at time 0 (prior to dosing), 48 h, and every 24 h following the water change up to 13 d post treatment initiation. Corals were not given supplemental food during the course of this experiment.

13-day turbidity exposure

A third experiment was conducted to determine the effects of a 13-day turbidity exposure on coral tissue regeneration using a 100 mg/L sediment load. We based the duration of this experiment on the wound healing process observed for the control fragments, factoring in an expected lag time for the dosed fragments. Glass dosing beakers with ASW were randomly arranged on a single 15-position stir plate (control and treatment, n = 4) and anthropogenic sediment was added and allowed to mix for 15 min before the addition of the coral fragments, as in previous experiments. Water quality measurements and lighting were as described above. Water changes with either fresh ASW (controls) or freshly-made treatment solution (turbid samples) were

performed every 96 h to keep salinity in check. Corals were imaged as described below at time 0 and every 24 h up to 13 d post treatment initiation. Corals in the turbidity treatment were agitated gently in the treatment water to remove accumulated sediment prior to imaging, then immediately replaced into the treatment beakers.

Coral tissue regeneration analysis

Prior to experiment initiation, *O. faveolata* fragments (1 cm x 1 cm x 1cm) were removed from the culture aquarium and placed in a Dremel workstation (Supplement 3), approximately 2 cm below a Dremel rotary tool fitted with a 2.0 mm diamond hole saw bit (Lasco Diamond Products, Los Angeles, CA). Coral support pegs were held in place manually as the rotating bit was lowered to the coral surface over the center of a polyp. Nubbins were wounded to a depth of approximately 2 mm (entire polyp was removed). Tissue slurry was removed by gentle application of an ASW stream using a 1000 µL micropipettor. The coral was placed in a 500 mL clean glass jar filled with ASW and bright field and fluorescent images (filter #U-MNV2: excitation: 400-410 nm; emission (barrier filter): 455 nm; dichromatic mirror: DM400-410 nm; Chroma Technology Corp, Bellows Falls, VT) were collected of the cut surface next to a centimeter ruler using a MVX10 research macro zoom microscope with a 0.63x objective (Olympus, Melville, NY) and equipped with a DP71 digital camera (Olympus, Center Valley, PA) (Supplement 4). The narrow violet wavelength excites the green fluorescent protein in *O. faveolata* tissues, allowing for accurate measurement of tissue re-growth. At experiment termination (96 h), coral wounds were imaged again as described above.

Skeletal area for each coral image was determined using a modified ImageJ (Schneider et al., 2012) macro from the NOAA/NCCOS Coral Disease and Health

Consortium website (https://cdn.coastalscience.noaa.gov/media/cdhc/Lesion_3mm_rule.txt). Pixel units were calibrated to the centimeter ruler in each image. Total area of bare skeleton and wound perimeter values were recorded for each fragment at time 0 and each experimental time point. Percent tissue regeneration was determined from the difference in skeletal area between the time 0 and the experimental time points. Linear healing per day was calculated using the area and perimeter of the wound in Equation 1 (modified from Gorin et al., 1996).

Equation 1: $(A_{t-1} - A_t)/\text{mean}(P_{t-1}, P_t)$

Where: A_t = skeletal area at given experimental time point

A_{t-1} = skeletal area at previous time point

P_t = wound perimeter at given experimental time point

P_{t-1} = wound perimeter at previous time point

Statistical analyses

Statistical analyses for the SUETOX test were performed using GraphPad Prism, version 9.4.0. using percent normal embryo development. Data were normally distributed (Shapiro-Wilk test) and residual variances were homogeneous. A one-way ANOVA was performed with a Dunnett's post test using the ASW treatment as the experimental control. Alpha was set to 0.05 for all tests.

For the 96-h dose-response test, three treatments (50, 100 and 150 mg/L) were compared to the no sediment control using a one-way ANOVA followed by Dunnett's post test. For the 48-h pulse-chase and 13-day turbidity challenge experiments, differences between treatments and controls (overall and at each time point) were

evaluated using linear and (where possible) nonlinear mixed-effects models in order to incorporate the fixed effect of treatment as well as the random effect of subject (individual coral fragments) and any potential within-subject serial autocorrelation over time. Models were tested under various within-subject correlation structures. The best-fitting models were selected based on significance of likelihood ratio tests, normality of residuals, and homogeneity of variance.

Results

Turbidity test design optimization

Ten turbidity tests (with and without coral) were performed to determine the optimal method for the coral exposures (Supplement 5). The method resulting in the most stable and easily-replicated turbidity mixture included using defined weights of dry, cryomilled sediment, with continuous mixing in a 2.0 L beaker (2.0 L ASW volume) using a magnetic stir plate-Teflon stir bar combination at 300 rpm. Coral fragments on Teflon pegs were supported in the beaker on an egg crate louver, cut to fit snugly in the beaker and positioned at the 1200 mL mark.

Boulder coral nubbin wounding technique

Chisels and leather punches have been used to wound large bouldering corals in the field, however when small chisels and punches were tested on the *O. faveolata* nubbins, the small coral fragments shattered. Various other methods were attempted, including chipping and scraping tissue using small flat tools (chisels, screwdrivers). The wounds created were very uneven and difficult to measure, since tissue was not removed evenly. Additionally, we could not create wounds of uniform sizes across replicates. We found that removing a single polyp with a rotary drilling tool created the

most uniform wound sizes. The drilling process created a tissue and skeleton slurry, which caused the remaining live tissue to bleach, if not removed. The slurry was rinsed from the live tissue with a gentle stream of ASW. This process resulted in *O. faveolata* nubbins with uniform wounds (~3 mm dia x 2 mm deep), and which healed ~60 % within four days.

Sea urchin embryo toxicity assay

Water quality parameters for the sea urchin treatments were within acceptable ranges for the test (Carr et al., 2006) (Supplement 6). Salinity ranged from 36 – 37 ppt and pH was between 8.32 and 8.40. Ammonia was at or below 13.4 µg/L for all treatments. No sediment toxicity was observed using the SUETOX test (Figure 1). A slight enhancement of normal embryo development in sediment treatments was noted (91-94 % normally developed embryos) compared to the ASW negative control (86 % normally developed embryos), but this was not statistically significant.

Orbicella faveolata turbidity challenge experiments

Water quality

General water quality parameters remained stable during the course of each acute turbidity challenge experiment. Seawater temperatures ranged from 25.0-27.5 °C, pH ranged from 8.00-8.40 and salinity was between 36-39 ppt. Sediment loads of 100 mg/L and greater resulted in reduced pH over time in the dose-response experiment, and between water changes for the pulse-chase and 13-day experiments (Figure 2). Turbidity results for each experiment are shown in Figure 3. Average peak turbidity in the dose response experiment was 4 NTU for the 50 mg/L sediment load, 20 NTU for the 100 mg/L treatment, and 30 NTU for the highest treatment. Peak turbidity

was at time 0 for the low sediment load, and at 32-36 h for the two higher sediment loads. No significant effects of measured water quality parameters on coral tissue regeneration or linear healing rates, independent of sediment additions, were observed. Particle size analysis of the wet anthropogenic sediment samples used in the coral challenge experiments demonstrated that most sediment grains were less than ~100 µm (Dv90 = 104 µm, Supplement 7), with more than 50 % of the sediment grains classified as coarse silts or very fine sands based on the Wentworth grain size chart (Wentworth, 1922).

Effects of 96 h dose response turbidity exposure on Orbicella faveolata *tissue regeneration*

Results of the turbidity 96-h dose response experiment for *O. faveolata* are presented in Figure 4. Turbidity from Port of Miami sediment homogenate negatively impacted coral tissue regeneration at all sediment loads (average peak turbidity = 4, 20 and 30 NTU). Percent regeneration was significantly lower for all three treatments compared to the control ($p = 0.0016$). Fluorescent images of representative *O. faveolata* fragments at time 0 and 96 h are shown in Figure 5.

Effects of acute, short-term turbidity on Orbicella faveolata *tissue regeneration*

A linear mixed-effects model fit to results of the 48-hr pulse-chase experiment did not detect any significant effect of turbidity on tissue regeneration and linear healing rates at any time point (Figure 6).

Effects of 13-day turbidity exposure on Orbicella faveolata *tissue regeneration*

Results of the 13-day turbidity exposure for *O. faveolata* are presented in Figure 7. While differences in tissue regeneration between treatment and control were

observed, the effect of treatment varied by time point (Figure 7A). Accelerated linear healing rate between day 1 and day 2 was noted despite continued sediment exposure (Figure 7B). The results of a nonlinear mixed-effects model incorporating a three-parameter logistic function to model the change in percent regeneration over time is shown in Figure 8. The only parameter to vary significantly between treatment and control was xmid (which represents the x value at the inflection point of the curve, ~50 %), with control xmid at 3.1 d versus 5.5 d for treated samples.

Discussion

Global commerce via shipping and the demand for deeper ports to accommodate larger ships places increased pressure on nearshore benthic marine communities such as coral reefs. Resource managers must weigh the benefits of commercial activities (ship traffic, dredging) in nearshore habitats with the health and longevity of those marine species they protect. Research to understand measurable thresholds for turbidity impacts is crucial for this decision-making process. To this end, we provide the first report of a turbidity exposure using port sediments, resulting in negative impacts to adult *O. faveolata* tissue regeneration after 96 hours, at turbidity levels below 5 NTU.

Dosing system

We created a relatively simple and inexpensive turbidity dosing system using a beaker and magnetic stirrer combination, taking care to eliminate potential negative effects of a vortex current within the beaker. The egg crate louver served two purposes: coral support and redirecting water flow. The egg crate provided sufficient interference and corals thrived in the microenvironment as a result. Experimental reproducibility was dependent upon the sediment particle size and dryness. We created turbid conditions

using simulated dredge sediment that mimics the particle size range of suspended sediments (coarse silts to very fine sands) found to negatively affect corals during dredging operations (Wang and Beck, 2017; Jones et al., 2016). Finer sediments ensured more complete suspension in the water column, thus more reproducible turbidity values. Evaporation was reduced with the use of glass plate beaker covers, however, water changes were required every 96 h to maintain acceptable water quality parameters for the longer experiments. Turbidity fluctuations are expected during a dredging project and depend upon weather conditions, water currents and tidal flow (Erftemeijer et al., 2012). In our experiments, turbidity did not remain constant, but the incremental increases (as the sediment became suspended slowly) and decreases (as the coral mucus trapped the sediment) mimic what might occur on the reef during dredging.

Sediment toxicity

Potential toxicity from inner harbor sediments is possible. We did not analyze the sediment for potential contaminants, however Fourney and Figueiredo (2017) reported that sediment sourced from the nearby Port Everglades inner harbor contained volatile organic compounds (0.02 mg/kg), metals (Pb and Zn) (78.02 mg/kg) and polycyclic aromatic hydrocarbons (PAH, 0.9 mg/kg) which could be toxic to corals. The Port of Miami sediment homogenate we used could have contained similar levels of toxicants, but due to the age and manipulations of the sediment (cryomilling, drying) prior to experiments, it is likely that any volatile organic compounds would be greatly reduced. However, contaminants such as metals or legacy organic compounds such as polychlorinated biphenyls (PCBs) would likely persist.

391 The SUETOX test is a sensitive assay that has been used to gauge toxicity of
392 marine sediment interstitial waters and industrial discharges (Balthis et al., 2018; Carr et
393 al., 2001; Carr et al., 2003; Chapman et al., 1995; May et al., 2022), Since marine
394 sediments can trap and concentrate chemical contaminants such as metals,
395 hydrocarbons, or pharmaceutical products, we exposed sea urchin embryos to the
396 same sediment concentrations used in the coral exposures to understand if residual
397 sediment contaminants could have played a role in the turbidity impacts observed in *O.*
398 *faveolata*. The results of the sea urchin embryo toxicity test indicate that sediment
399 contaminants likely did not influence the results, since no impacts to urchin embryo
400 development were observed in the 48-h static test.
401 Turbidity effects on coral tissue regeneration
402 We observed significantly decreased tissue regeneration in *O. faveolata*
403 fragments subjected to 50-150 mg/L of an anthropogenic sediment mixture for 96 h.
404 Interestingly, we did not see a correlation with dose and effect. Coral mucus was an
405 efficient sediment trap resulting in decreased turbidity over time and sediment
406 accumulated in the wound area for all turbidity treatments. This may be a physical
407 factor limiting the tissue regrowth, since we observed delayed healing in the presence of
408 sediment in the 13-d experiment compared to the no sediment controls. However, it is
409 likely that with the constant production of mucus for clearing sediment, less energy is
410 available to the coral for other activities, such as wound healing, feeding, respiration or
411 growth. The results of the sea urchin embryo development test indicate that sediment
412 toxicity likely is not a factor in delayed tissue regeneration for these acute exposures.

Significant impacts from turbidity on *O. faveolata* tissue regeneration were not observed for the shortest exposure duration (48 h), however this may be a conservative result since sediment was manually removed prior to placement in fresh ASW. Tissue regeneration reductions were statistically significant in the 13-day continuous exposure, but did not directly mimic our observations in the 96-h dose response experiment (no statistical significance on days 3 and 4). We speculate that the differences could be due to the daily removal of sediment from the wound site for tissue imaging in the 13-d experiment, or individual variability due to innate factors. Manzello et al. (2021) have shown that *O. faveolata* skeletal growth may be more resilient to turbidity impacts than other stony coral species such as *Pseudodiploria strigosa*, which indicates that *O. faveolata* may have more energy available for physiological processes like tissue regeneration. While tissue healing rates of treated fragments lagged behind controls by 2.4 days, healing for both control and treated fragments was nearly 100 % by day 13 (Figure 7), demonstrating that *O. faveolata* may recover from initial turbidity insults with exposures of less than two weeks and below 30 NTU. However, the effects of multiple stressors present during a dredging project (e.g., elevated turbidity, sediment deposition on live tissue and light reduction) requires further testing.

We noted an accelerated linear healing rate following placement in ASW (48-72 h) in the 48-h pulse-chase experiment and also between 24-48 h in the 13-day continuous exposure experiment. Since the anthropogenic sediment likely contains a portion of organic components, it is likely that this increased availability of nutrients to the coral animal (via heterotrophy) or symbionts (increased primary production from biochemical cycling) would generate a coral ‘growth spurt’ while the nutrients last.

436 Since the availability of soluble nutrients (e.g., amino acids, fatty acids, etc) also can
437 affect growth and development of urchin embryos (Shilling and Bosch, 1994), the slight
438 increase in percent normal embryos we observed for sediment-treated samples in the
439 sea urchin toxicity test could be evidence for increased micronutrients in the sediment
440 exposures. Similar to pH observations at the Port of Miami during dredging operations
441 (Enochs et al., 2019), we observed a drop in pH in our challenge systems for sediment
442 loads of >100 mg/L. This may result from the enhanced growth response of the coral
443 animal due to subsequent increased CO_2 produced from cellular respiration, or
444 decreased alkalinity from calcium carbonate deposition. However, reduced light from
445 the suspended sediment, should not be discounted as a factor in initial enhanced
446 healing rates. Increased turbidity has been shown to darken some coral tissues (i. e.,
447 increase zooxanthellae numbers) for low (0-15 mg/L) suspended sediment
448 concentrations (Jones et al., 2020; Luter et al., 2021). This may be a direct result of the
449 increased organic materials in the suspended sediment, or a shift by the holobiont to
450 accommodate the reduction in photosynthetic products. This likely comes at an energy
451 cost for the coral animal, but also could result in enhanced short-term coral tissue
452 growth. We did not calculate symbiont numbers in these acute exposure experiments
453 since wounding the corals would affect the outcome, however, this endpoint should be
454 considered for further work.

455 While the objective of this study was to gauge turbidity impacts from dredging, it
456 also is reasonable to apply this knowledge to other sources of turbidity in the nearshore
457 marine environment. Turbidity in southeast Florida may be influenced by construction in
458 the coastal zone, or storm events which flush sediments from inlets onto the reef. Since

turbidity levels from inlets have been observed within the tested range of our study (Whitall et al., 2019), we would expect that stony corals would be negatively impacted. However, a better understanding of how these types of intermittent sediment fluxes may affect the reef ecosystem, and ESA corals in particular, is needed.

Future direction

We observed impacts to *O. faveolata* tissue regeneration in acute turbidity challenge experiments, within the range of 4-30 NTU. Our results suggest that *O. faveolata* can recover from acute turbidity insults within a short time (days), yet increased turbidity from dredging activities may last many weeks to months. However, we must emphasize that in using aged, cryomilled sediments, potential sources of stressors including some chemical contaminants and microbial pathogens were likely greatly reduced. In addition, our laboratory studies did not mimic light attenuation occurring at depth with increased turbidity. We recommend that future research incorporate light attenuation and elevated temperatures to model seasonal or possible climate change scenarios. We also recommend longer-term (months) turbidity exposures to more accurately gauge dredging effects near coral reefs. And since dredging activities may be intermittent (depending upon working conditions), repeated exposure scenarios are important to consider, since cumulative insults could impair coral health.

Acknowledgements

The authors would like to thank Jennifer Moore (NOAA Coral Reef Conservation Program), Kurtis Gregg (NOAA National Marine Fisheries Service), and Shelby Wedelich, Jamie Monty and Daryll Joyner (Florida Department of Environmental

Protection) for helpful discussions which guided this study. We would also like to thank Ron Kothera (CSS, Inc. contractor to NOAA) and Jennifer Ness (National Institutes for Standards and Technology, Charleston, SC) for assistance with sediment particle size analysis, Emily Parsons (student, University of Charleston) for technical assistance and Dr. Jeff Guyon (NOAA, Charleston Laboratory) for statistical assistance. Additionally, gratitude is expressed to NOAA scientists, Dr. Dave Whitall and Dr. Tony Pait, for providing critical reviews which greatly improved the manuscript.

Funding

This work was supported by the National Oceanic and Atmospheric Administration Coral Reef Conservation Program project #1133. Additional funding to address priority ESA and EFH consultation needs was supplied by the NOAA National Marine Fisheries Service Southeast Regional Office. Contributions by LAM, CVM, and ZJM were performed under NOAA-CSS, Inc. contract number EA133C17BA0049/C0002.

NOAA disclaimer

The scientific results and conclusions, as well as any opinions expressed herein, are those of the author(s) and do not necessarily reflect the views of NOAA or the Department of Commerce. The mention of any commercial product is not meant as an endorsement by the Agency or Department.

503 **References**

504 ASTM, 2006. "Standard Guide for Conducting Static Acute Toxicity Tests with Echinoid
505 Embryos", E 1563–95, *American Society for Testing and Materials*, West Conshohocken,
506 PA, pp. 1-22. Available from: https://www.astm.org/e1563-98r12.html

507 Bak, R.P.M., 1978. Lethal and sublethal effects of dredging on reef coral. Mar. Pollut.
508 Bull. 9(1):14–6. https://doi.org/10.1016/0025-326X(78)90275-8

509 Balthis W., Cooksey C., Fulton M., Hyland J., May L., Wirth E., et al., 2018.
510 Assessment of Ecological Condition and Potential Stressor Impacts in Offshore Areas of
511 Florida Keys National Marine Sanctuary. Charleston, SC, United States. Nov. 2018. p.
512 1–80. https://doi.org/10.25923/vtsz-v706

513 Bessell-Browne, P., Negri, A.P., Fisher, R., Clode, P.L., Duckworth, A., Jones, R., 2017.
514 Impacts of turbidity on corals: The relative importance of light limitation and suspended
515 sediments. Mar. Pollut. Bull. 117:161-170.
516 https://doi.org/10.1016/j.marpolbul.2017.01.050

517 Carr, R.S., Biedenbach, J.M., Hooten, R.L., 2001. Sediment quality assessment survey
518 and toxicity identification evaluation studies in Lavaca Bay, Texas, a marine Superfund
519 site. Environ. Toxicol. 16:20-30. https://doi.org/10.1002/1522-7278(2001)16:1<20::AID-
520 TOX30>3.0.CO;2-1

521 Carr, R.S., Biedenbach, J.M., Nipper, M., 2006. Influence of potentially confounding
522 factors on sea urchin porewater toxicity tests. Arch. Environ. Contam. Toxicol.
523 51(4):573-9. https://doi.org/10.1007/s00244-006-0009-3

524 Carr, S.R., Chapman, D.C., 1992. Comparison of whole sediment and pore-water
525 toxicity tests for assessing the quality of estuarine sediments. Chem. Ecol. 7:19-30.
526 https://doi.org/10.1080/02757549208055430

527 Carr, S.R., Chapman, D.C., Long, E.R., Windom, H.L., Thursby, G., Sloane, G.M., *et al.,*
528 1996. Sediment quality assessment studies of Tampa Bay, Florida. Environ. Toxicol.
529 Chem. 15:1218-1231. https://doi.org/10.1002/etc.5620150730

530 Carr R.S., Nipper M., Plumlee G.S., 2003. Survey of marine contamination from
531 mining-related activities on Marinduque Island, Philippines: Porewater toxicity and
532 chemistry. Aquat. Ecosyst. Health Manag. 6(4):369–79.
533 https://doi.org/10.3133/ofr01441

534 Chapman, G., Denton, D., Lazorchak, J., 1995. Short-Term Methods for Estimating the
535 Chronic Toxicity of the Effluents and Receiving Waters to West Coast Marine and
536 Estuarine Organisms, in: US EPA (Ed.), Washington, D. C. Available from:
537 https://www.epa.gov/sites/default/files/2015-08/documents/short-term-chronic-marine-
538 and-estuarine-wet-manual_2002.pdf

539 Cunning, R., Silverstein, R.N., Barnes, B.B., Baker, A.C., 2019. Extensive coral
540 mortality and critical habitat loss following dredging and their association with remotely-
541 sensed sediment plumes. Mar. Pollut. Bull. 145:185-199.
542 https://doi.org/10.1016/j.marpolbul.2019.05.027

543 Dallmeyer, D.G., Porter, J.W., Smith, G.J., 1982. Effects of particulate peat on the
544 behaviour and physiology of the Jamaican reef-building coral *Montastrea annularis*.
545 Mar. Biol. 68:229–233. https://doi.org/10.1007/BF00409589

546 Dodge, R. E., Vaisnys J. R., 1977. Coral populations and growth patterns: Responses
547 to sedimentation and turbidity associated with dredging. J. Mar. Res. 35:715-730.
548 Available from:
549 https://nsuworks.nova.edu/cgi/viewcontent.cgi?article=1046&context=occ_facarticles/

550 Dustan, P., Fauth, J., Pante, E., Banks, K., Downs, C., 2008. Using cellular diagnostics
551 to link land-based sources of pollution with coral reef degradation in South Florida, Proc.
552 11th Int. Coral Reef Symp., pp. 495-499. Available from:
553 http://reefbase.org/resource_center/publication/pub_27569.aspx

554 Enochs, I.C., Manzello, D.P., Jones, P.R., Stamates, S.J., Carsey, T.P., 2019. Seasonal
555 carbonate chemistry dynamics on Southeast Florida coral reefs: Localized acidification
556 hotspots from navigational inlets. Front. Mar. Sci. 6-2019.
557 https://www.frontiersin.org/articles/10.3389/fmars.2019.00160

558 Erftemeijer, P.L., Riegl, B., Hoeksema, B.W., Todd, P.A., 2012. Environmental impacts
559 of dredging and other sediment disturbances on corals: a review. Mar. Pollut. Bull.
560 64(9):1737–65. https://doi.org/10.1016/j.marpolbul.2012.05.008

561 Federal Register, 2014. "Endangered and Threatened Wildlife and Plants: Final Listing
562 Determinations on Proposal To List 66 Reef-Building Coral Species and To Reclassify
563 Elkhorn and Staghorn Corals." 79 FR 53851 (09/10/2014). Accessed through:
564 https://www.federalregister.gov/documents/2014/09/10/2014-20814/endangered-and-
565 threatened-wildlife-and-plants-final-listing-determinations-on-proposal-to-list-66 on
566 2021-08-27.

567 Fisher, E.M., Fauth, J.E., Hallock, P., Woodley, C.M., 2007. Lesion regeneration rates
568 in reef-building corals *Montastraea* spp. as indicators of colony condition. Mar. Ecol.
569 Prog. Ser. 339:61-71. https://doi.org/10.3354/meps339061

570 Florida Ports Council, 2016. The Statewide EconomicI of Florida Seaports. Florida
571 Seaport Transportation and Economic Development Council, Tallahassee, FL.
572 December 2016. 30 pp. Available from: https://flaports.org/wp-
573 content/uploads/EconomicImpactsofFloridaSeaports.pdf

574 Fourney, F., Figueiredo, J., 2017. Additive negative effects of anthropogenic
575 sedimentation and warming on the survival of coral recruits. Sci. Rep. 7:12380.
576 https://doi.org/10.1038/s41598-017-12607-w

577 Goh, N.K.C., Chou, L.M., 1995. Growth of five species of gorgonians (Sub-Class
578 Octocorallia) in the sedimented waters of Singapore. Mar. Ecol. 16:337–
579 346. https://doi.org/10.1111/j.1439-0485.1995.tb00416.x

580 Gorin, D.R., Cordts, P.R., Lamorte, W.W., Menzoian, J.O., 1996. The influence of
581 wound geometry on the measurement of wound healing rates in clinical trials. J. Vasc.
582 Surg. 23:524-528. https://doi.org/10.1016/S0741-5214(96)80021-8

583 Gramer, L.J., Hendee, J.C., 2018. Coastal Turbidity on the Southeast Florida Shelf—
584 Monitoring Turbid Water Sources and Fates by Satellite. NOAA Technical
585 Memorandum, OAR-AOML-105, 31 pp. Available from:
586 https://www.coris.noaa.gov/activities/southeast_florida_turbidity/welcome.html

596 Hennige, S.J., Smith, D.J., Perkins, R., Consalvey, M., Paterson, D.M., Suggett, D.J.,

2008. Photoacclimation, growth and distribution of massive coral species in clear and turbid waters. Mar. Ecol. Prog. Ser. 369:77–88. https://www.jstor.org/stable/24872637

Hoeksema, B. W., Cairns, S., 2020. World List of Scleractinia. *Orbicella faveolata* (Ellis & Solander, 1786). Accessed through: World Register of Marine Species at: http://www.marinespecies.org/aphia.php?p=taxdetails&id=758261 on 2020-06-11.

Jokiel, P.L., Rodgers, K.S., Storlazzi, C.D.,Field, M.E., Lager, C.V., Lager, D. 2014. Response of reef corals on a fringing reef flat to elevated suspended-sediment concentrations: Molooka'I, Hawai'i. Peer J. 2:e699. https://peerj.com/articles/699/

Jones, R., Bessell-Browne, P., Fisher, R., Klonowski, W., Slivkoff, M., 2016. Assessing the impacts of sediments from dredging on corals. Mar. Poll. Bull. 102:9-29. https://doi.org/10.1016/j.marpolbul.2015.10.049

Jones, R., Giofre, N., Luter, H.M., Neoh, T.L., Fisher, R., Duckworth, A., 2020. Responses of corals to chronic turbidity. Sci. Rep. 10:4762. https://doi.org/10.1038/s41598-020-61712-w

Kramarsky-Winter, E., Loya, Y., 2000. Tissue regeneration in the coral *Fungia granulosa*: The effect of extrinsic and intrinsic factors. Mar. Biol. 137:867-873. https://doi.org/10.1007/s002270000416

Luter, H.M., Pineda, M.-C., Ricardo, G., Francis, D.S., Fisher, R., Jones, R., 2021. Assessing the risk of light reduction from natural sediment resuspension events and

617 dredging activities in an inshore turbid reef environment. Mar. Poll. Bull. 170:112536.
618 https://doi.org/10.1016/j.marpolbul.2021.112536

619 Manzello, D.P., Kolodziej, G., Kirkland, A., Besemer, N., Enochs, I.C., 2021. Increasing
620 coral calcification in *Orbicella faveolata* and *Pseudodiploria strigosa* at Flower Garden
621 Banks, Gulf of Mexico. Coral Reefs 40:1097-1111. https://doi.org/10.1007/s00338-021-
622 02108-8

623 May, L.A., Burnett, A.R., Miller, C.V., Pisarski, E., Webster, L.F., Moffitt, Z.J.,
624 Pennington, P. Wirth, E., Baker, G., Woodley, C.M., 2020. Effect of Louisiana sweet
625 crude oil on a Pacific coral, *Pocillopora damicornis*. Aquat. Tox. 222:105454.
626 https://doi.org/10.1016/j.aquatox.2020.105454

627 May, L.A., McDonald, E.M., Kothera, R.T., Toline, C.A., McDonough, V., Moffitt, Z.J., et
628 al., 2022. Assessment of sediment porewater toxicity in Biscayne National Park with
629 sea urchin (*Lytechinus variegatus*) embryos. PLoS ONE 17(12): e0278695.
630 https://doi.org/10.1371/journal. pone.0278695

631 Meesters, E., Bak, R.P.M., 1993. Effect of coral bleaching on tissue regeneration
632 potential and colony survival. Mar. Ecol. Prog. Ser. 96:189-198.
633 https://doi.org/10.3354/meps096189

634 Miller, M.W., Karazsia, J., Groves, C.E., Griffin, S., Moore, T., Wilber, P., Gregg, K.,
635 2016. Detecting sedimentation impacts to coral reefs resulting from dredging the Port of
636 Miami, Florida, USA. Peer J. Nov 17:4:e2711. https://peerj.com/articles/2711/

637 Moses, E.F., Hallock, P., 2016. “Coral Regeneration Assay,” in: Woodley, C.M., Downs,
638 C.A., Bruckner, A.W., Porter, J.W., Galloway, S.B. (Eds.), Diseases of Coral. John
639 Wiley & Sons Inc., Hoboken, NJ, pp. 472-481.

640 Muscatine, L., Porter, J.W., 1977. Reef corals: Mutualistic symbioses adapted to
641 nutrient-poor environments. BioScience 27:454-460. https://doi.org/10.2307/1297526

642 Rice, S.A., Hunter, C.L., 1992. Effects of suspended sediment and burial on
643 scleractinian corals from west central Florida patch reefs. Bull. Mar. Sci. 51:429-442.
644 Available from:
645 http://hunterlabhawaii.com/docs/pubs/Rice%20Hunter%20Sediment%201992.pdf

646 Rodriguez-Villalobos, J.C., Work, T.M., Calderon-Aguilera, L.E., 2016. Wound repair in
647 *Pocillopora*. J. Invertebr. Pathol. 139:1-5. https://doi.org/10.1016/j.jip.2016.07.002

648 Schneider, C. A., Rasband, W. S., Eliceiri, K. W., 2012. NIH Image to ImageJ: 25 years
649 of image analysis. Nat. Methods, 9(7):671–675. https://doi.org/10.1038/nmeth.2089

650 Shilling F.M., Bosch I., 1994. Pre-feeding embryos of Antarctic and temperate
651 echinoderms use dissolved organic material for growth and metabolic needs. Mar.
652 Ecol. Prog. Ser. 109:173-182. Available from: http://www.jstor.org/stable/24846183

653 Swart, P.K., 2016. Report on the Mineralogy and Stable Carbon and Oxygen Isotopic
654 Composition of Samples Supplied by NOAA. Final Report to the NOAA National Marine
655 Fisheries Service, 28 June 2016, 16 pp.

656 Telesnecki, G.J., Goldberg, W.M., 1995. Effects of turbidity on the photosynthesis and
657 respiration of two south Florida reef coral species. Bull. Mar. Sci. 57:527-539.

Available from: https://www.ingentaconnect.com/contentone/umrsmas/bullmar/1995/00000057/00000002/art00016?crawler=true

Traylor-Knowles, N., 2016. Distinctive wound-healing characteristics in the corals *Pocillopora damicornis* and *Acropora hyacinthus* found in two different temperature regimes. Mar. Biol. 163:231. https://doi.org/10.1007/s00227-016-3011-y

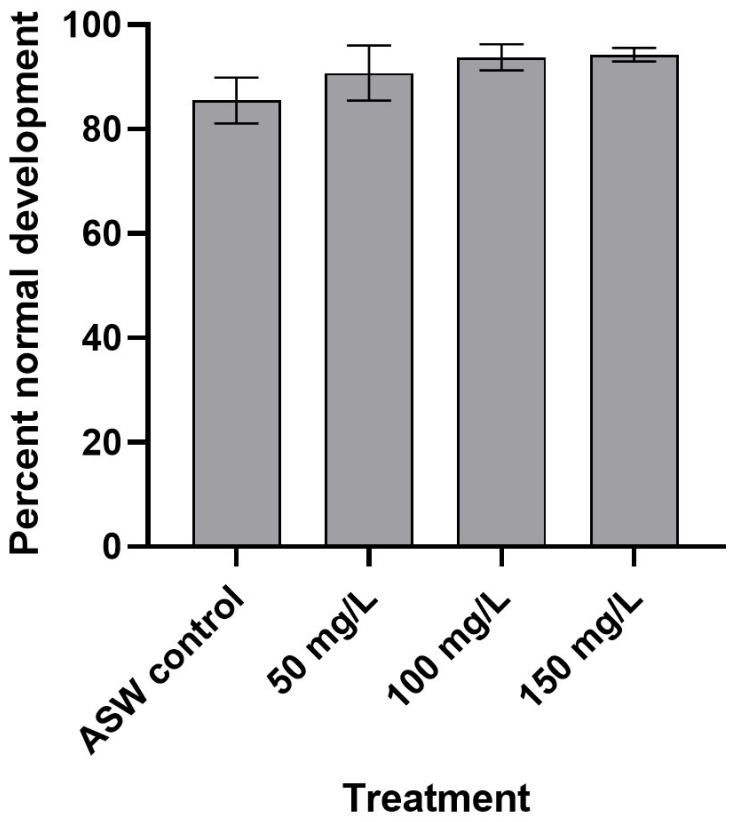
US Environmental Protection Agency, 1988. Water quality standards criteria summaries: A compilation of state/federal criteria. Office of Water Regulations and Standard. Washington, D.C. EPA 440/5-88013. National Technical Information Service document #PB 89–141451.

Wang, P., Beck, T.M., 2017. Determining dredge-induced turbidity and sediment plume settling within an intracoastal waterway system. J. Coast. Res. 33:243-253. https://doi.org/10.2112/JCOASTRES-D-16-00083.1

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30(5):377–392. http://www.jstor.org/stable/30063207

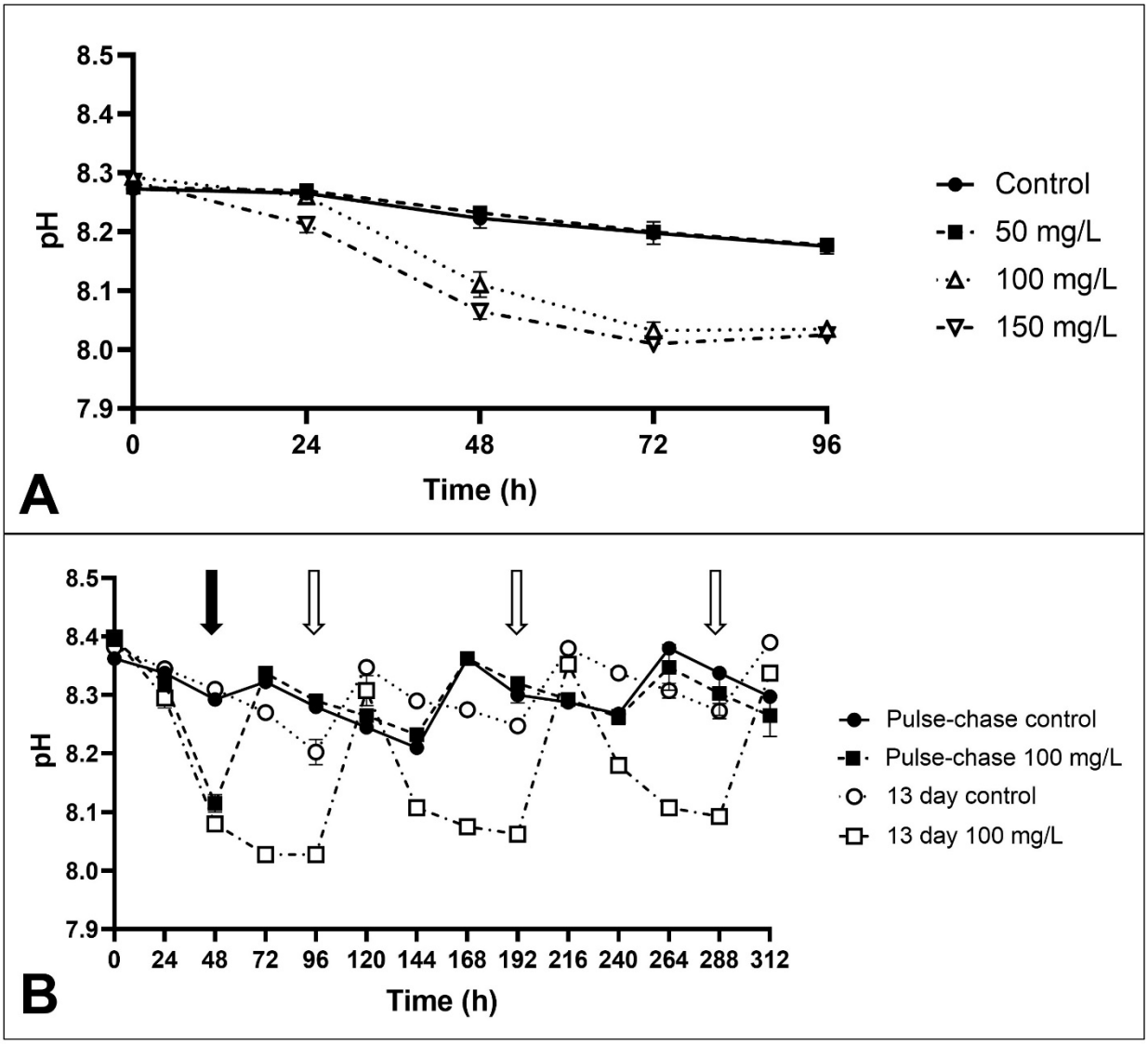
Whitall, D., Bricker, S. Cox, D., Baez, J., Stamates, J., Gregg, K., Pagan, F., 2019. Southeast Florida Reef Tract Water Quality Assessment. NOAA Technical Memorandum NOS NCCOS 271. Silver Spring. 116 pages. https://doi.org/10.25923/kyft-ja41

Figures



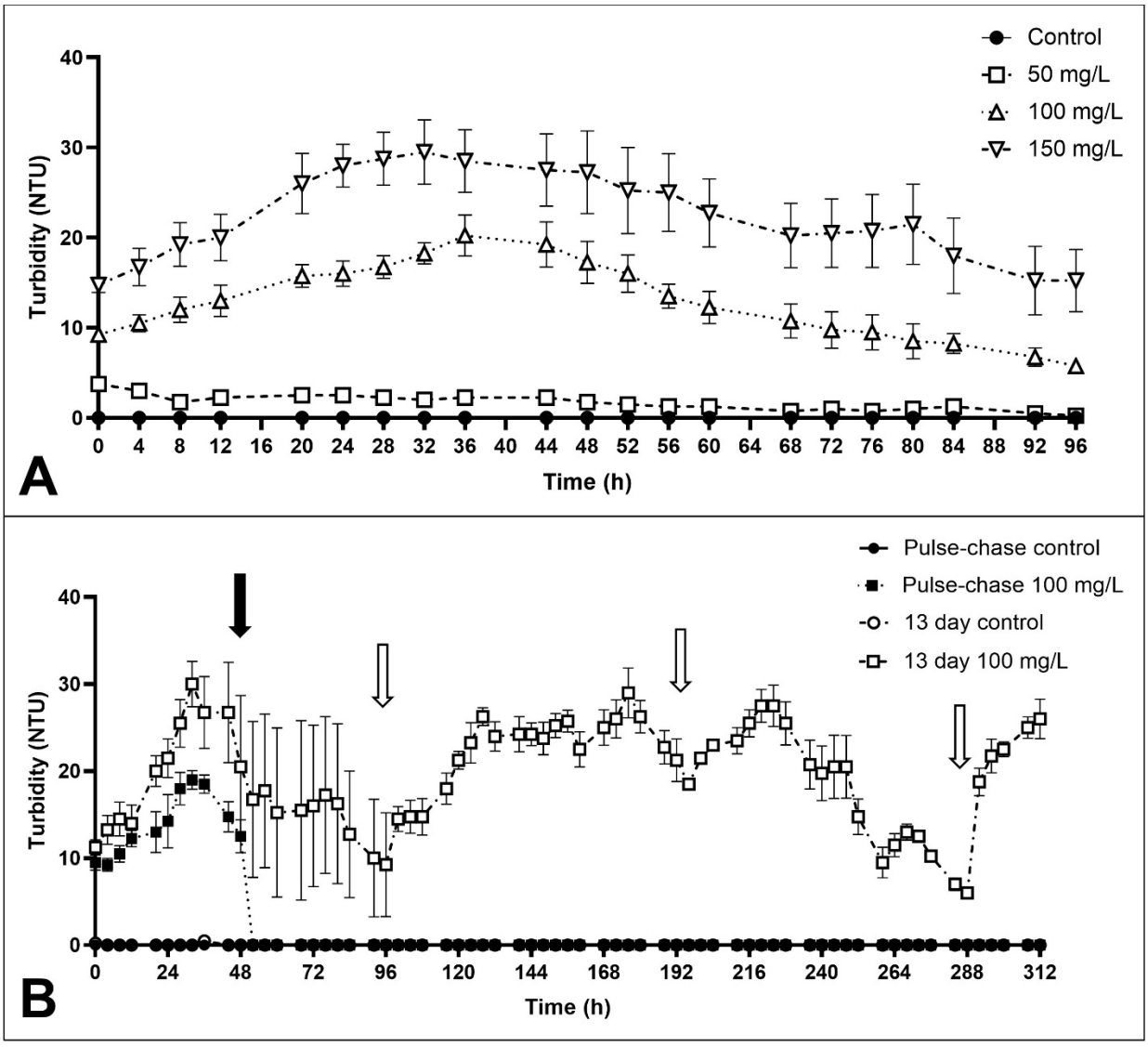
678

679 **Figure 1.** Results of the sea urchin embryo development toxicity assay. Percent normal
680 development for each treatment was not statistically different from the artificial seawater
681 (ASW) negative control. Error bars represent the standard error.



682

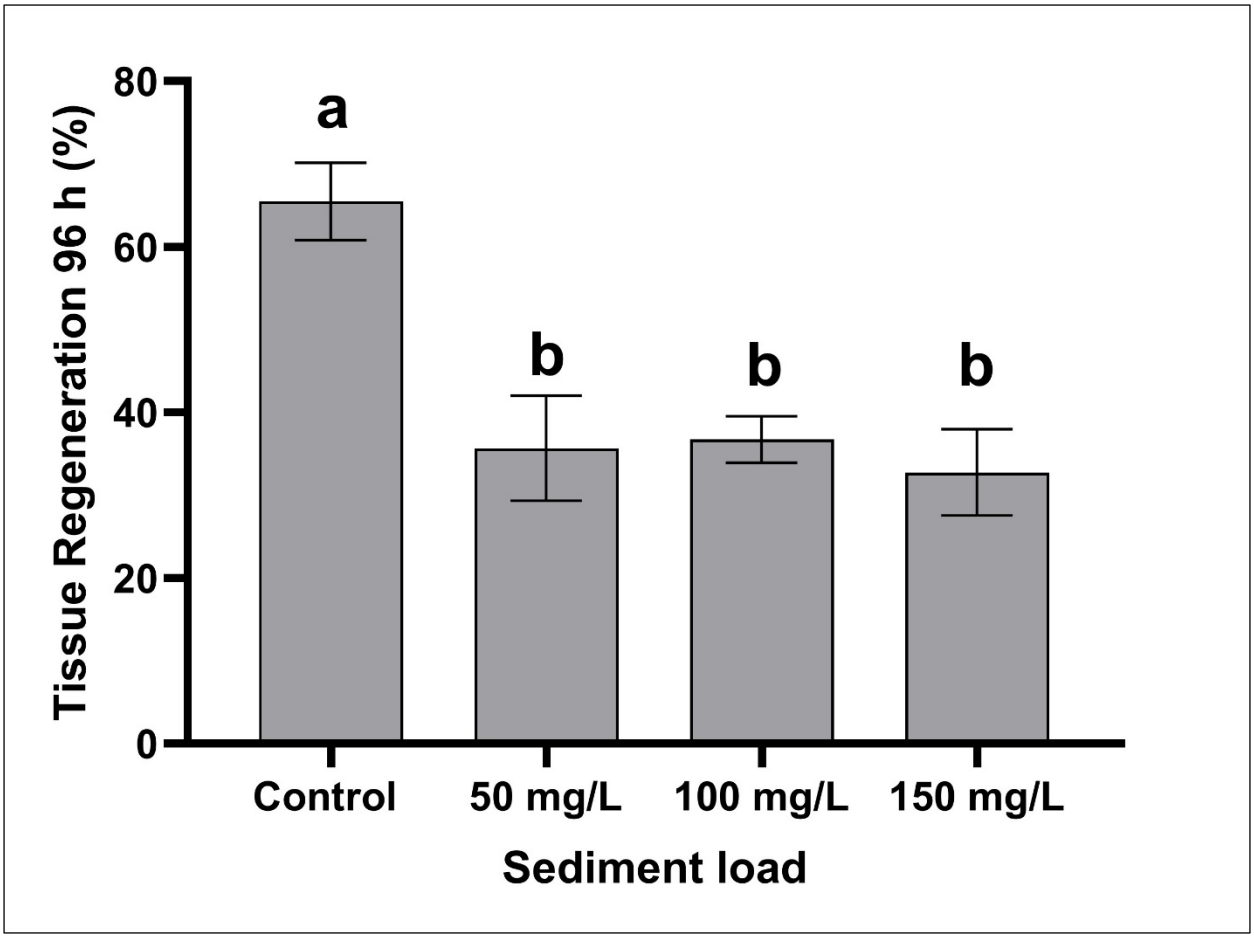
683 **Figure 2.** pH measurements over time for the 96-h dose response experiment (panel
684 A) and for the 48-h pulse-chase and 13-day experiments (panel B). Decreases in pH
685 over time were noted for treatments with ≥100 mg/L sediment (panel A). For the pulse-
686 chase experiment, both treatments were replaced with fresh seawater at 48 h (black
687 arrow). Subsequent water changes for both pulse-chase and control treatments were
688 performed every 96 h. White arrows indicate water and treatment changes for the 13-
689 day experiment (every 96 h). Error bars represent the standard error.



690

691 **Figure 3.** Turbidity measurements over time for the 96-h dose response experiment
692 (panel A) and for the 48-h pulse-chase and 13-day experiments (panel B). Turbidity
693 remained stable across replicates during the dose response experiment. For the pulse-
694 chase experiment, the 100 mg/L sediment treatment was changed to fresh seawater at
695 48 h (black arrow). Subsequent water changes for both pulse-chase treatments were
696 performed every 96 h. One replicate in the 13-day experiment had much higher
697 turbidity than the other two replicates between 48 and 96 h. White arrows indicate

698 water and treatment changes for the 13-day experiment. Error bars represent standard
699 error.



700

701 **Figure 4.** Percent tissue regeneration for *Orbicella faveolata* following a 96-h exposure
702 to Port of Miami sediment homogenate at three concentrations. All treatments had
703 significant reductions in tissue growth (ANOVA, p=0.0016), indicated by differences in
704 letter designations above each column. Average peak turbidity associated with each
705 sediment load was 4 NTU (50 mg/L), 20 NTU (100 mg/L) and 30 NTU (150 mg/L). Error
706 bars represent standard error of the mean.

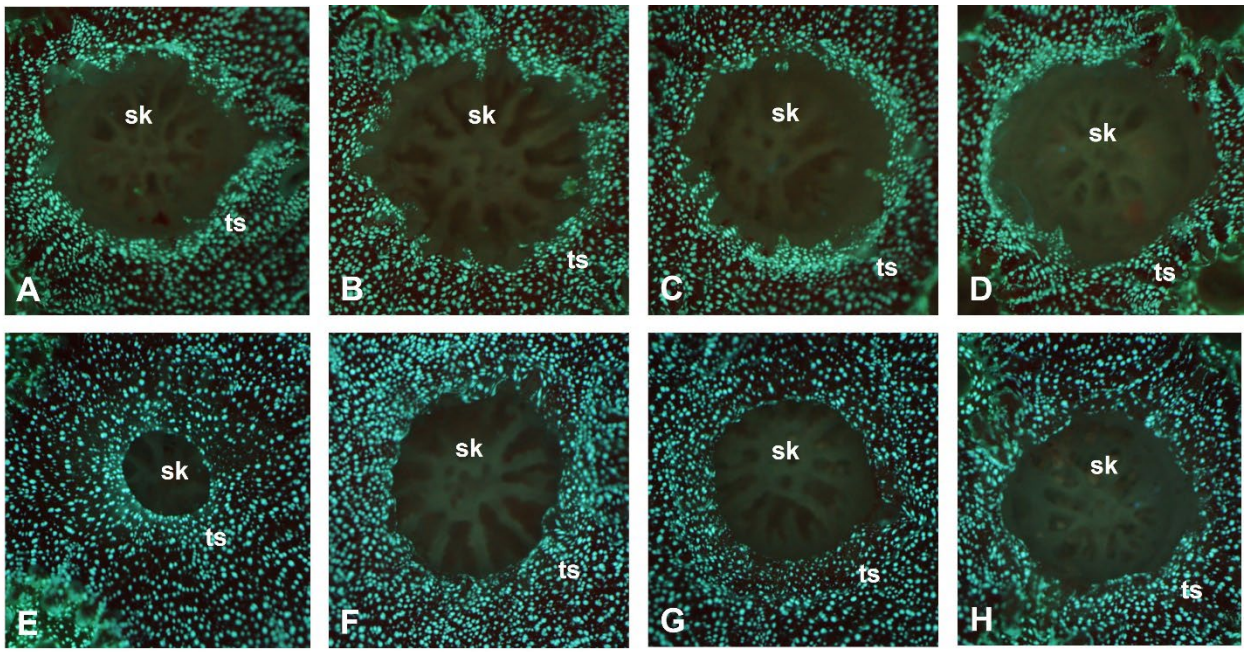
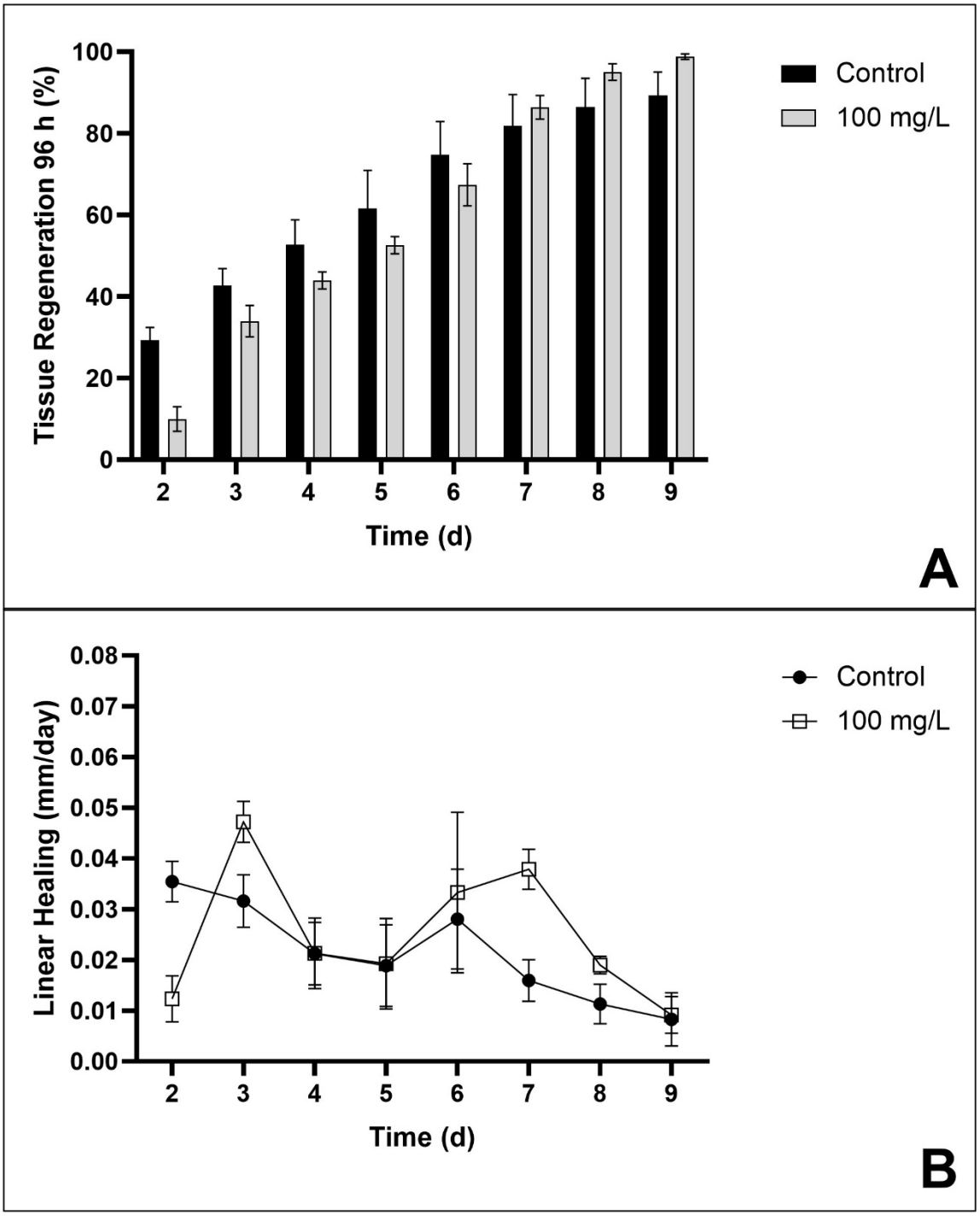


Figure 5. Fluorescent images of representative *Orbicella faveolata* fragments in the 96-h dose response experiment with Port of Miami sediment homogenate. Panels A-D = time 0 images; Panels E-H = images at 96 h. Skeleton (sk) and live tissue (ts) are indicated for controls (panels A and E), 50 mg/L sediment (panels B and F), 100 mg/L sediment (panels C and G) and 150 mg/L sediment (panels D and H).



713

714 **Figure 6**. Results of the 48-h pulse-chase experiment with *Orbicella faveolata*. Panel A

715 = percent tissue regeneration and panel B = linear healing (mm/day). No significant

differences were observed between the 30 NTU (100 mg/L sediment) treatment and control using a linear mixed-effects model. Error bars represent standard error.

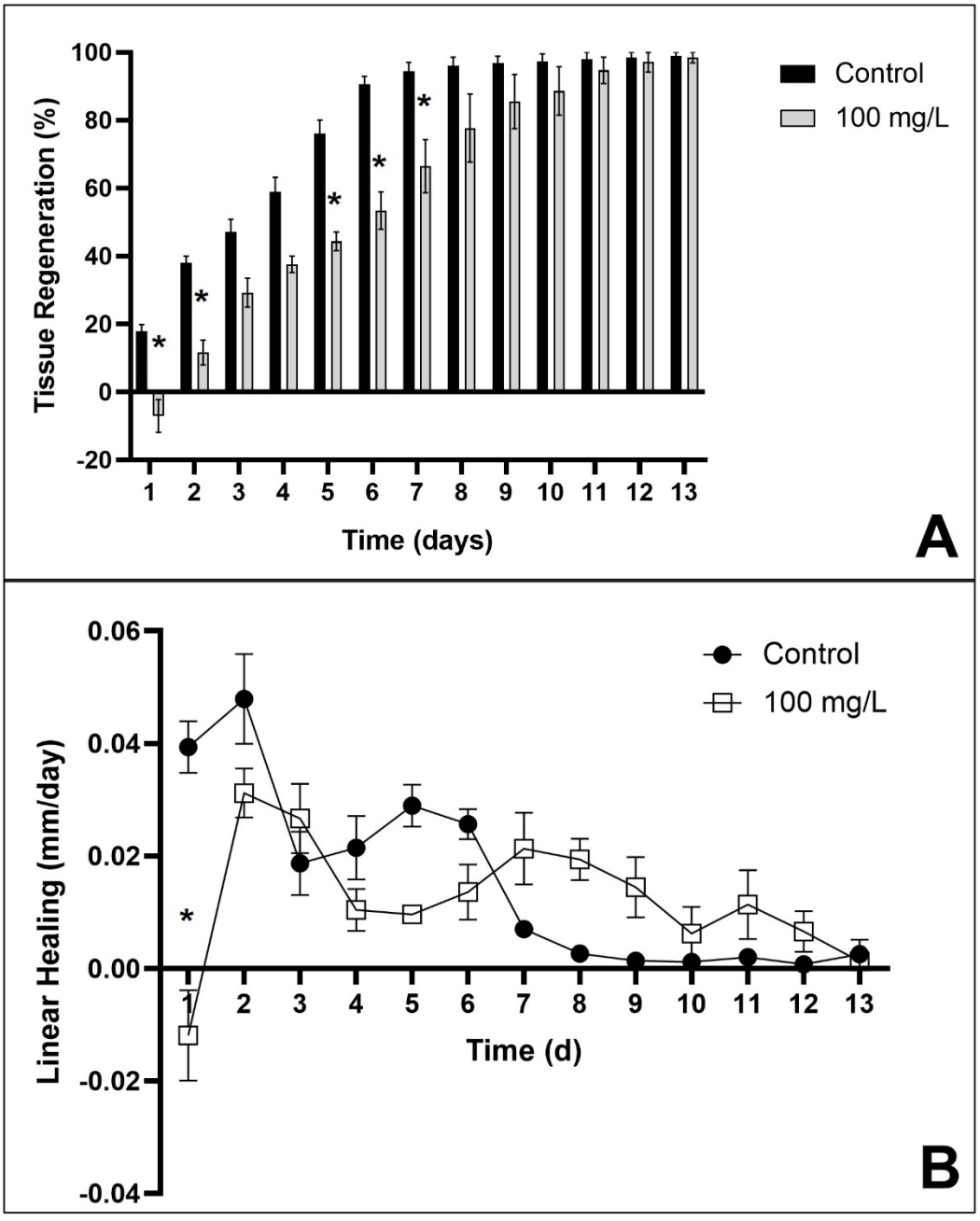


Figure 7. Results of the 13-day turbidity exposure with *Orbicella faveolata*. Panel A = percent tissue regeneration and panel B = linear healing (mm/day). Differences between the 30 NTU (100 mg/L) treatment and control were determined using a linear mixed-effects model. Percent tissue regeneration was significantly different on days 1, 2, 5, 6 and 7. Linear healing rate was significantly different on the first day. (Asterisks denote significance, where $p < 0.05$.) Accelerated healing for treated coral fragments was observed between days 1 and 2. Error bars represent standard error

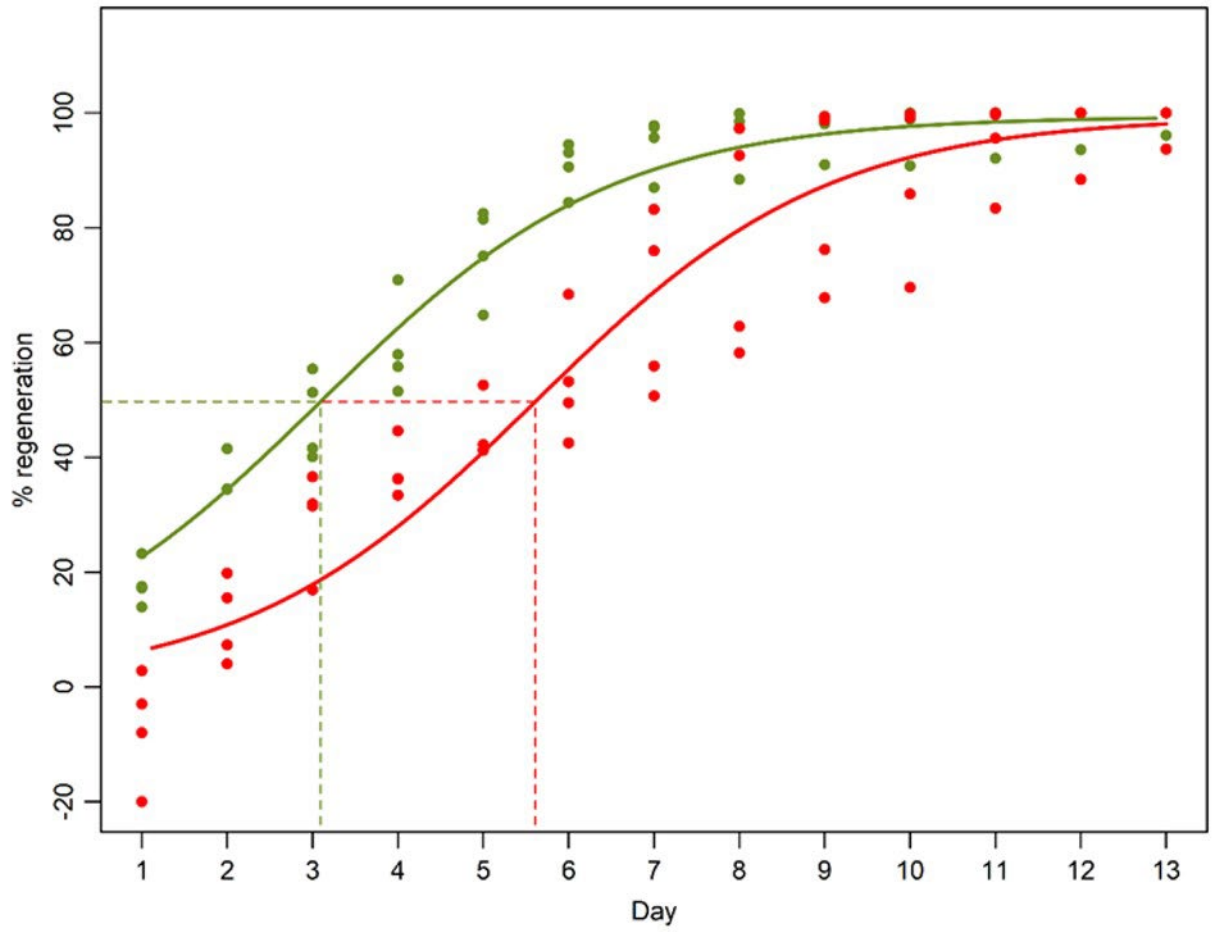


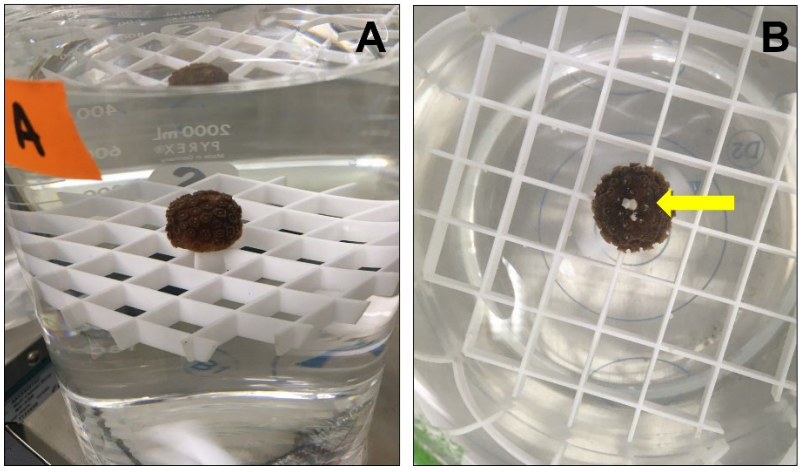
Figure 8. Tissue regeneration results with the 13-day turbidity exposure using the nonlinear mixed-effects model, with percent regeneration over time modeled using a three-parameter logistic function. Based on likelihood ratio tests, the only parameter to

vary significantly ($p < 0.05$) between treatment (red line) and controls (green line) was xmid (representing the x value at the inflection point of the curve), which was at 3.1 days for the controls and 5.5 days for coral fragments exposed to Port of Miami sediment homogenate.

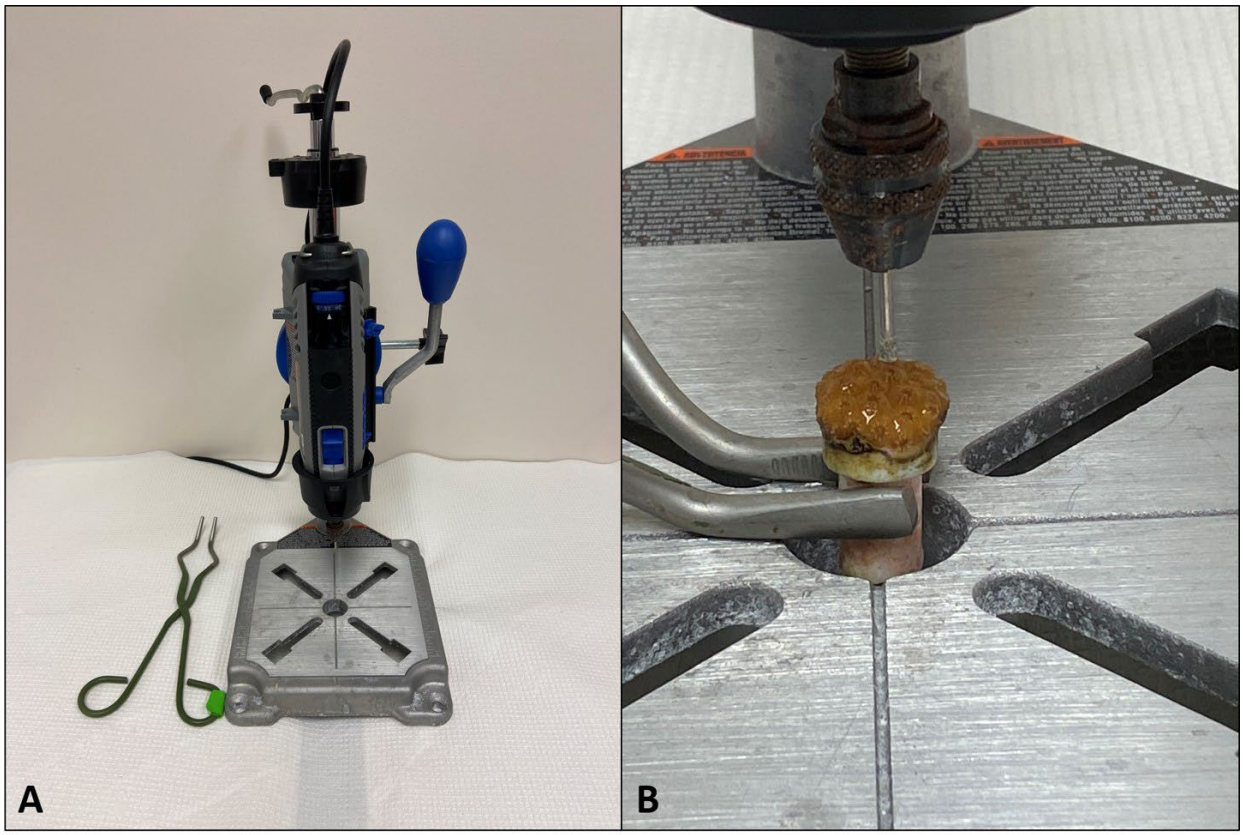
Supplement 1. Sources of supplies and equipment used in the preliminary turbidity tests.

Item	Source (location)	Model or Product #
Beaker, 2 L glass	Fisher Scientific (Waltham, MA)	02-540R
Stir bar, 2" Teflon	Fisher Scientific (Waltham, MA)	14-512-127
Stir plate, 15-position	Jeiotech Lab Companion (Billerica, MA)	AAH332615U
Egg crate louver	ePlastics (San Diego, CA)	W/EGG.375X2X4
PP perforated sheeting, 3/16"	US Plastics Corp. (Lima, OH)	42562
Silicone gel	Marineland (Blacksburg, VA)	31010
Aquarium pump	Hydor, USA (Sacramento, CA)	Koralia Nano 240
Light source	EcoTech Marine (Allentown, PA)	Radion XR30w Pro LED

Supplement 2. Side (panel A) and top (panel B) views of *Orbicella faveolata* fragment in the test vessel. Coral is supported by an egg crate louver, cut to fit snugly in the beaker. The wound created for the tissue regeneration assay is indicated with a yellow arrow (panel B, shown with accumulated sediment during exposure).

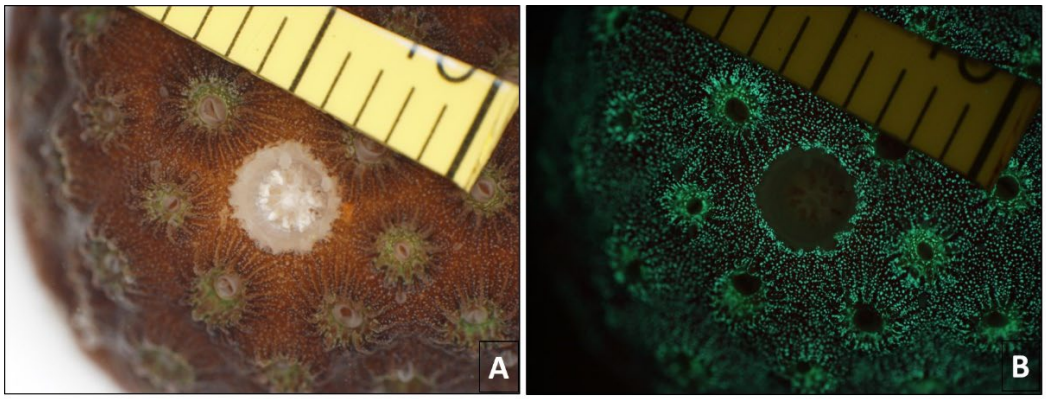


743 **Supplement 3.** View of the Dremel workstation used for wounding *Orbicella faveolata*
744 fragments and the stainless-steel tongs for holding coral fragment in place (panel A). A
745 close-up view of an *O. faveolata* coral fragment under the 2.0 mm diamond hole saw bit
746 is shown in panel B.



747

748 **Supplement 4.** Photomicrograph images of the *Orbicella faveolata* 2.0 mm diamond
749 hole saw wound under bright field (panel A) and near-violet fluorescent (panel B)
750 illumination. A centimeter ruler (with mm increments) shown in each image was used to
751 calculate skeletal area and wound perimeter using ImageJ.



752

753 **Supplement 5.** Results of preliminary turbidity tests and experimental parameters
754 used. Abbreviations: PP = polypropylene, PS = polystyrene, NTU = nephelometric
755 turbidity units, PAR = photosynthetically active radiation, OFAV = *Orbicella faveolata*.

Date	Coral species	Vessel	Light source	Mixing apparatus	Coral support	Duration	Sediment	Results
2/13/19	none	2 L plastic beakers, 2.0 L seawater volume	ambient	Small (40 gal/d) aquarium pump suspended from custom PP frame	none	5 h	Defined sediment loads (20, 30, 40 g/L) using wet Port of Miami mix	Experiment termi after 5 h with turb out of target rang NTU). Tested 1:1 1:20 dilutions of 2 stock, which fell i target turbidity ra
5/6/19	OFAV	2 L glass beakers	One Ecotech	Small (40 gal/d)	Custom PP	96 h	20 g wet Port of	Diluting sediment solution was time

		with custom round glass covers, 1.5 L seawater	Marine Radion XR30w Pro LED light, PAR = 125-150 µmol/m^2/s	aquarium pump suspended from custom PP frame	frame with 1 cm holes on silicone support in beaker		Miami mixture used to make a conc. stock for dilution to appropriate turbidity	consuming as tur was not stable ov Custom PP suppo frame accumulate sediment (>90 % turbidity reduction Aquarium pump k sediment suspen but heated water declining coral he
5/13/19	none	2 L glass beakers with custom round glass covers, 2.0 L seawater	ambient	15-position stir plate with 2" Teflon stir bar in glass beaker, 250 rpm	PS egg crate louver cut to fit inside beaker, held with silicone	215 h	Defined sediment loads (1, 3, 5 g/L) using wet Port of Miami mixture	Turbidity more sta without coral, but significant fluctua over time. Turbidi ranged from 23 -2 NTU over time wi highest turbidity a for the two lower sediment amount

5/23/19	none	2 L glass beakers with custom round glass covers, 2.0 L seawater	ambient	15-position stir plate with 2" Teflon stir bar in glass beaker, 300 rpm	PS egg crate louver cut to fit inside beaker, held with silicone	120 h	Defined sediment loads (0.5 and 0.75 g/L) using wet Port of Miami mixture	Turbidity increase 20 to >100 NTU d days, but appeare stablilize after 3 d Increased turbidit to higher stir rate (increased from 2 300 rpm).
12/2/19	none	2 L glass beakers with custom round glass covers, 2.0 L water volume	ambient	15-position stir plate with 2" Teflon stir bar in glass beaker, 300 rpm	PS egg crate louver cut to fit inside beaker, held in place with silicone	72 h	Cryomilled sediment homogenate (0.1, 0.3 and 0.5 g/L).	Turbidity stable fo h for two lower se loads (0.1 g/L = 5 and 0.3 g/L = 40 but still some sed accumulating on crate and silicone supports. Turbidi increased for the sediment load (>1 NTU).
12/9/19	none	2 L glass beakers	ambient	15-position stir plate	PS egg crate	144 h	Cryomilled sediment	Sediment accumu on silicone suppo

		with custom round glass covers, 2.0 L water volume		with 2" Teflon stir bar in glass beaker, 300 rpm	louver cut to fit inside beaker, held in place with silicone		homogenate at 0.2, 0.25 and 0.3 g/L	to account for differences betwe replicate test sam Bubbles accumul on the egg crate a trapped sediment
12/18/19	none	2 L glass beakers with custom round glass covers, 2.0 L water volume	ambient	15-position stir plate with 2" Teflon stir bar in glass beaker, 300 rpm	PS egg crate louver cut to fit snugly inside beaker, no silicone support	96 h	Cryomilled sediment homogenate dried in oven to remove liquid. Tested 0.1, 0.2 and 0.3 g/L.	Dried cryomilled sediment homoge resulted in stable turbidity for all se loads for 96 h. Tu for each was: 0.1 ~15 NTU; 0.2 g/L NTU; 0.3 g/L = ~9
1/14/20	OFAV	2 L glass beakers with custom	One Ecotech Marine Radion	15-position stir plate with 2" Teflon stir	PS egg crate louver cut to fit	72 h	Dried and cryomilled sediment homogenate	Sediment accumu in top coral woun Water quality parameters remai

		round glass covers, 2.0 L water volume	XR30w Pro LED light, PAR = 125-150 µmol/m2/s	bar in glass beaker, 300 rpm	snugly inside beaker, no silicone support		(0.2 g/L) and control (no sediment) tested with wounded coral	stable over 72 h. intial increase and stable after the in h (~40 NTU).
1/23/20	OFAV	2 L glass beakers with custom round glass covers, 2.0 L water volume	One Ecotech Marine Radion XR30w Pro LED light, PAR = 125-150 µmol/m2/s	15-position stir plate with 2" Teflon stir bar in glass beaker, 300 rpm	PS egg crate louver cut to fit snugly inside beaker, no silicone support	96 h	Dried and cryomilled sediment homogenate (0.2 g/L in duplicate) tested with wounded coral to determine coral effects over time.	Sediment accumu in side coral woun Water quality parameters remai stable. Turbidity decreased over ti less than 5 NTU.
1/27/20	OFAV	2 L glass beakers with custom	One Ecotech Marine Radion	15-position stir plate with 2" Teflon stir	PS egg crate louver cut to fit	96 h	Dried and cryomilled sediment homogenate	Experiment condu temperature-cont room. Compresso a few hours into

		round glass covers, 2.0 L water volume	XR30w Pro LED light, PAR = 125-150 µmol/m2/s	bar in glass beaker, 300 rpm	snugly inside beaker, no silicone support		(0, 0.05, 0.1, 0.15 g/L in triplicate) tested with wounded coral for 96 h.	experiment, but w continued. Tissu regeneration for c was lower than ex at experiment termination, likely seawater tempera (25-29 °C).

Supplement 6. Results of the sea urchin embryo development toxicity test.

Test species = Lytechinus variegatus. Sperm dilution used: 1:250. Sperm count (undiluted = 1.26 x 10^10 cells/mL. Ova count = 4200 eggs/mL. Fertilization = 91%.
Abbreviations: ASW = artificial seawater; N = normally developed embryos; U = underdeveloped embryos; A = arrested embryos; M = malformed embryos.
The results of four replicate vials are presented.

	Vial 1					Vial 2					Vial 3					Vial 4				
TREATMENT	**N**	**U**	**A**	**M**	**TOTAL**	**N**	**U**	**A**	**M**	**TOTAL**	**N**	**U**	**A**	**M**	**TOTAL**	**N**	**U**	**A**	**M**	**TOTAL**
ASW	78	1	5	16	100	91	1	2	6	100	95	5	0	0	100	78	4	1	17	100
50 mg/L	98	1	0	1	100	95	4	1	0	100	75	1	0	24	100	95	0	2	3	100
100 mg/L	87	5	4	4	100	93	4	2	1	100	97	2	0	1	100	98	2	0	0	100
150 mg/L	96	3	0	1	100	92	4	1	3	100	92	2	2	4	100	97	1	1	1	100

Supplement 7. Particle size analysis results of the Port of Miami cryomilled sediment homogenate samples used in the sea urchin and coral experiments.

NIST Biorepository Particle Size Report

Measurement Details	
Operator Name	jmn1
Sample Name	Average of 'PortofMiami_Wet02'

Measurement Details	
Measurement Date Time	9/28/2022 11:18:01 AM
Result Source	Averaged

Analysis	
Particle Name	Cement
Particle Refractive Index	1.680
Particle Absorption Index	0.100
Dispersant Name	Seawater
Dispersant Refractive Index	1.390
Scattering Model	Mie
Analysis Model	General Purpose
Weighted Residual	0.38 %
Laser Obscuration	0.65 %

Concentration	0.0015 %
Span	2.699
Volume Below (10.1) µm	7.53 %
D [4,3]	55.3 µm
Dv (10)	11.8 µm
Dv (50)	34.3 µm
Dv (90)	104 µm
Residual	0.35 %

Frequency