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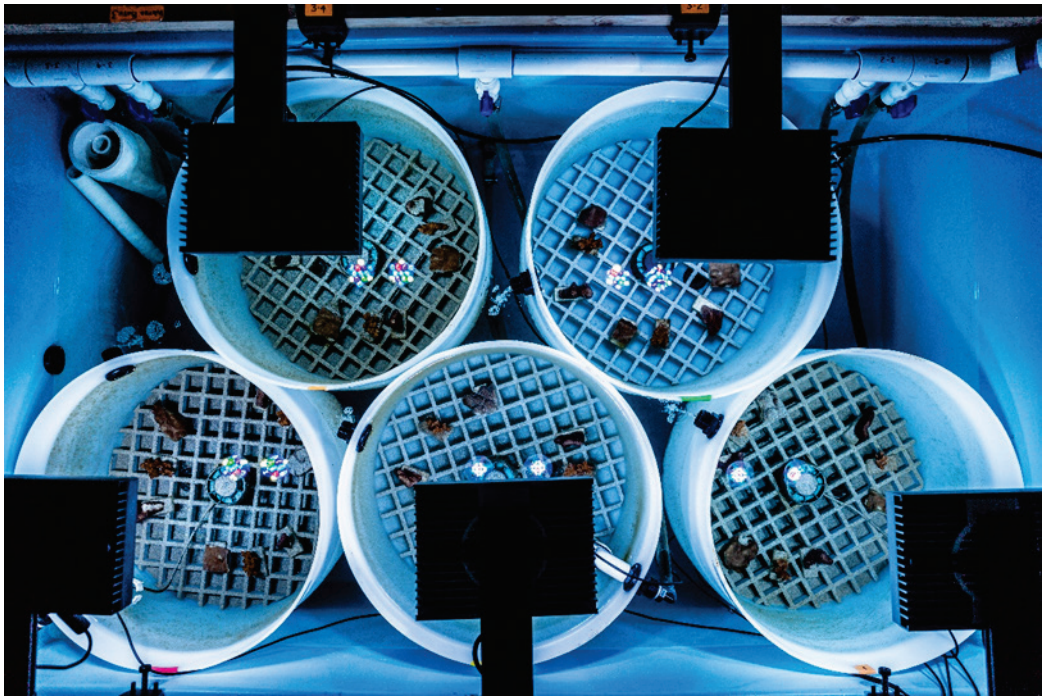
Effects of Sedimentation on Three Hawaiian Coral Species under Laboratory Conditions

Justin Wilkens, Alexandria Barkman, Alexi Meltel,
Burton Suedel, and Robert H. Richmond

August 2023



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Effects of Sedimentation on Three Hawaiian Coral Species under Laboratory Conditions

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Final report

Prepared for US Army Engineer Research and Development Center
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Under Risk Informed Management Approach for Evaluating Dredging Related Effects on Sensitive Habitats
DOER Project number 19-10
AMSCO code 089500

Abstract

Sedimentation can occur near a dredge operation in pulses over days, and potentially impact coral reefs occurring in close proximity. To improve the ability to predict the effects of dredging on corals, the effects of sedimentation in two 18-day experiments were studied for three common coral species representing different morphologies. In a laboratory setting, coral fragments were exposed to four sedimentation concentrations dosed every four days ranging from 0 to 60 mg cm^{-2}. Separate experiments were performed in series, once with fine grain sediment and repeated with a coarse grain sediment. A 30-day sediment free observation period followed each experiment. Coral responses were measured throughout the experiment and at the end of the 18-day exposure and 30-day sediment free observation period. Photosynthetic yield, lipid ratios, tissue color, tissue loss, growth, and sediment cover varied among the treatment groups. All coral species were minimally affected when sediment concentrations were at or below 6 mg cm^{-2}. *P. meandrina* and *P. lobata* experienced the most sediment coverage and tissue loss when exposed to sediment concentrations >30 mg cm^{-2} for either sediment. *M. capitata* experienced no sediment coverage or tissue loss when exposed to either sediment, but a reduction in photosynthetic yield at 60 mg cm^{-2} fine grain sediment was observed. During the 30-day post-exposure sediment free observation period, *P. meandrina* tissue loss continued, *P. lobata* nearly completely regrew lost tissue, while *M. capitata* showed no lingering effects. This study improves the US Army Corps of Engineers (USACE) ability to estimate the impacts of dredging on coral reefs.

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Preface

This report is part of a larger study, “Risk Informed Management Approach for Evaluating Potential Dredging Related Effects on Sensitive Habitats.” This project was funded by the USACE Engineering Research and Development Center (ERDC), Dredging Operations and Environmental Research (DOER) program under the Risk Informed Management Approach for Evaluating Dredging Related Effects on Sensitive Habitats, DOER Project number 19-10, AMSCO code 089500. Dr. Todd Bridges was the program manager, and the Ecosystem Management and Restoration Research Program (EMRRP) program manager was Dr. Brook Herman.

This report was written under the direct supervision of Mr. James Lindsay, EPR branch chief, EL; Mr. Warren P. Lorentz, EP division chief; and Dr. Edmond J. Russo, EL director. Mr. Jase Ousley was Headquarters USACE Navigation Business Line Manager, and Mr. Charles E. Wiggins, ERDC Coastal and Hydraulics Laboratory, was the ERDC technical director for Civil Works and Navigation, Research, Development, and Technology Transfer portfolio.

The authors thank Drs. Alyssa Calomeni and Mark Ballentine for reviewing an earlier version of this report. Thanks are also extended to Dr. Anthony Montgomery of the US Fish and Wildlife Service for technical and logistical support and the University of Hawai‘i at Mānoa’s Kewalo Marine Laboratory for providing laboratory space for the experiments.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

The US Army Corps of Engineers (USACE) maintains navigable waterways in US ports and harbors by dredging (i.e., underwater excavation of bottom sediment) which can occur in proximity to coral reefs (e.g., Honolulu Harbor, Hawaii; Miami Harbor, Florida; Apra Harbor, Guam). While dredging, a portion of the bottom sediments become resuspended and create a sediment plume near the dredging operation. The sediment plume is often described through spatial and temporal measurements of turbidity (an optical measurement of cloudy water), total suspended sediment concentrations (TSS, mg L^{-1}), sedimentation rate (mg cm^{-2} d^{-1}), and underwater light concentrations (mol photons m^{-2} s^{-1}), all of which can help predict the potential impacts on coral reefs (Jones et al. 2016, 2019, 2020; Erftemeijer et al. 2012; Wilber et al. 2001). To understand the effects of dredging near coral reefs, a risk assessment approach is needed to appropriately evaluate sediment plume characteristics. As part of a risk-based approach, experiments generating effects data representing a range of potential exposure conditions in the field can improve our ability to estimate the potential impacts of dredging on special aquatic sites such as coral reefs.

1.1 Background

In Spring 2021, the USACE Honolulu District was leading efforts to complete maintenance dredging of the federal navigation project in Honolulu Harbor. The effects of dredging induced turbidity plumes and sedimentation on coral reef ecosystems adjacent to the east and west of the entrance channel were the main environmental concerns in Honolulu Harbor. The use of a mechanical dredge equipped with an environmental bucket and partial silt curtains deployed as a risk management measure in the entrance channel and full silt curtains in the harbor was approved to reduce turbidity outside of the dredging footprint.

Turbidity plumes generated by mechanical dredging are commonly monitored and evaluated to help determine the environmental consequences of USACE dredging projects near special aquatic sites (e.g., coral reefs and submerged aquatic vegetation). However, evaluations of monitored turbidity plumes often suffer from relatively few turbidity samples that are limited spatiotemporally. Additionally, there is usually a

lack of data regarding determining TSS and sedimentation effects on local coral species of concern. Therefore, environmental regulatory oversight of dredging often relies on conservative best management practices given the uncertainty regarding risks to special aquatic sites. Current approaches include seasonal dredging restrictions through environmental windows (e.g., avoid coral spawning seasons; see Reine et al. 1998) and engineering controls such as use of an environmental bucket and silt curtains to minimize resource exposure. Given current data gaps, the effects experiments will serve as meaningful scientific contributions to advance the science about the effects of dredging on special aquatic sites such as corals. Data generated from laboratory effects studies will be used to frame our understanding of the effects of suspended sediments and sedimentation on corals and to better inform risk management of these resources.

Researchers from the US Army Engineer Research and Development Center (ERDC) met with government and university leaders USACE Honolulu District (POH) and Pacific Ocean Division (POD), National Oceanic and Atmospheric Administration-National Marine Fisheries Service, US Fish and Wildlife Service Pacific Islands Fish and Wildlife Office, US Naval Facilities Engineering Command Pacific, US Environmental Protection Agency (USEPA), Hawai‘i Division of Aquatic Resources, University of Hawai‘i (Kewalo Marine Laboratory and Hawai‘i Institute of Marine Biology), and Hawai‘i Department of Transportation-Harbors to discuss what types of data were needed and how to generate these to address concerns about the impacts of dredging on corals. Initial input focused on factors as they relate to the effects of dredge induced suspended sediments and sedimentation. Input received from these discussions helped refine the design of the experiments and the subsequent results presented herein.

1.2 Objective

In this study, laboratory experiments were conducted to examine the effects of two locally collected sediments on three native Hawai‘i coral species. The coral species tested exhibited different morphologies that represented corals found in and near Honolulu Harbor and were exposed to sedimentation concentrations that could be anticipated around an operating mechanical dredge in the harbor.

1.3 Approach

To examine the potential impacts of sedimentation on corals in Honolulu Harbor, three coral species representing different growth forms were exposed to a range of sedimentation concentrations expected to occur near a dredge operation in a controlled laboratory exposure system. Separate 18-day exposure periods, once for fine grain sediment and repeated with a coarse grain sediment, were performed to study the impact of sedimentation concentrations created by the introduction of a series of single pulsed doses on days 0, 4, 8, 12 and 16. At the end of the 18-day exposure, the response of each coral species to sedimentation concentrations was determined through several endpoint measurements. A 30-day sediment free observation period followed the 18-day exposure where lingering effects of the corals were monitored.

2 Methods

2.1 Source of corals and maintenance

Experiments were conducted with coral morphologies commonly found near Honolulu Harbor including a branching growth form of *Pocillopora meandrina*, a massive growth form of *Porites lobata*, and a plating growth form of *Montipora capitata*. In Kewalo Basin, southeast of the entrance to Honolulu Harbor approximately 1 km, up to three healthy coral colonies of *P. meandrina* and two colonies of *P. lobata* were collected at a depth of 6 m (collection permit SAP 2021-46) by detachment of the colony from the substrate through careful use of a hammer and chisel. Collection of the plating growth form of *M. capitata* corals was not logistically possible due to diver safety concerns in the harbor. Instead, five colonies of the branching growth form of *M. capitata* were collected from Kāneʻohe Bay, Oʻahu (collection permit SAP 2021-23) at a depth of 5 m. All corals were placed in coolers filled with seawater and transported back to Kewalo Marine Laboratory. Once at the laboratory, they were placed in two outdoor flow-through (1 L min^{-1}) water tables receiving 5 μm filtered sea water for a minimum 2-week quarantine during which minimal tissue loss occurred due to collection. Outdoor water tables were naturally illuminated and covered with shade cloth. Photosynthetically Active Radiation (PAR) measurements in one water table was recorded with a spherical underwater quantum sensor (LI-193, LI-COR, Lincoln, NE) logged every 10 s (LI-1500, LI-COR, Lincoln, NE) for four consecutive days to determine representative lighting conditions in the outdoor tanks. Max PAR ranged from 577 to 686 μmol photons m^{-2} s^{-1} under the shade cloth and up to 1,203 μmol photons m^{-2} s^{-1} when the shade cloth was briefly removed for tank maintenance (Figure 1). The mean (standard deviation) daily light integral experienced by corals in the water table was 4.5 (0.35) mol m^{-2} d^{-1}.

After quarantine, fragments of corals approximately 10 cm^{-2} were cut from the collected colonies of each species with a diamond tipped band saw. Other than general fragment size, there was less control over, for example, the actual shape such as the branch thickness or spacing for *P. meandrina* or *M. capitata* corals, or the distance between hemispherical shapes or depressions for *P. lobata* corals because logistically this was not practical due to limited coral resources. This resulted in similar sized corals that represented morphological nuances within each species. The coral

fragments were glued (IC-Gel™ CA Paste, Bob Smith Industries, Atascadero, CA, USA) to marble tiles (4.8 × 9.6 cm) and returned to water tables for a two-week period (Figures 2 and 3). To identify individual corals, each tile was etched with a unique number. The number was used to randomly assign corals of each species to each test aquarium. See experimental design in section 2.3 for more details about tank assignments.

Figure 1. Representative photosynthetically active radiation (PAR) measurement and daily light integral (DLI) collected 03-04 March 2021 in the outdoor water tables where corals were initially quarantined after collection.

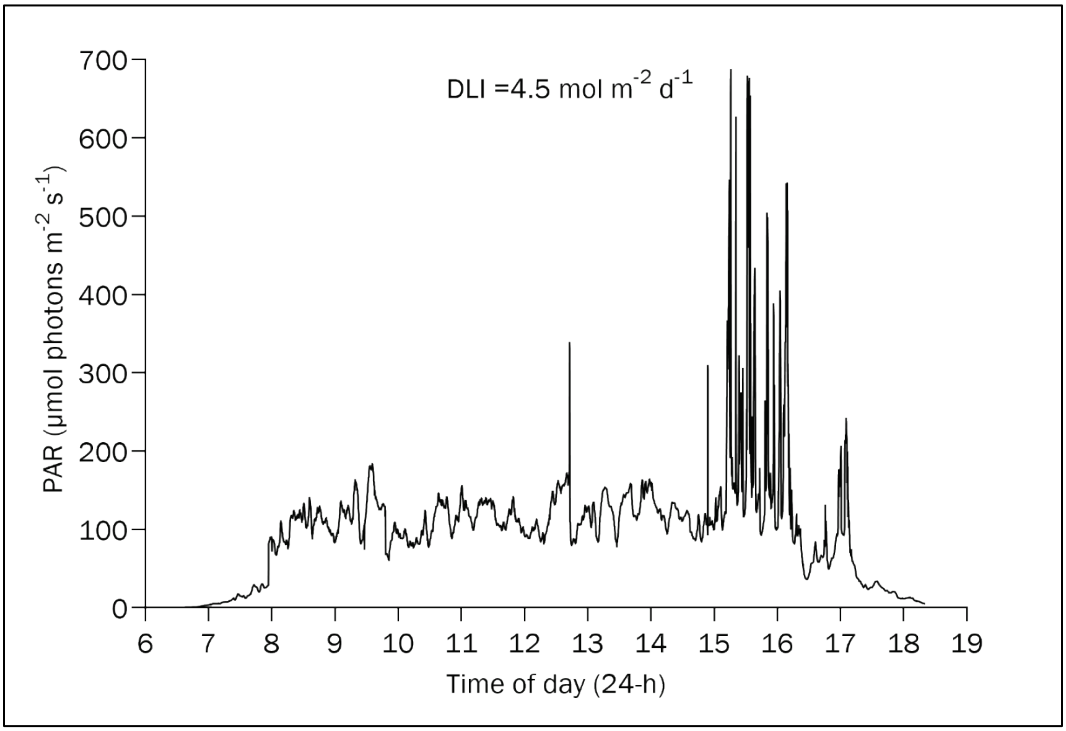
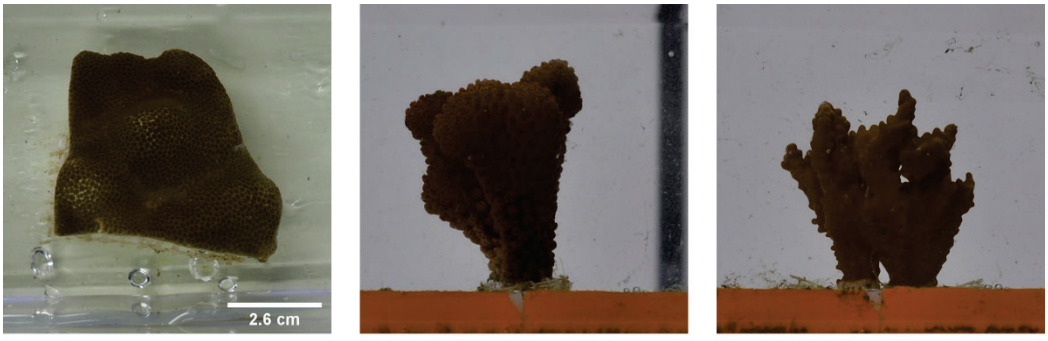


Figure 2. Corals acclimating in an outdoor water table after they were cut from the collected colonies and subsequently glued to marble tiles (4.8 × 9.6 cm) prior to the experiment (Photo: Justin Wilkens).

Figure 3. Examples of coral fragments cut from the collected colonies of each coral species with a diamond tipped band saw then glued to marble tiles. *Porites lobata* (*left*), *Pocillopora meandrina* (*middle*), and *Montipora capitata* (*right*) (Photo: Justin Wilkens).



2.2 Source and characterization of test sediment and water

To help understand the relationships between dredged sediment characteristics and potential effects on corals, test sediments with a higher proportion of fine grain particles (i.e., silts and clays) and another with coarse grained particles (i.e., sand particles) collected from dredged material management units (DMMUs, i.e., areas to be dredged; labeled U1 thru U7; USACE 2015) in Honolulu Harbor were desired for the

experiments (Figure 4). This study was focused on the physical rather than the chemical effects of sedimentation. Therefore, fine and coarse grain sediments collected from the harbor were from DMMUs which initially passed suitability evaluations for ocean disposal (USEPA/USACE 1991) rather than from DMMUs which required special handling (i.e., contaminated). Fine grain sediments in the inner harbor were identified in DMMUs U2, U3b, and U4, while coarse grain sediments were identified at the U7 entrance channel site. At each inner harbor site, a Ponar grab sampler was used to collect 19 L of sediment. At the entrance channel U7 site sediment, a high proportion of rubble and hard bottom were encountered and after many attempts to collect sediment, only a fraction of the amount needed for testing was collected. For this reason, a second collection location was needed for coarse grain sediment. The entrance channel is in a high energy environment as evidenced by the coarse grain bottom sediment encountered during collection. In the field, the U7 sediment was visually compared (particle size and color) to sediments from other alternative collection sites from similar high energy environments including Sand Island just west of the entrance channel and Kuliʻouʻou Beach Park. Kuliʻouʻou Beach Park was chosen as a close match to the entrance channel sediment in terms of particle size, color, and distance from known sources of contamination. At the park, three 19 L samples were collected 15 m seaward of the tideline (Figure 5). Test sediments placed in polyethylene buckets were brought back to the laboratory and stored at 4°C until composited. For each sediment type, buckets were individually homogenized then approximately equal portions of sediments from each bucket were combined, homogenized again, and lastly, wet-sieved through a 1 mm mesh metal sieve to remove debris.

Sieved sediments and water used for experiments were analyzed for contaminants. Contaminants included in the analyses were Polychlorinated biphenyls Aroclors using USEPA Method 8082, pesticides using USEPA Method 8081, semi volatile organic compounds using USEPA Method 8270C, and USEPA Method 6000/7000 series for metals. Kewalo Marine Laboratory water was sourced from Kewalo Basin approximately 500 m seaward of the laboratory. Sea water used in the acclimation/quarantine tanks and in the experiments was filtered through a 5 μm filter prior to use. For water analysis, a 5 μm filtered water sample was collected prior to introduction into an experimental tank.

For the basic characterization of the physical properties for tested sieved sediments, the particle size distribution (hydrometer test; ASTM D422) was measured and settleable solids was analyzed by volumetric method based on measurement of volume of settled suspensions in Imhoff funnels (Weber et al. 2006). Sediment volume was determined by the suspension of 15 g dry weight (DW) of test sediment in 1,000 ml of sea water (35 ppt) in Imhoff funnels and expressed as proportion of total sediment volume after 2 hr of sedimentation time. Sedimentation rate was determined by measurement of the sediment volume after 15, 30, 60, and 90 min. Compaction of sediment was determined by measurement of the sediment volume at 0.5, 1, 1.5, 2, 18 and 38 hr after the initial 2 hr sedimentation time and calculated as proportion of sediment volume.

Figure 4. Honolulu Harbor, Hawai'i, USA. Fine-grain sediments were collected at dredged material management units (DMMUs) U2, U3b, and U4 and combined for analysis (Satellite photo: Google Earth, Maxar Technologies, 2021).

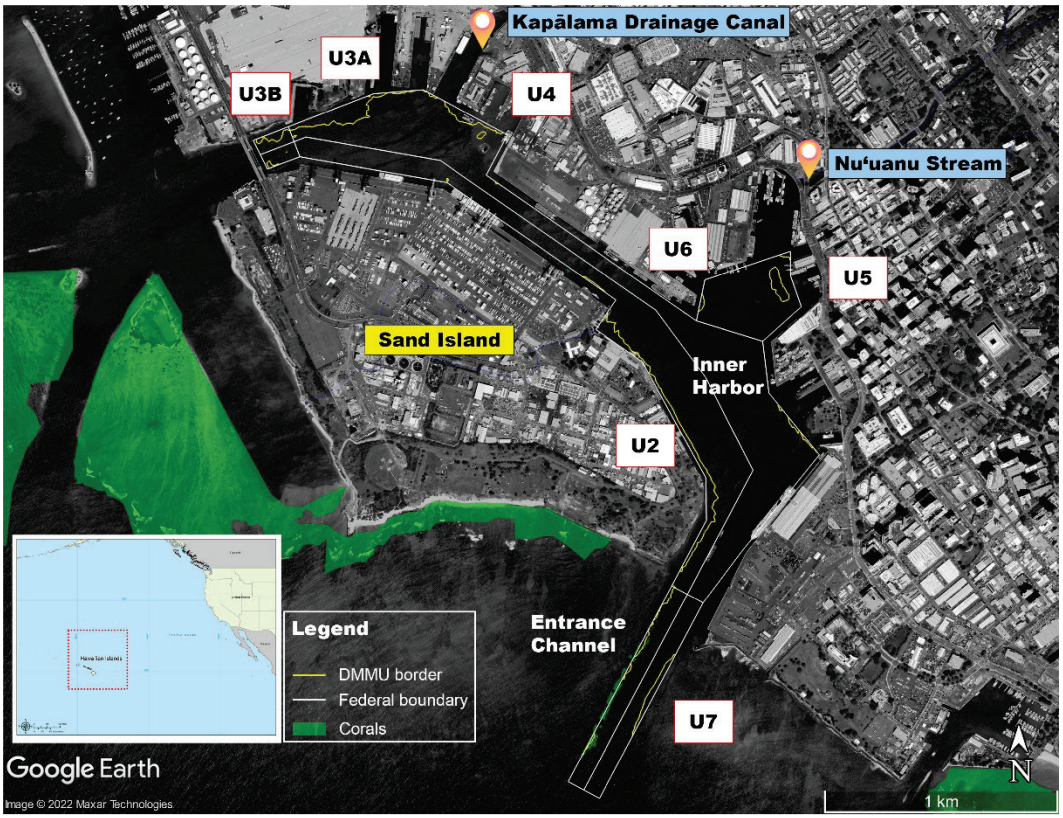


Figure 5. Kuli'ou'ou Beach Park, Hawai'i, USA. Coarse-grain sediments were collected approximately 15 m seaward of the shoreline within the *red circle* (Satellite photo: Google Earth).

2.3 Exposure system and experimental treatments

In a controlled environment room at the Kewalo Marine Laboratory, Honolulu, HI, two sedimentation experiments, one with fine grain sediment and the other with coarse grain sediment, were conducted using the Fish Larvae and Egg Exposure System (FLEES) in February and March 2021. The FLEES supports the design of experiments requiring exposure to suspended sediments or sedimentation (Lutz et al. 2012; Wilkens and Suedel 2017). The FLEES consists of three rectangular water baths, each with five partially submerged flow through circular test tanks (n=15; 114 L polyethylene dome bottom graduated tank, #5200, Tamco Industries, Lima, OH, USA, modified to 70 L) each filled with 55 L of 5 µm filtered seawater (sourced from Kewalo Basin approximately 500 m seaward of the laboratory) introduced continuously through a diffused outlet near the top of the tank at a mean rate (± standard deviation) of 960 ± 210 ml min^{-1} (~24 tank volumes per day; Figure 6). Corals were arranged in a circle on a fiberglass grate (70% opening) near the bottom in each test tank at a depth from the water surface of 27 cm (Figure 7). Each test tank was illuminated

by an LED aquarium light (Hydra 26 HD and 32 HD, AquaIllumination, Bethlehem, PA, USA; color channels were used at equal intensities; see manufacturer's baseline spectrum) mounted 33 cm above the center of each tank. The lights provided an 11 hr photoperiod from 0630 to 1830, and simulated sunrise/sunset made up of two 4.5 hr periods of increasing/decreasing light intensity, separated by a constant maximum light intensity from 11:30 to 13:30 (Figure 8). Each light's power output was adjusted until ~660 PAR was achieved at maximum intensity which was verified by a PAR measurement using a spherical micro quantum sensor (US-SQS/L sensor with ULM-500 data logger, Heinz Walz GmbH, Germany) near the center of the tank 7 cm below the water surface (Figure 9). The maximum light intensity was chosen to simulate approximate light intensities that would occur at 5–8 m depths in the absence of suspended sediment (i.e., no dredging). When light attenuation was accounted for, the daily light integral for corals on the bottom grate was 12.8 mol m^{-2} d^{-1}. Experiments were conducted under a constant flow rate created by a pump (MDX-3-1/2, March Manufacturing Inc., Glenview, IL, USA) positioned separately as part of each test tank. The pump outlet was centered in the tank bottom under the grate such that water flow was directed upward through the center of the tank. A submerged pump centered on top of the grate and outlet faced upwards and was used to mix and suspend introduced sediment (Nero 5 Powerhead, AquaIllumination, Bethlehem, PA, USA).

At the time of this study, information from the 2021 Honolulu Harbor maintenance dredging was not available to determine a meaningful exposure scenario, so other sources of information were used. Based on NOAA Chart 19367 and USFWS (2014), coral reef resources are predominately located in the nearshore along the southern shoreline of Sand Island, west of the entrance channel where coral density is greater (Figure 4). Additional corals are located near the entrance channel margins and scattered at lower densities over a large area between the entrance channel and Sand Island. Shoaled sediment in the entrance channel was to be dredged via a mechanical dredge equipped with an environmental bucket. The dredged sediment was to be placed into a scow for transport to appropriate disposal sites. To manage the risk of potential impacts of dredging induced suspended sediment plumes, silt curtains were required to encircle the dredge operation to reduce the drift of suspended sediments outside of the excavation area in the dredge prism. As part of best management practices specified for the project,

containment scows were sized and sealed to prevent overflow/leakage of dredged sediment. The resuspension of excavated sediment from the bucket dredging operations has been reported to range from 1.5 to 3% of bucket volume (Bohlen et al. 1979; Anchor Environmental 2003). Because the primary coral resources of concern are outside the federal boundary and to the east and west of the entrance channel, the exposure scenario was based on the planned entrance channel dredging operations.

To avoid waterway congestion and for safety, the entrance channel dredging was initially only allowed to occur during overnight hours when commercial vessel traffic was at its lowest. In the initial plans, the dredge was allowed approximately eight days per month to complete work in the entrance channel DMMU. In one potential scenario, these operations could yield pulsed (i.e., sediment plume at night only) dredge plume events for eight consecutive nights, or more realistically, when accounting for work delays due to sea conditions and vessel traffic, for eight nonconsecutive, irregularly spaced nights which is what occurred after this study. Because the latter scenario was more likely, the exposure rate (percentage exposure to corals per time; 8-day/30-day =27%) was used to calculate five doses for an 18-day exposure period where sediment was introduced on nonconsecutive, but evenly spaced days (i.e., dose every four days; Figure 10). An 18-day duration was chosen to allow for time to separately examine the exposure to fine grain sediment (inner Honolulu Harbor) and coarse grain sediment (Kuliʻouʻou Beach Park) but is also reasonably within the range of days required to dredge various harbor DMMUs.

For each experiment, three individuals of each coral species were randomly selected and placed into each test tank (n =3 species; n =9 corals per tank; n =15 test tanks) which was randomly assigned a sedimentation concentration treatment. Each test tank was an experimental unit. Corals were introduced into the test aquaria 72 hr prior to the start of the experiment allowing time to acclimate to the experimental conditions in the laboratory. Over each 18-day experiment, corals were exposed to sedimentation concentration treatments of 0-control, 6, 30, and 60 mg cm^{-2} that were introduced as a single dose on days 0, 4, 8, 12 and 16 (n = 5 doses). Sedimentation concentrations were based on tank bottom two-dimensional surface area which was used to determine the weight of sediment needed to create the sedimentation concentrations over a flat surface (see section 2.4 for more details on pulsed sediment dose). At the conclusion of the 18-day experiment, sediment was gently washed from

each coral, then the corals were placed back into outdoor acclimation tanks covered with shade cloth and observed for an additional 30 days (Figure 11). These sedimentation concentration treatments were within a range of effects thresholds reported in Rogers (1990), Foster et al. (2010), and Nelson et al. (2016). Because more is known about the control corals from similar studies, the number of control replicates was decreased (n = 3) in favor of additional replicates for each treatment group receiving sediment (n = 4 each).

Figure 6. The exposure system within a temperature and light-controlled area at the Kewalo Marine Laboratory. The system consisted of three rectangular water baths each with five partially submerged flow through circular test tanks. Each tank was filled with 55 L of 5 µm filtered seawater introduced continuously through a diffused outlet near the top of the tank (Photo: Justin Wilkens).

Figure 7. A test tank bottom where corals were randomly placed on a grate in a circular pattern around the powerhead. The labels describe the features and capabilities of the tank (Photo: Justin Wilkens).

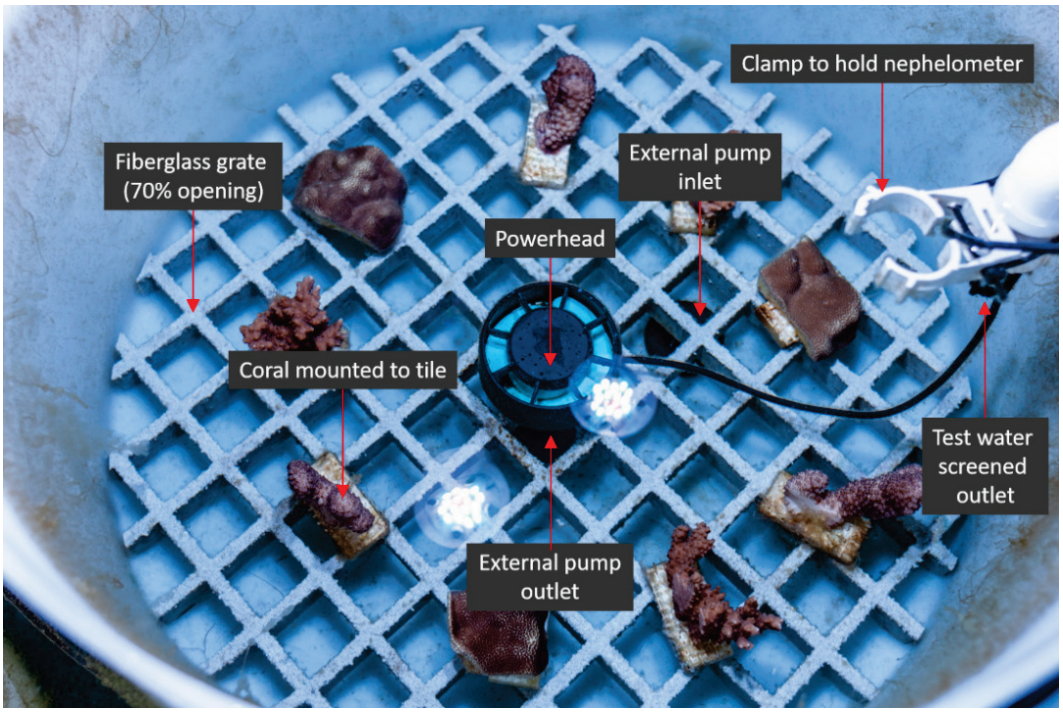


Figure 8. PAR (µmol quanta m^{-2} s^{-1}) measured at 1 sec intervals in an exposure tank to depict the 12 hr light:dark light regime and daily light integral (DLI mol m^{-2} d^{-1}) without test sediment present.

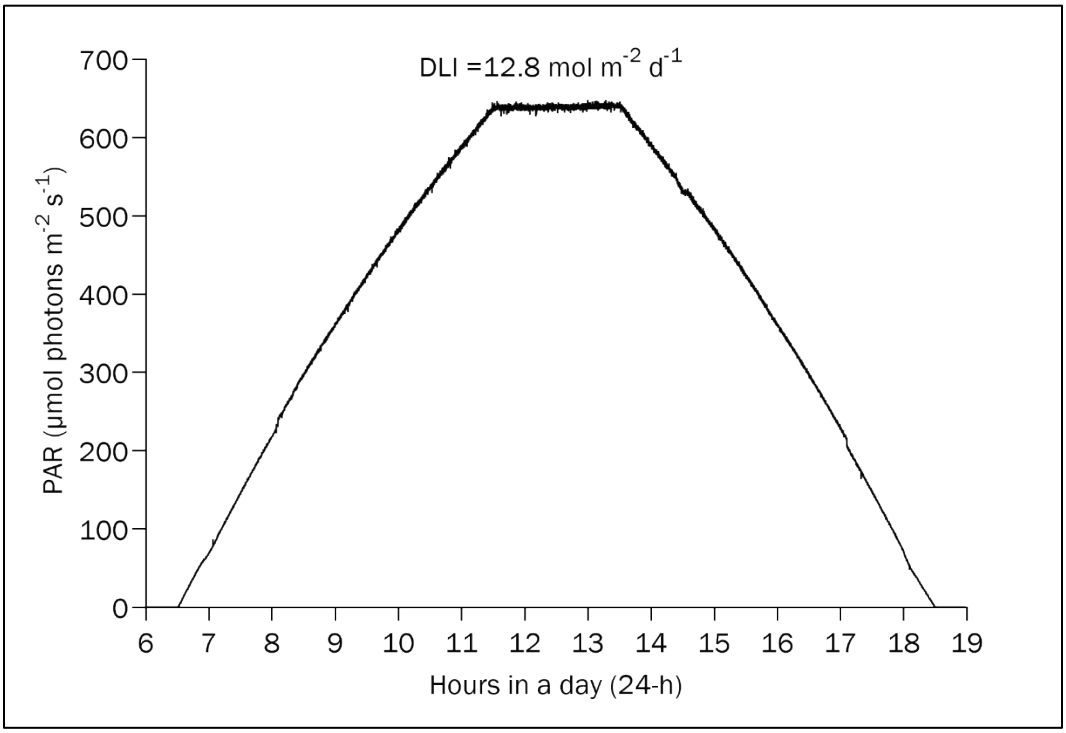


Figure 9. Photo of light measurement in a test tank. Each light's power output was adjusted until approximately 660 PAR was achieved at maximum intensity, which was verified by a PAR measurement near the center of the tank 7 cm below the water surface. A nephelometer clamped to the screened water outlet (*left*) measured turbidity (Photo: Justin Wilkens).

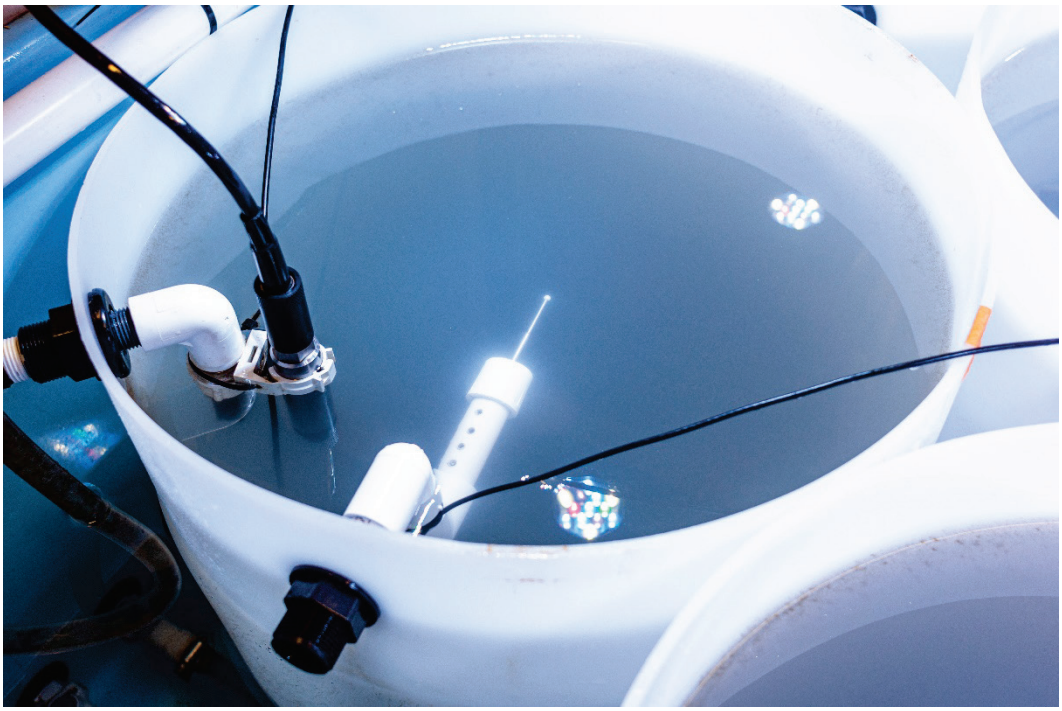


Figure 10. Conceptual diagram shows five evenly spaced doses (dose on day 0, 4, 8, 12, and 16) during each 18-day exposure.

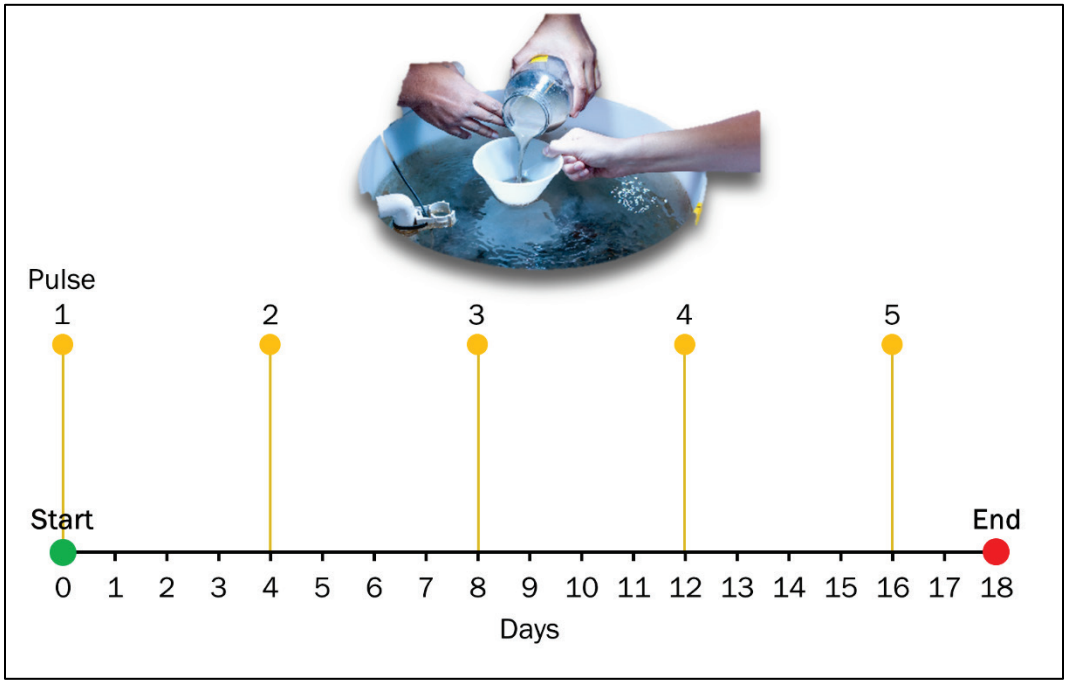
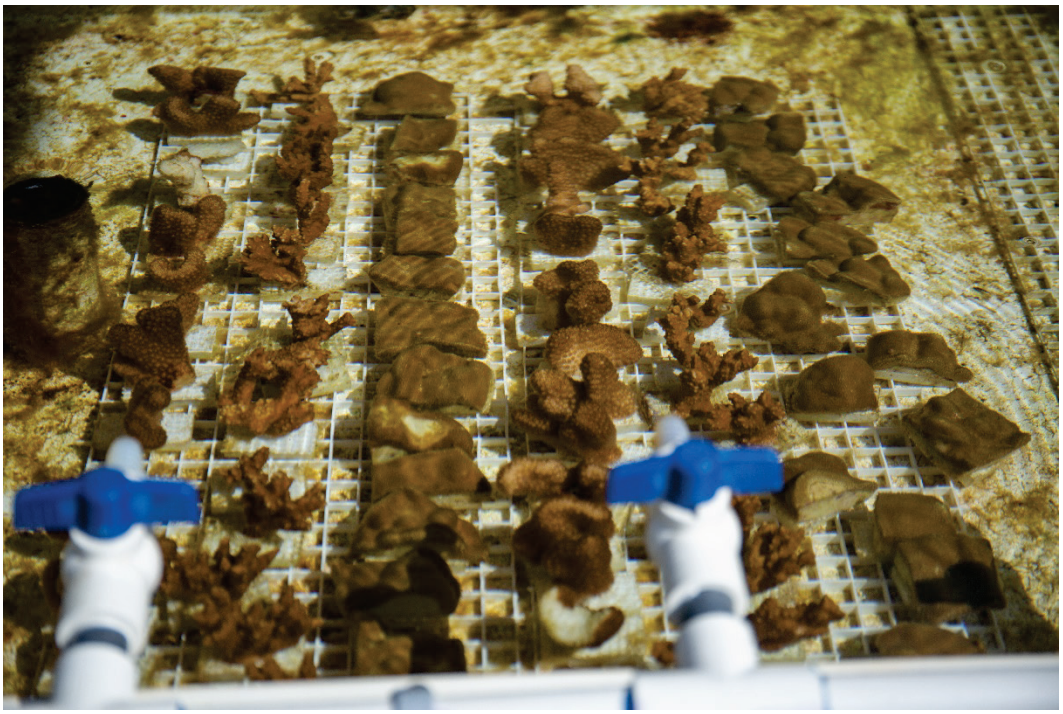


Figure 11. After an 18-day exposure to fine- or coarse-grain sedimentation (0 to 60 mg cm^{-2}), corals were transferred to outdoor water tables pictured here for a 30-day sediment-free observation period (Photo: Justin Wilkens).



2.4 Pulsed sediment dose procedure and associated measurements

Sediment percent moisture and the tank bottom two-dimensional surface area (i.e., diameter of bottom grate circle) were used to determine the wet weight (WW) of sediment needed to create the sedimentation concentrations over a flat surface for the test tanks assigned to the treatment groups of 6, 30, and 60 mg cm^{-2}. The calculated WW of fine grain sediment was mixed with 1 L of filtered seawater in a glass beaker to create a slurry or was washed from a weigh boat for coarse grain sediment (Figures 12 and 13). To initiate the introduction of test sediment, the water supply was turned off to each test tank. Then, the slurry was poured and rinsed from the beaker or weigh boat into the tank through a funnel placed at the water surface and positioned over a powerhead on the bottom grate. When sediment was introduced, the powerhead was used in continuous mode at 5% power to mix and suspend the sediment for approximately 30 sec before shutting off. Lastly, sedimentation was allowed to occur for 15 min before the pump and water supply resumed. This procedure was designed to homogenous the suspension of sediment in the tank prior to sedimentation. The Kuliʻouʻou Beach Park sediment, which was primarily sand, clogged the powerhead at 5%, therefore, 10% power was used. The sediment dose events (n =5 doses) were characterized through the

measurement of net sedimentation rate after a 15 min sedimentation period, turbidity (NTUs), TSS concentrations (mg L^{-1}), and light intensity (PAR at µmol photons m^{-2} s^{-1}).

The 15 min net sedimentation rate was measured in three sediment traps placed in two replicate tanks assigned to 6, 30, and 60 mg cm^{-2} treatment groups (i.e., 2 reps of 3 traps per dose x 5 doses: n =10 determinations for each treatment group). The sediment trap consisted of a polyvinyl chloride (PVC) cap with a surface area of 28.6 cm^{-2} and was placed on the bottom grate within the same circle as the corals (Figures 14 and 15). At the end of the 15 min sedimentation period, the PVC caps were removed, and the contents were filtered through pre-weighed filters (0.45 µm, 47 mm diameter, HAWG047S6, Millipore Sigma, MA, USA), dried at 60°C overnight, and weighed (to 0.0001 g) to determine dry sediment weight. The results were normalized to the sediment trap surface area and expressed as the unit, mg cm^{-2} 15 min DW. Observations made in preliminary tests of the pulsed dose regimen and supported by Imhoff observations determined that >90% of suspended sediment settled within 15 min after a pulsed dose.

Turbidity in test tanks was measured every 20 sec in one replicate tank assigned to 6, 30, and 60 mg cm^{-2} treatment groups with a nephelometer (OBS-3+ turbidity sensor, Campbell Scientific, Logan, UT, USA) on each dose day until the turbidity returned to pre-dose conditions (95% of turbidity measurements <1.92 NTU on days with no sediment dose). The TSS concentrations were determined on each dose day for all replicate tanks assigned to 6, 30, and 60 mg cm^{-2} treatment groups either immediately after the introduction of sediment or at the end of the 15 min sedimentation period. The collected water was filtered through pre-weighed 0.45 µm, 47 mm diameter filters, dried at 60°C overnight, and weighed (to 0.0001 g) to determine TSS in mg L^{-1}. Light intensity (PAR at µmol photons m^{-2} s^{-1}) was measured once immediately after sediment introduction and once at the end of the 15 min sedimentation period for every replicate of all treatment groups except controls using the spherical micro quantum sensor. Sediment doses generally began at 0930. Aquarium light intensity ramped up from 0630 to 1130 at approximately 2.2 PAR min^{-1}, thus the observed percent decrease in PAR measured immediately after sediment introduction was used to determine percent decrease of the expected PAR at 0930 which was 396 µmol photons m^{-2} s^{-1} and at the end of the sedimentation period which was 438 µmol photons

m^{-2} s^{-1}. Water quality (dissolved oxygen, mg L^{-1}; temperature, °C; salinity, ppt; and pH; Pro Plus multiparameter instrument, YSI Incorporated, Yellow Springs, OH, USA) was measured daily in each test tank and ammonia was measured once in each test tank on day 9. Water quality measurements were also taken during the 30-day post exposure sediment free observation period.

Figure 12. Procedure for adding fine-grain sediment to test tanks (Photo: Justin Wilkens).

Figure 13. Procedure for adding coarse-grain sediment to test tanks (Photo: Justin Wilkens).

Figure 14. Photo of three sediment traps (PVC cap with a surface area of 28.6 cm^{-2}) placed on the bottom grate near corals prior to a sediment dose (Photo: Justin Wilkens).

Figure 15. A sediment trap (PVC cap with a surface area of 28.6 cm^{-2}) removed from a test tank after the 15 min sedimentation period following sediment dosing. The contents were used to determine the 15 min net sedimentation concentration (mg cm^{-2}) (Photo: Justin Wilkens).

2.5 Coral measurements overview

For each 18-day experiment, three individuals of each coral species (n = 3 coral species; n = 9 total corals per aquarium) were placed into test tanks which were randomly assigned to a sedimentation concentration treatment group of 0-control (n = 3 reps), 6 (n = 4 reps), 30 (n = 4 reps), and 60 mg cm^{-2} (n = 4 reps). A total of 135 corals (45 fragments of each coral species) were used for each experiment (fine and coarse grain sediment). Combined, a total of 270 corals (90 fragments of each coral species) were used in the study.

The sedimentation concentrations used in this study were selected to span the range of potential effects in the three test species, including causing tissue bleaching or loss of tissue (Jones et al. 2016; Weber et al. 2006). Additionally, corals were expected to reallocate energy toward production of mucus to clear sediment or repair damaged tissue. Given sufficient time and sedimentation concentrations, this reallocation of energy could potentially lead to a decrease in growth, depletion of energy stores, or changes in protein expression (Meesters et al. 1992; Stafford-Smith 1993; Riegl and Branch 1995; Fabricius 2005).

To determine the response of corals to sedimentation, sublethal endpoints including growth, percent tissue loss, color, two-dimensional (2D) surface area (for tissue loss), photosynthetic efficiency, and physiological condition of corals were measured. Destructive endpoints for lipid measurement and tissue thickness (for *P. lobata* only) were also determined. For each experiment, on day 0 and at the end of the 18-day exposure, all sublethal endpoints were measured for every coral tested (n = 135 per experiment) apart from photosynthetic efficiency which logistically could be measured on only one coral from each species in each replicate (n = 45 fragments per experiment). After sublethal measurements were completed at the end of the 18-day exposure, one coral from each species in each replicate (n = 45 fragments per experiment) was sacrificed for lipid measurement and the same corals were used for tissue thickness. The remaining corals (n = 90 fragments per experiment) were then transferred to an outdoor water table for the 30-day sediment free observation period. At the end of 30-day observation, all sublethal endpoints were measured for all corals except for photosynthetic efficiency which again could be measured on only one coral from each species in each replicate. All corals were then sacrificed for lipid measurement and tissue thickness. In addition to the 270 corals used in the study, extra fragments from each species were sacrificed for day 0 lipid measurement and tissue thickness. The following sections describe each endpoint in further detail.

2.6 Sublethal endpoints

2.6.1 Coral physiological condition measurements

During each 18-day exposure, the mean physiological response of each coral species was determined daily by measurements made on the three corals of each species in each replicate while they remained in-place in the test tank. At the end of the exposure, one coral of each species from each replicate was sacrificed for destructive endpoints. The remaining corals were transferred to the outdoor water table for the 30-day sediment free observation where the mean physiological response of each coral species was determined weekly by measurements made on the two remaining corals of each species in each replicate while they remained in-place. Evaluation of coral physiological condition in each 18-day exposure and 30-day sediment free observation period included Boolean and proportional estimates of the following:

1. Visual estimates of polyp behavior including extension (yes =extended, no =not extended) and response to tank tap stimuli (yes =polyps retract when tank tapped, no =no retraction of polyp when tank tapped)
2. Percent of tissue bleached (the loss of the dinoflagellate symbionts)
3. Tissue paleness (yes =tissue color appearing to pale, no =no paleness)
4. Coral color matched to the color number on the Hawaiian Koʻa Card (Bahr et al. 2020)
5. Percent tissue loss (tissue loss for corals that were not covered by sediment)
6. Mucus production (yes =visible mucus layer, no = no mucus layer).
7. Percent sediment cover over surface of corals (during 18-day exposure only)

2.6.2 Coral growth, color, and tissue loss measurements

Corals were photographed on day 0, at the end of the 18-day exposure, and at the end of the 30-day sediment free observation period next to a scale and white balance card (ColorChecker, m50101, X-Rite, USA). Profile photos were taken of *M. capitata* and *P. meandrina* and from above for *P. lobata* using a digital camera (Nikon D90 equipped with the AF NIKKOR 24mm f/2.8D lens, Nikon Inc, Japan). With photo editing software (Photoshop, Adobe, USA) the color of each photograph was adjusted using the white balance card visible in each photo and the AF NIKKOR 24mm lens correction profile was applied. Because algae had grown on some tiles, the base of *M. capitata* and *P. meandrina* was sometimes obscured. To improve selection consistency between photograph days, a mask was created which overlapped the top of the tile and several millimeters of the coral base. A selection tool (Magic Wand Tool) was then used to select the unmasked pixels of the coral and the selection was saved as a JPEG file. The JPEG file was used to examine 2D surface area (cm^{-2}), tissue color changes, and tissue loss using ImageJ (version 1.53i, NIH, Bethesda, MD), an open-source software for processing and analyzing images.

In ImageJ, after setting the scale of the photos, the color threshold tool (using the HSB color space and default thresholding method) was used to select the whole coral. The total surface area of this selection was recorded as the 2D surface area. For corals with tissue loss, the difference between total 2D surface area and live tissue 2D surface area as selected by the color threshold tool was used to determine percent tissue loss. To determine tissue color, the color threshold tool was used to select the

entire coral when no tissue loss was detected, or when tissue loss was detected, only the live tissue was selected. The selection was then converted to a 3-slice stack (RGB stack) and used to measure color values for the red, green, and blue color channels. The measurements were converted to unweighted grayscale (red channel + green channel + blue channel/3).

The skeletal weight of each coral was estimated from its buoyant weight in seawater measured on day 0, after the 18-day exposure, and at the end of the 30-day observation (Davies 1989). To measure buoyant weight, each coral was roped with string from three different points and then placed in a 2 L beaker of test water. The string was then attached to an under-hook weighing attachment of a digital balance and the coral was weighed to the nearest 0.01 g. Growth rate recorded as buoyant weight or 2D surface area at the end of the 18-day exposure and the 30-day post-exposure observation were expressed as percent of initial measurement on day 0 and day 18, respectively.

2.6.3 Coral photosynthetic efficiency measurements

An increase in suspended sediment and sedimentation decreases the light availability for coral algal symbionts and if the duration is sufficient, will lead to a depression in photosynthetic efficiency. This would reduce the production of the corals' main source of energy (Erftemeijer et al. 2012; Tuttle and Donahue 2020). Extensive sedimentation and turbidity can induce damage to coral algal symbionts leading to decreased photosynthetic efficiency (Philipp and Fabricius 2003) which often precedes a bleaching event (Fitt and Warner 1995). Pulse Amplitude Modulation Fluorometry is a method often used to measure these changes in photosynthetic efficiency in corals. The use of the parameters such as quantum yield (*Fv/Fm*) and relative electron transport rate (rETR) are used to assess photosynthetic performance and stress of corals (Bhagooli et al. 2021). Photosynthetic efficiency of one coral of each species randomly selected from each tank (n =45 total corals) was obtained on day 0 and at the end of each 18-day exposure using a Pulse Amplitude Modulation (PAM) fluorometer (Diving-PAM, Walz Gmbh, Germany). Prior to the measurement of photosynthetic efficiency, selected corals were dark adapted for 20 min. The Diving-PAM was used to run a rapid light curve (RLC, intensity: 8, Gain: 2). To begin the RLC, a quasi-dark measurement (0.15 µmol photons m^{-2} s^{-1}) that does not induce photosynthesis was used to determine the proportion of closed reaction

centers in Photosystem II by measuring the minimum fluorescence (F_o). Next, a high intensity saturating pulse (10,000 µmol photons m^{-2} s^{-1}) closed all the reaction centers and the maximum fluorescence (F_m) was measured. Quantum yield (Equation 1) was calculated using the formula

$$Quantum\ yield = \left(\frac{F_m - F_o}{F_m}\right). \quad (1)$$

Finally, actinic light of 8 incrementally increasing irradiances (0, 66, 90, 125, 190, 285, 420, 625, 820 µmol photons m^{-2} s^{-1}) each exposed for a 10 sec duration was used to induce photosynthesis and subsequently to measure photosynthesis as a function of irradiance. Relative electron transport rate (rETR, Equation 2) was calculated at each measurement using the formula

$$rETR = \left(\frac{D_f}{F'_m}\right) \times PAR \times AF \times 0.5, \quad (2)$$

where

D_f = F_m'-F_o';
F'_m = maximum fluorescence (light adapted);
$\left(\frac{D_f}{F'_m}\right)$ = the effective quantum yield;
AF = the absorption factor which represents the absorbed fraction of PAR (0.8);
PAR = Photosynthetically Active Radiation; and
0.5 = accounts for half of the electrons absorbed by photosystem II, while the others are absorbed by photosystem I.

The maximum electron transport rate was recorded (*ETRm*). Three rapid light curves were run at different locations on each coral the day before each 18-day experiment (day 0) and the day after the end of each 18-day experiment (day 19). Photosynthetic efficiency recorded as *Fv/Fm* and *ETRm* at the end of the 18-day exposure were expressed as percent change of initial measurement on day 0. Differences in *Fv/Fm* and *ETRm* between treatment group means were compared.

2.7 Destructive endpoints

2.7.1 Coral tissue thickness

Measurements of the coral skeleton occupied by live tissue (i.e., tissue thickness) is commonly used as an indicator of stress for *P. lobata* (Barnes and Lough 1992; Rotmann et al. 2012). Tissue thickness of corals that occur in areas where sedimentation concentrations are high has been documented to decrease (Barnes and Lough 1999). Before each experiment the thickness of live tissue was measured for four sacrificial corals to assess changes in tissue thickness. Then, after the 18-day exposure and 30-day observation, *P. lobata* frozen in liquid nitrogen for lipid analysis were also used to measure tissue thickness. To measure tissue thickness, samples were sectioned along the longest side of the polygon shaped fragments into 5 mm thickness slices using a diamond tipped bandsaw. The slices were oven-dried for 24 hr at 60° C. Thickness of live tissue was measured with a digital caliper (to the nearest 0.001 mm) from the tissue surface to the boundary of live tissue along each fragment slice at ten sites and averaged. Changes in tissue thickness at the end of the 18-day exposure and the 30-day post-exposure observation were expressed as percentages of the initial measurement on day 0 and day 18, respectively.

2.7.2 Coral lipid measurements

For lipid analysis, before each experiment extra corals (n =5) not slated for use in the experiments were flash frozen in liquid nitrogen and stored at -80°C. At the end of each 18-day experiment, one coral of each species per tank (n =45 total corals) was randomly selected for lipid analysis, and all remaining corals (n =90) were frozen at the end of the 30-day observation. For lipid analysis, 0.5 g of coral tissue was ground into a fine powder with a mortar and pestle over liquid nitrogen. Then, tissue was homogenized in water and split in half for protein and lipid extractions. Lipids were extracted in 2:1 chloroform: methanol solutions, washed with 88% Potassium Chloride, and 50% methanol as described in (Gulko and Jokiel 1995) with modifications. Lipid was added to pre-weighed tubes, vacuum dried, then weighed to obtain lipid per sample. Protein samples were homogenized in 6M Urea, then spun at 10,000 rpm for 25 min. The Qubit assay was used to quantify the protein in each sample.

2.8 Data analysis

Data were analyzed using R version 4.2.1 (R Development Core Team 2021) and the graphical user interface R commander (Rcmdr package; Fox 2022). Differences in endpoints between treatment group means were compared. To stabilize variance tissue loss proportion data were arcsine-square root transformed. Initially, data were explored by producing boxplots to visualize the distribution of data for each treatment group. The data were then analyzed using a one-way analysis of variance (ANOVA). The standardized residuals from the fitted ANOVA model were observed in diagnostic plots (e.g., normal quantile-quantile plot) to determine if approximate normal distribution was achieved (Kozak and Piepho 2018). Normality and homogeneity of variance using the residuals were also checked using Shapiro-Wilk's test and Levene's test, respectively, but due to small sample size were less relied upon relative to the former diagnostic plots. In many cases, the ANOVA assumptions were not met. Therefore, a one-way permutation test which does not rely on approximate normal distributions or homogeneity of variance was used to test for differences in means using the permKS function in the perm package (Fay and Shaw 2010, 2021; Helsel et al. 2020a). A user-friendly R script version of the permutation test, perm1way.R, was used (Helsel et al. 2020b). If a difference between the treatment groups was detected ($P < 0.05$), a Dunn's test for multiple comparisons of mean rank sums with one control (PMCMRplus package; Pohlert 2021) was used to compare the 6, 30, and 60 mg cm^{-2} treatment groups to the control group. A one-tailed Dunn test adjusted with the Benjamini-Hochberg method to reduce the false discovery rate was implemented in the kwManyOneDunnTest function.

Regression coefficients were estimated by applying the ordinary least square regression to build a model that used the independent variable, turbidity, to estimate dependent variables, TSS, and PAR (e.g., $TSS = aTurbidity + b$) in treatment groups dosed with sediments (6, 30, and 60 mg cm^{-2}). The independent variable is the turbidity recorded in one replicate per treatment group on each day sediment was dosed. On each dose day, mean TSS concentration measurements were made in each replicate of each treatment group and paired with the turbidity recorded on the same day. The mean percent decrease in PAR consisted of measurements in each replicate for each treatment group made immediately after sediment introduction and followed again with another measurement after a 15 min sedimentation period and were paired with a turbidity measured at the same times. Model suitability was determined by testing the residuals for

homoscedasticity and a normal distribution using the Breusch-Pagan test and Shapiro-Wilk's test of normality. Homoscedasticity and normal distribution were accepted for turbidity, TSS, and PAR data.

3 Results and Discussion

3.1 Characteristics of the water and sediments used

Dissolved oxygen, salinity, pH, and temperature were within acceptable limits to maintain coral health in each 18-day experiment and in each 30-day observation period (Table 1). For both 18-day experiments combined, the dissolved oxygen ranged from 5.7 to 8.25 mg L^{-1}, temperature ranged from 23.5 to 25.6°C, salinity ranged from 33.9 to 36.1 ppt, and pH ranged from 7.9 to 8.1. Ammonia nitrogen was not detected. The variations in water quality in each laboratory experiment were closely associated with water quality conditions measured in other outdoor tanks which held display corals at Kewalo Marine Laboratory that received unfiltered sea water. Detailed water chemistry for the 5 μm filtered sea water pumped from Kewalo Basin and used in the experiments is provided in Appendix A.

Table 1. Mean (standard deviation) of water quality parameters measured daily in each test tank where corals were exposed to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during separate 18-day experiments with fine grain and coarse grain sediments each followed by a 30-day sediment free observation period in outdoor tanks. Water quality in unrelated outdoor tanks (reference) stocked with display corals and supplied with the same sea water but unfiltered were also measured.

Days	Sediment	Treatment (mg cm^{-2})	Dissolved oxygen (mg L^{-1})	Temperature (C°)	Salinity (ppt)	pH
18	Fine grain	0	6.52 (0.37)	24.86 (0.46)	34.83 (0.15)	8.05 (0.06)
		6	6.43 (0.38)	24.82 (0.45)	34.83 (0.15)	8.05 (0.06)
		30	6.35 (0.38)	24.88 (0.44)	34.83 (0.15)	8.05 (0.06)
		60	6.32 (0.38)	24.86 (0.46)	34.83 (0.16)	8.04 (0.06)
	Coarse grain	0	6.50 (0.51)	24.78 (0.22)	34.63 (0.41)	8.05 (0.04)
		6	6.55 (0.56)	24.80 (0.23)	34.63 (0.41)	8.05 (0.05)
		30	6.43 (0.45)	24.75 (0.22)	34.62 (0.41)	8.05 (0.04)
		60	6.42 (0.46)	24.79 (0.24)	34.63 (0.41)	8.04 (0.04)
30	N/A	N/A	6.47 (0.60)	24.40 (0.37)	34.63 (0.47)	8.05 (0.04)
48	N/A	Reference tank	6.44 (0.62)	24.49 (0.51)	34.51 (0.44)	8.04 (0.05)

The physical, organic, and nutrient-related parameters measured in each test sediment are listed in Table 2. These parameters along with the results of the chemical analysis of USEPA's list of priority pollutants are provided

in Appendix B. The inner harbor sediments contained predominantly fine sand (23%), silt (53.4%), and clay (21.3%) particles whereas the Kuli‘ou‘ou sediment was characterized by coarser grained particles which included medium (20.9%) and fine sands (75%), with less than 5% silts and clays. The chemical analysis detected increased concentrations of contaminants and metals in the inner Honolulu Harbor sediments compared to sediments collected from Kuli‘ou‘ou Beach Park. The increased concentrations of contaminants and metals in the inner Honolulu Harbor was consistent with previous analyses of Inner Harbor sediments (USACE 2015). This result was not unexpected for sediments occurring in the urbanized Honolulu Harbor area which is a depositional environment where more fine grain sediments (e.g., fine sand, silt, and clay particles) exist and have a higher sorptive capacity for contaminants (Parham et al. 2008). The Kuli‘ou‘ou Beach Park sediment is in a higher energy environment as evidenced by the dominance of coarse grain particles found there and distance from known contamination sources. Total organic carbon and total phosphorous was greatest in the fine grain sediment, but total nitrogen was higher in the coarse grain sediment.

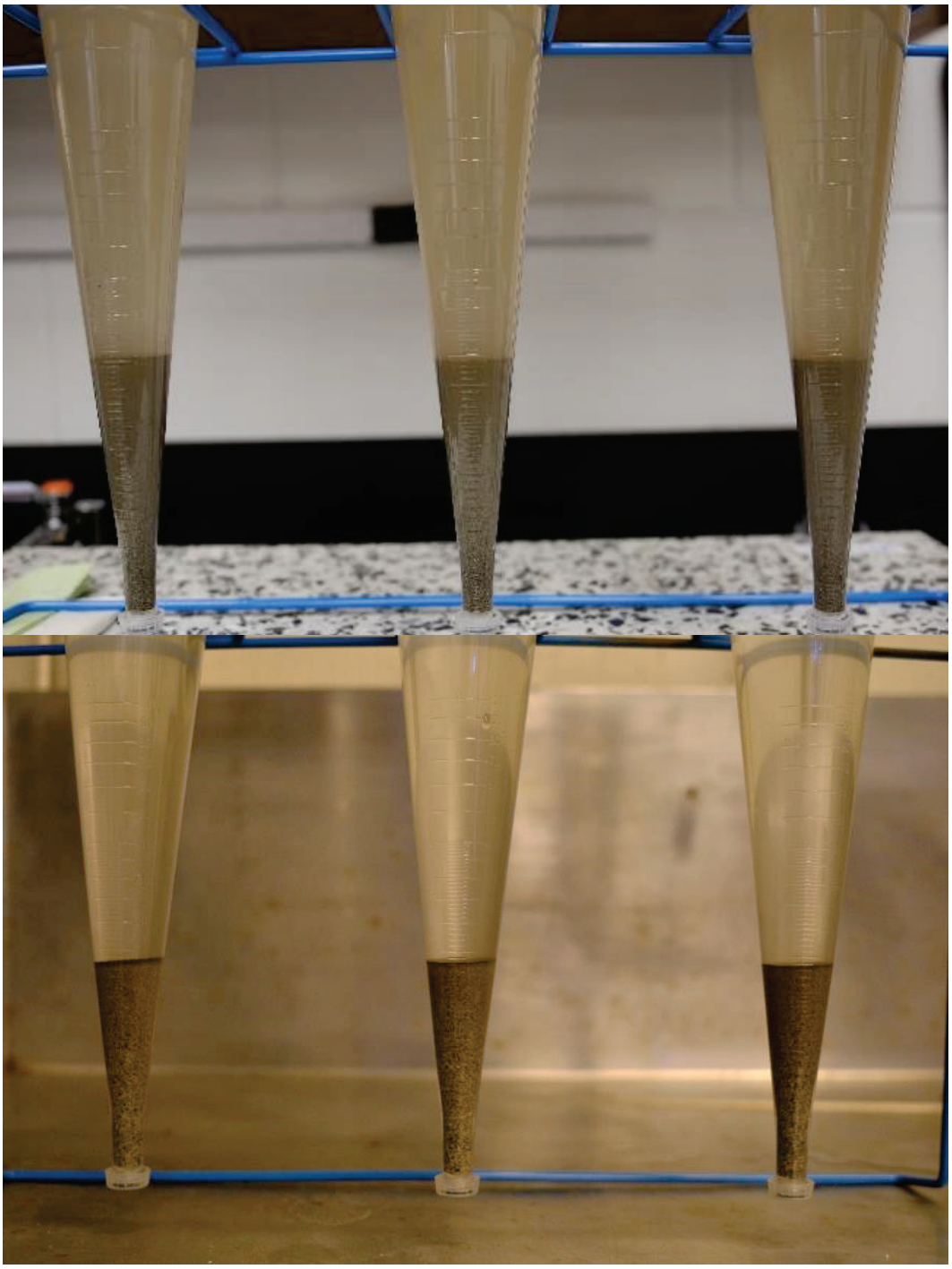
In Imhoff funnels, the sediment volume of the fine grain sediment after 2 hr sedimentation time was 23 ml 15 g DW^{-1} while for the coarse grain sediment it was 14 ml 15 g DW^{-1} (Figure 16; Table 2). The quickest sedimentation rate occurred within the first 15 min where fine grain and coarse grain sediment volume was 93% and 94% of the 2 hr sediment volume, respectively. No further compaction occurred for either sediment after 38 hr. These results were similar to sediment volumes reported in Weber et al. (2006) for fine sands (63-250 μm grain; 12.2 ml 15 g DW^{-1}) and medium sands (250-500 μm grain; 12.9 ml 15 g DW^{-1}) which settled to 95-99% of the 2 hr sediment volume with no further compaction. The Imhoff data supported the decision to allow for a 15 min sedimentation period to follow immediately after each sediment dose in which >90% of the sedimentation occurred prior to restoration of water flow.

Table 2. Parameters measured to characterize test sediments collected from the inner Honolulu Harbor (fine grain) and from Kuli‘ou‘ou Beach Park (coarse grain). Other contaminants analyzed in test sediments are provided in Appendix B.

		Inner Honolulu Harbor	Kuli‘ou‘ou Beach Park
Grain size (%)[1]	**Description**	**Fine Grain**	**Coarse Grain**
Medium Sand	1 mm to 425 µm	2.3	20.9
Fine Sand	425-75 µm	23.0	75.0
Silt	75-2 µm	53.4	1.0
Clay	2 µm	21.3	3.1
Imhoff funnel (15 g dry weight [DW] of test sediment in 1,000 ml of sea water (35 ppt))			
Sediment volume (SV)	ml 15 g^{-1} DW at 2 h	23	14
Sedimentation rate (% 15 min)	15 min SV as proportion of 2 h SV	93	94
Sedimentation rate (% 1 h)	1 h SV as proportion of 2 h SV	98	100
Compaction (%)	38 h SV as proportion of 2 h SV	99	99
Organic and nutrient-related parameters			
Total organic carbon	%	5.1	4.3
Total nitrogen	%	0.12	0.52
Total phosphorus	%	0.14	0.099

[1]Sediments were initially passed thru a 1 mm sieve (sieve size #18) to remove debris.

Figure 16. Photo of Imhoff funnels approximately 15 min after the introduction of 15 g dry weight of fine-grain sediment (top photo) and coarse-grain sediment (bottom photo) in 1,000 ml of sea water (35 ppt) (Photos: Justin Wilkens).



3.2 Sedimentation, turbidity, total suspended solids, and underwater light in tanks

Measured sedimentation concentrations determined using sediment traps approximated nominal sedimentation concentrations for each experiment although the use of coarse grain sediment, which was nearly an order of magnitude heavier by volume than the fine grain sediment, resulted in greater variation of sedimentation rates due to the difficulty to suspend the sediment when dosed (Table 3). The mean (standard deviation) net sedimentation rates in the sediment traps removed at the end of the 15 min sedimentation period for the experiment conducted with fine grain sediment was 4 (±1), 21 (±3), and 47 (±13) mg cm^{-2} 15 min for nominal sedimentation treatment groups 6, 30, and 60 mg cm^{-2}, respectively. In the experiment with coarse grain sediment, the mean sedimentation rates were 7 (±3), 37 (±17), and 77 (±37) mg cm^{-2} 15 min for the sedimentation treatment groups of 6, 30, and 60 mg cm^{-2}, respectively.

Regression results effectively corroborated the turbidity, TSS, and PAR measurements acquired during the 15 min settling period. The coefficient estimates from the regression indicated a significant linear regression between increases in turbidity and TSS and increase in turbidity and decrease in PAR (Figure 17). The coefficients used to estimate TSS and PAR were on average within 2.1% (±4.3%) of actual mean measurements and were used to estimate exposure conditions for TSS and PAR during the 15 min sedimentation period (Figure 18). As expected, on the days test tanks were dosed with test sediments an increase in turbidity and TSS concentrations resulted in a concomitant decrease in underwater light immediately after sediment was dosed. This was followed by a relatively rapid decrease in turbidity and TSS and gradual increase in underwater light, eventually returning to reference conditions (turbidity ≤1.92 NTU) 100 to 200 min after each sediment dose (Figure 19).

Table 3. Wet weight (WW) of sediment introduced into test tanks to create sedimentation concentration of 0-control, 6, 30, and 60 mg cm^{-2} DW. Sediment was introduced every 4 days during separate 18-day laboratory experiments in which a fine grain and coarse grain sediment was used. Sediment was allowed to settle for 15 min before pumps and water were restored. Mean (standard deviation) of sedimentation at the end of 15 min (mg cm^{-2} 15 min DW), and total suspended sediment (TSS in mg L^{-1}), turbidity (NTU), and underwater light (PAR, µmol photons m^{-2} s^{-1}) concentrations in test tanks was made immediately after sediment introduction (start) and again at the end of the 15 min period of sedimentation (end).

	Sedimentation concentration treatment groups			Start of 15 min sedimentation period			End of 15 min sedimentation period		
Sediment	Treatment (mg cm^{-2} DW)	Sediment introduced (g WW)	Measured sedimentation (mg cm^{-2} 15 min DW)	TSS (mg L^{-1})	Turbidity (NTU)	PAR (396 µmol photons m^{-2} s^{-1})[1]	TSS (mg L^{-1})	Turbidity (NTU)	PAR (438 µmol photons m^{-2} s^{-1})[1]
Fine grain	0	0	0	<4	<2	396	<4	<2	438
	6	21	4 (1)	159 (17)	60 (11)	312 (12)	69 (3)	44 (2)	387 (24)
	30	102	21 (3)	652 (45)	249 (49)	78 (14)	197 (6)	136 (10)	248 (13)
	60	204	47 (13)	1,247 (117)	446 (82)	13 (5)	238 (16)	187 (17)	232 (25)
Coarse grain	0	0	0	<4	<2	396	<4	<2	438
	6	14	7 (3)	19 (9)	6 (2)	386 (5)	13 (5)	5 (1)	410 (4)
	30	69	38 (17)	78 (32)	20 (7)	323 (14)	33 (5)	16 (3)	366 (27)
	60	137	78 (37)	115 (26)	50 (23)	248 (10)	62 (9)	36 (2)	302 (10)

[1] The decrease in PAR observed within each treatment group was averaged and the ramp up of lights (i.e., increase in light intensity) over the observation period was factored in. Sediment introduction started at approximately 0930 each day, thus, based on the lighting regime, PAR was normalized to the expected PAR at 0930 which was 396 µmol photons m^{-2} s^{-1}. PAR increased at a rate of 2.2 µmol photons m^{-2} min^{-1} x 20 min and thus, the end PAR was normalized to 438 µmol photons m^{-2} s^{-1}.

In the fine grain sediment experiment, TSS and corresponding turbidity concentrations measured immediately after the introduction of sediment and at the end of the 15 min sedimentation period were an order of magnitude higher compared to the same treatment groups in the coarse grain sediment experiment. Also in the fine grain experiment, sediment dosed in tanks assigned to the 6, 30, and 60 mg cm^{-2} treatment groups yielded a mean measured TSS (and corresponding turbidity) concentration of 159 mg L^{-1} (60 NTU), 652 mg L^{-1} (249 NTU), and 1,246 mg L^{-1} (446 NTU), respectively, immediately after dosing. For the same treatment groups in the coarse grain sediment experiment the measured TSS was 19 mg L^{-1} (6 NTU), 78 mg L^{-1} (20 NTU), and 115 mg L^{-1} (50 NTU), respectively. At the end of the 15 min sedimentation period in the fine grain sediment experiment, tanks assigned to the 6, 30, and 60 mg cm^{-2} treatment groups had a mean measured TSS concentration of 69 mg L^{-1} (44 NTU), 197 mg L^{-1} (136 NTU), and 238 mg L^{-1} (187 NTU), respectively. For the same treatment groups in the coarse grain sediment experiment the measured TSS was 13 mg L^{-1} (5 NTU), 33 mg L^{-1} (16 NTU), and 62 mg L^{-1} (36 NTU). Within the 15 min sedimentation period, corals at the bottom of the tank in the fine grain experiment were not visible from the tank water surface in any treatment where sediment was dosed (Figure 20), while coral shapes were visible only at the lowest treatment for the coarse grain experiment.

The effect of a sediment dose on underwater light intensity was most notable in the experiment conducted with fine grain sediment immediately after dosing where PAR percent decrease was 21, 80, and 97% for treatment groups 6, 30, and 60 mg cm^{-2}, respectively. In the coarse grain sediment experiment the percent decrease in PAR immediately after dosing was 3, 18, and 37% for treatment groups 6, 30, and 60 mg cm^{-2}, respectively. A photo of test tanks one day after the third dose of coarse grain sediment shows how reference conditions appeared relative to dosed tanks during experiments (Figure 21). The differences in underwater light intensity as well as mean TSS and turbidity between experiments is explained by the differences in sediment characteristics (Table 2).

Figure 17. Linear regression of turbidity (NTU) and total suspended sediment (TSS in mg L^{-1}) measured during the 15 min sedimentation period in test tanks where corals were exposed to sedimentation concentrations of 0-control, 6, 30, and 60 mg cm^{-2} introduced every four days during an 18-day experiment performed once with fine grain sediment (a, b, and c) and with a coarse grain sediment (e, f, and g). A single linear regression of NTU and PAR (µmol photons m^{-2} s^{-1}) was made for combined treatment groups in the fine grain (d) and coarse grain sediment (h) experiments.

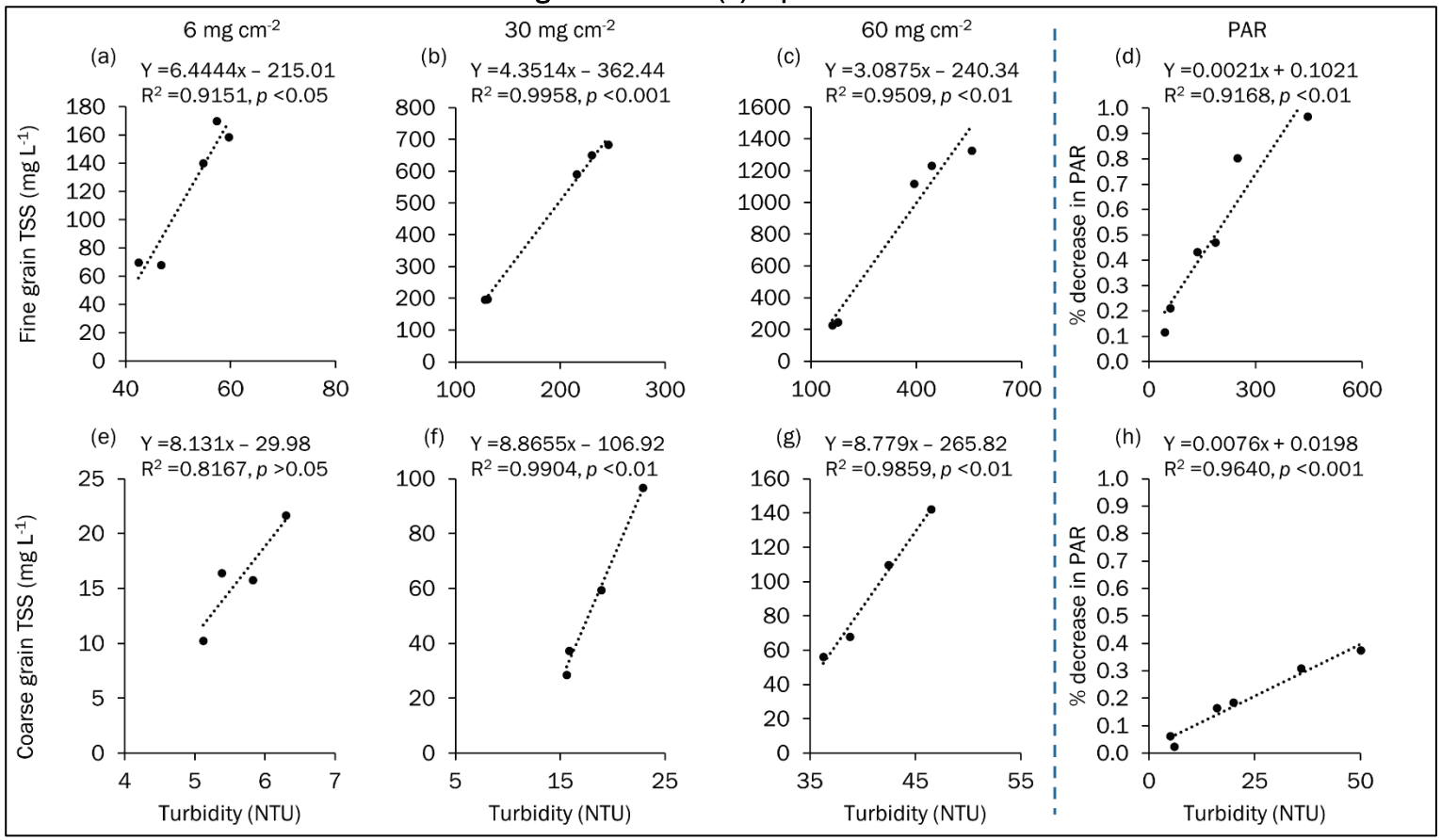


Figure 18. Turbidity (NTU; black line) estimated total suspended solids (TSS in mg L^{-1}; *dotted line*) and underwater light (PAR in µmol photons m^{-2} s^{-1}; *orange line*) during the 15 min sedimentation period in test tanks where corals were exposed to sedimentation concentrations of 0-control, 6, 30, and 60 mg cm^{-2} introduced every four days during an 18-day experiment performed once with fine grain sediment and again with coarse grain sediment.

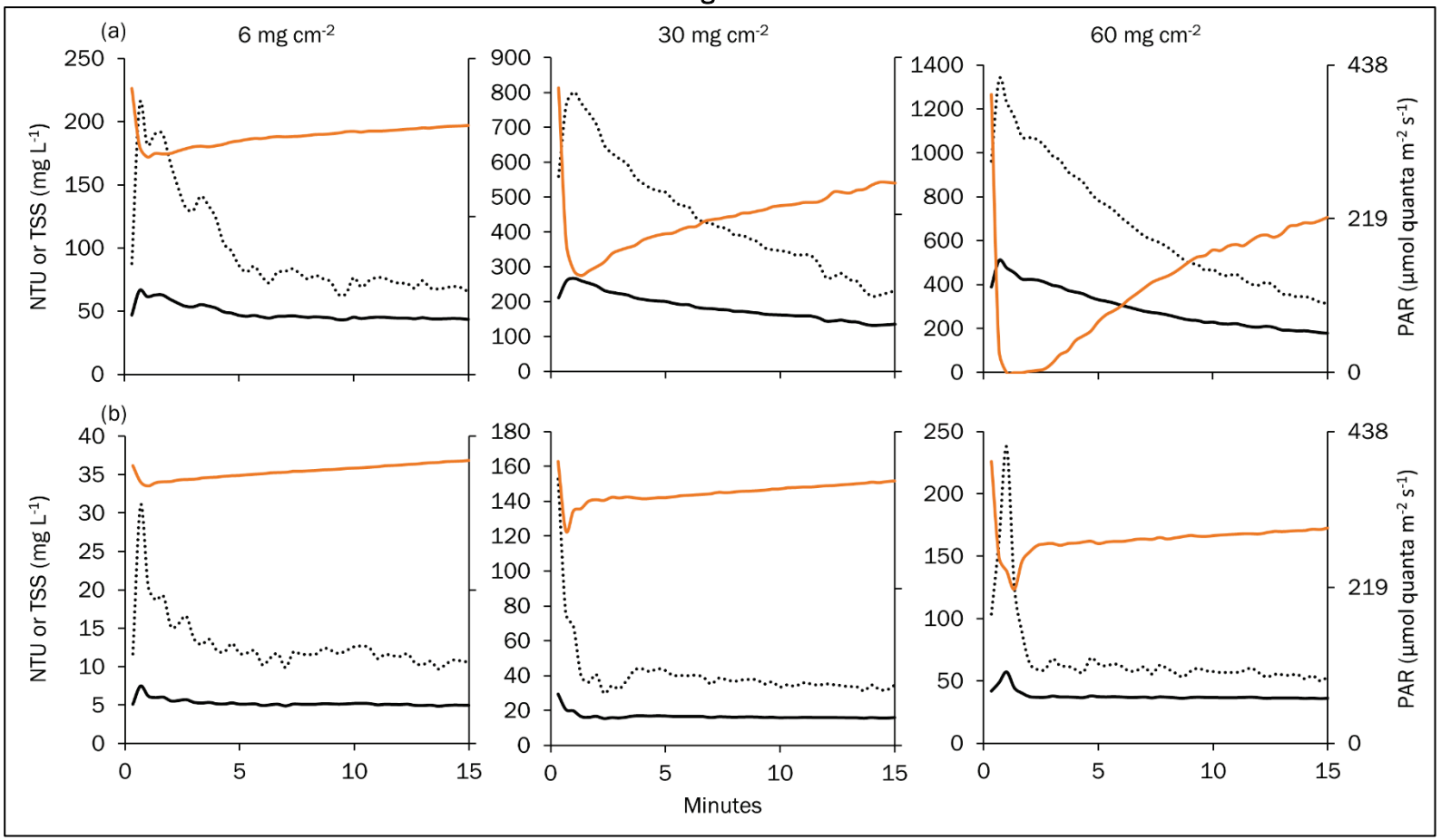


Figure 19. Turbidity (NTU) measured every 20 sec by a nephelometer placed into one replicate tank of each 6, 30, and 60 mg cm^{-2} treatment group on each sediment dose day (n =5 doses). Measurements continued until turbidity returned to reference (≤1.92 NTU) conditions for fine grain (*a*) and coarse grain (*b*) sediment experiments.

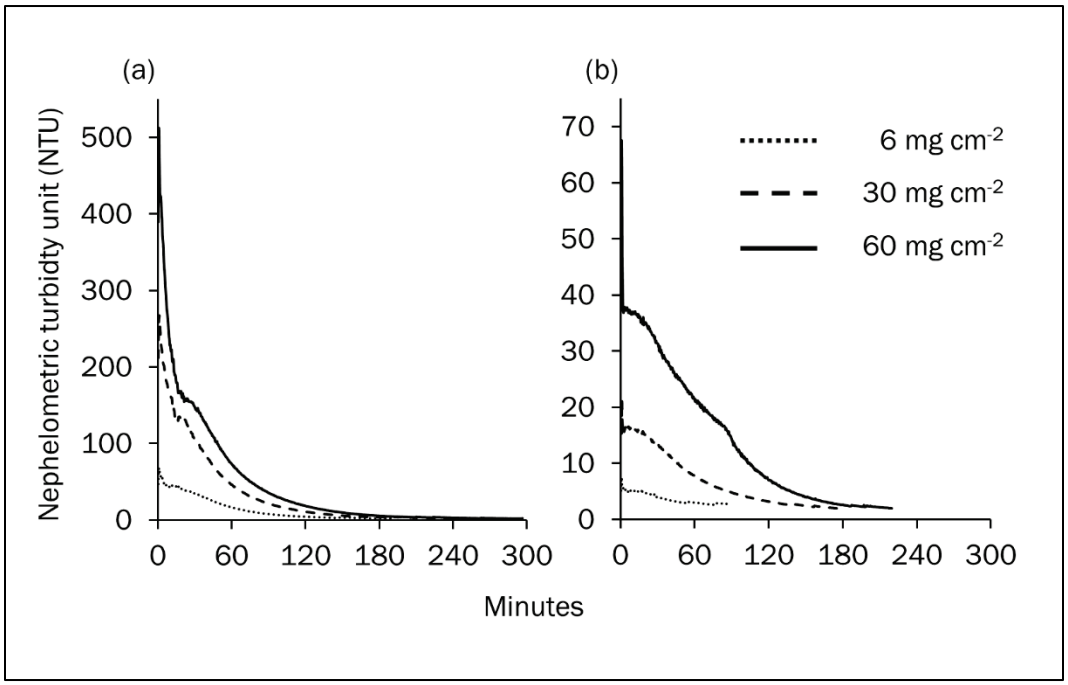
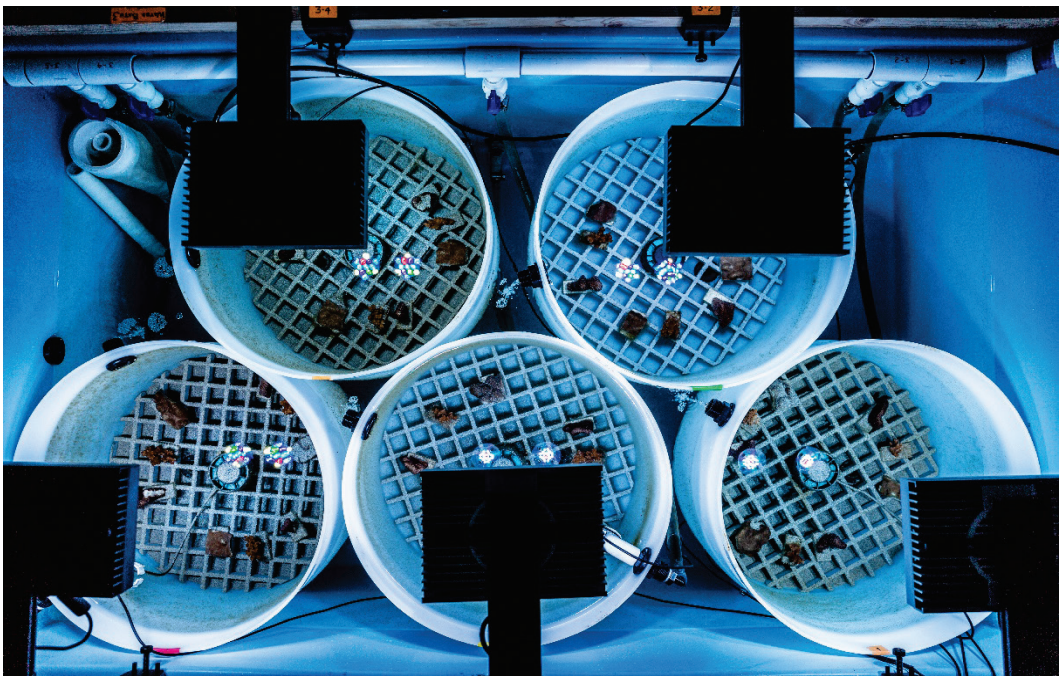


Figure 20. Photo taken during 15 min sedimentation period in one module of test tanks dosed with fine grain sediment to create sedimentation concentrations of 0-control, 6, 30, and 60 mg cm^{-2}. *Clockwise from top left*: 60, 6, 60 0 (control), and 30 mg cm^{-2} (Photo: Justin Wilkens).

Figure 21. Photo of one module of test tanks one day after the third dose of coarse grain sediment used to create sedimentation concentrations of 0-control, 6, 30, and 60 mg cm^{-2}. *Clockwise from top left*: 60, 0 (control), 30, 6, and 60 mg cm^{-2} (Photo: Justin Wilkens).



3.3 Sediment coverage of corals and tank surfaces

The percentage of sediment coverage of corals generally increased as sedimentation concentration and number of doses increased but substantially varied within treatment groups and within coral species (Figures 22 to 25). For corals in either experiment, daily visual estimates indicated the mean percent sediment coverage increased by the third sediment dose and continued to increase for the remainder of the experiment for some, but not all corals. Visual inspections made between doses revealed all horizontal test tank features near the bottom of the tank (e.g., grate, powerhead pump, coral tile) were completely covered by sediment (Figure 26).

The mean (range) percent sediment coverage for sedimentation concentrations made with fine grain sediment at the end of the 18-day experiment for *P. lobata* was 19% (range 0.3 to 63.3%), 81% (range 33.3 to 98.3%), and 60% (range 1.7 to 86.7%) in the 6, 30, and 60 mg cm^{-2} treatment groups, respectively (Figure 27). The lower percent sediment coverage in the 60 mg cm^{-2} treatment group was due to one replicate where sediment did not appreciably accumulate on the surface of the corals. With this replicate excluded, the sediment coverage increases to

79%. For *P. lobata* exposed to sedimentation concentrations made with coarse grain sediment the mean percent sediment coverage was 1% (range 0 to 4%), 23% (range 10 to 48.3%), and 48% (range 33.7 to 60%) in the 6, 30, and 60 mg cm^{-2} treatment groups, respectively (Figure 28). In either experiment, sediment was observed in the depressions between hemispherical shapes of the corals, or in some cases, resulted in 100% coverage of the corals by a thin layer of either sediment type.

The mean percent sediment coverage for sedimentation concentrations made with fine grain sediment at the end of the 18-day experiment for *P. meandrina* was 1% (range 0 to 1%), 12% (range 1.7 to 26.7%), and 16% (range 1.7 to 41.7%) in the 6, 30, and 60 mg cm^{-2} treatment groups, respectively, on day 18 (Figure 29). For *P. meandrina* exposed to sedimentation concentrations made with coarse grain, the mean percent sediment coverage was 0.5% (range 0 to 0.3%), 5% (range 0 to 13.3%), and 11% (range 0 to 40%) in the 6, 30, and 60 mg cm^{-2} treatment groups, respectively (Figure 30). If the coral was vertically oriented, the sediment was usually observed in a checkered like pattern between the verrucae which were regularly spaced over the coral's surface. If the branch was sloped, the sediment would fill in the voids between verrucae and eventually cover a larger continuous surface area. Maximum coverage of 80% was estimated for one coral in the fine grain experiment with a sloped orientation.

The mean percent sediment coverage for sedimentation concentrations made with either a fine or coarse grain sediment at the end of the 18-day experiment for *M. capitata* was 1% or less in all treatment groups (Figures 31 and 32). On sediment dose days, once turbidity returned to reference conditions, some corals in vertical or sloped orientations were observed accumulating some sediment around verrucae (<5%) which were less numerous and more irregularly spaced as compared to *P. meandrina*. But, by the next morning when daily observations were made (24 hr), no sediment remained on these corals.

At the end of the experiment, corals removed from the treatments dosed with sediment had all accumulated sediment on top of the tile to a visually estimated thickness of approximately 5 mm (Figure 25). As a result, in both experiments some corals experienced minor tissue loss (e.g., 1%) or paleness near the bottom margin next to where sediment accumulated on the tile.

Figure 22. Photo of corals after fifth dose of fine grain sediment used to create the 60 mg cm^{-2} sedimentation concentration. Sediment covered horizontal surfaces, including the bottom grate, pump, coral, and tile (Photo: Justin Wilkens).

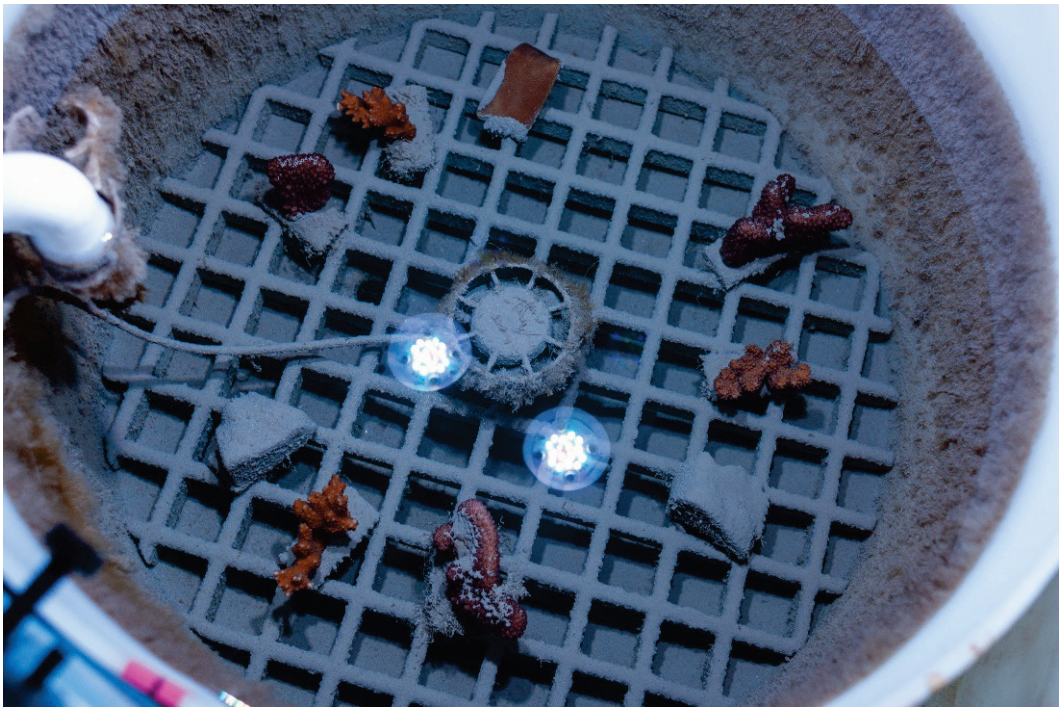


Figure 23. Photo of corals after fifth dose of coarse grain sediment used to create the 60 mg cm^{-2} sedimentation concentration. Sediment covered horizontal surfaces, including the bottom grate, pump, corals, and tile (Photo: Justin Wilkens).

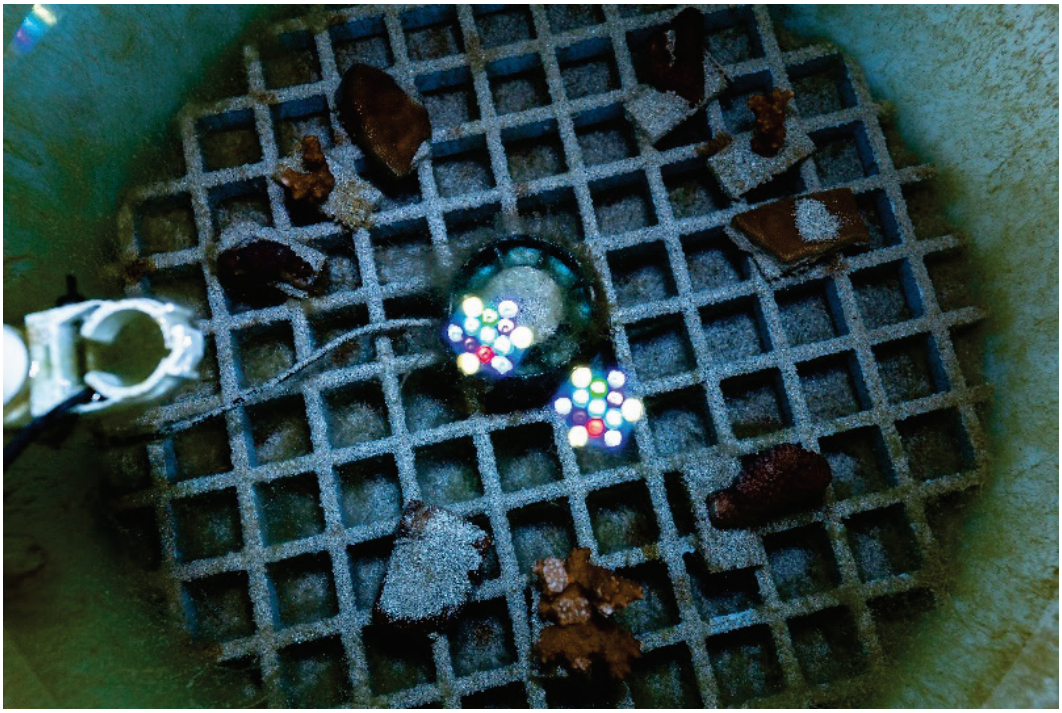


Figure 24. Photo, from *left*, of *P. lobata*, *M. capitata*, and *P. meandrina* after third dose of coarse grain sediment used to create the 60 mg cm^{-2} sedimentation concentration (Photo: Justin Wilkens).

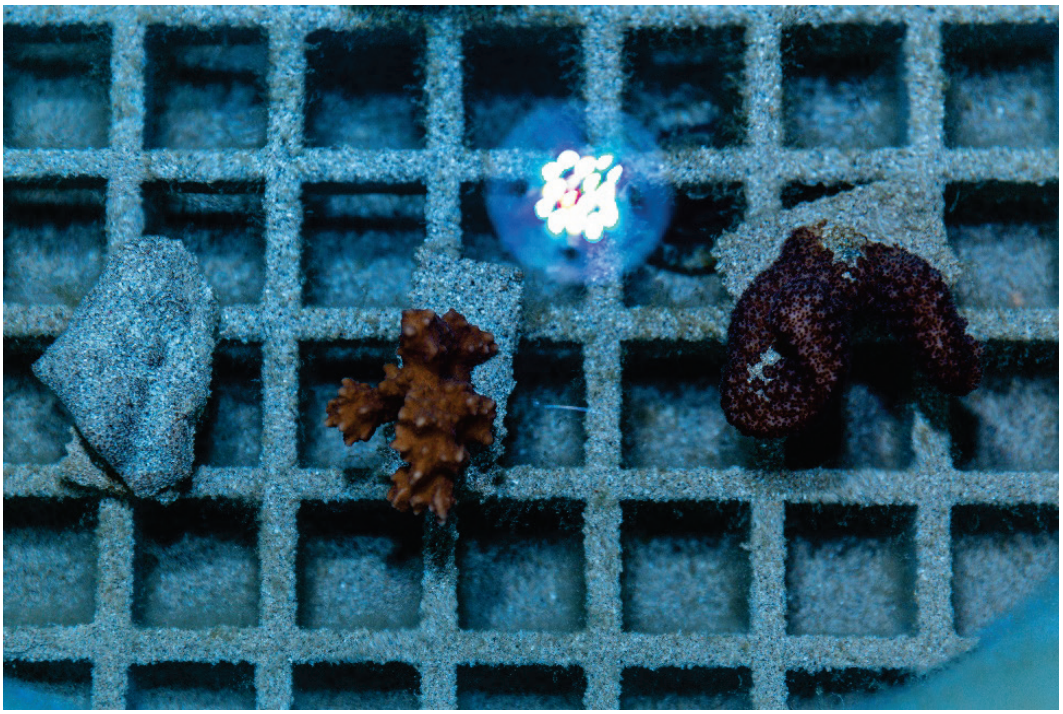
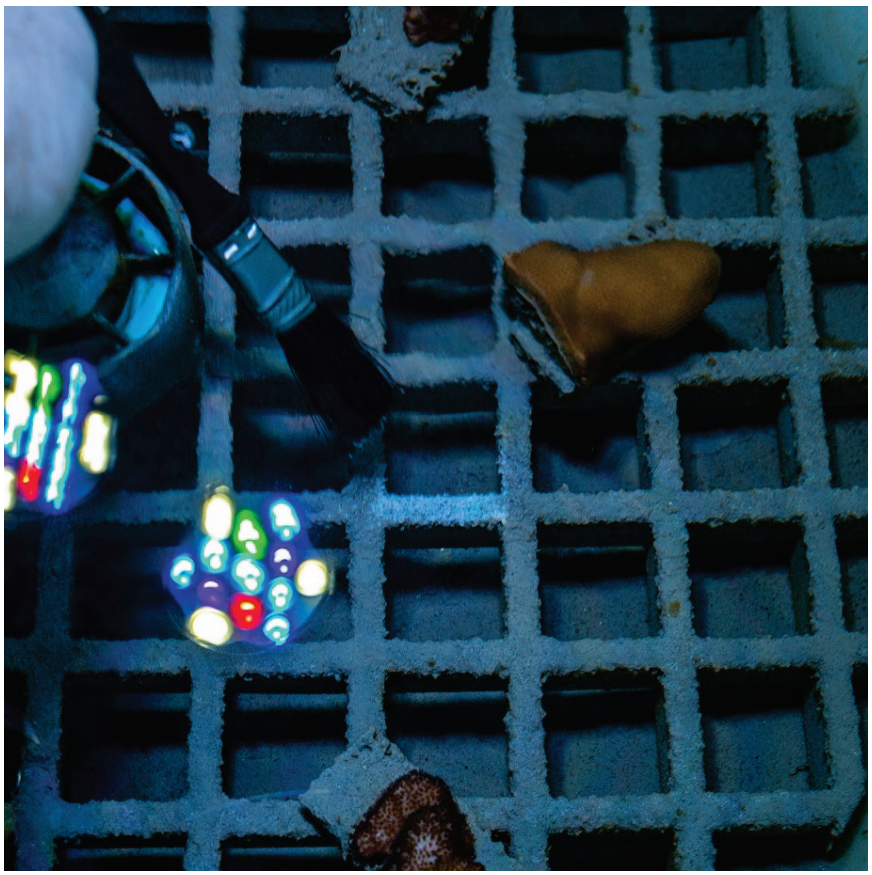


Figure 25. Photo of *M. capitata* (*left*) and *P. meandrina* (*right*) after an 18-day exposure in the 60 mg cm^{-2} sedimentation treatment group made with coarse grain sediment (Photo: Justin Wilkens).

Figure 26. The sediment on the bottom grate is brushed away to highlight sediment coverage after second dose to create sedimentation concentration of 60 mg cm^{-2} with fine grain sediment (photo: Justin Wilkens).



3.4 Daily coral physiological condition observations

The purpose of the daily observations of corals in-place was to document obvious changes in coral condition, monitor onset and any progression of tissue loss, and production of mucus. The results of these observations are presented for each coral species by experiment in Figures 27–32. After the second dose of sediment, some of the qualitative observations (e.g., polyp extension or retraction) became more challenging to document because sediment covered more of the coral tissue, obscuring the polyps.

Corals in the control groups appeared healthy throughout both 18-day experiments and no tissue loss was visually observed. In the fine grain experiment, visual detection of tissue loss was apparent in *P. meandrina* as early as day 9 in treatment groups where sediment was introduced. While in the coarse grain experiment, tissue loss was observed as soon as day 3. As the tissue died, it sloughed off and exposed the skeleton. The start of tissue

loss for *P. lobata* was more difficult to confirm once sediment accumulated on the corals but there was some visual evidence that tissue loss began to occur as early as day 9 in the fine grain sediment experiment and was detected by day 4 in the coarse grain sediment experiment. No tissue loss occurred in *M. capitata* except for where sediment accumulated on top of the tile and around the bottom margins of the corals.

During the 18-day exposure, except for corals covered by sediment, extended polyps were visible and observed to retract after slightly tapping on the test tank for most corals in all treatments in either experiment. In each experiment there was a noticeable decrease in polyp extension and retraction with increasing sedimentation concentration for *P. lobata* some of which was attributed to settled sediment, but for *P. meandrina* and *M. capitata* polyp behavior decreased at approximately the same proportion across treatments with increasing sediment concentration. In both experiments, tissue paleness measurements were variable but were most apparent in *P. meandrina*, followed by *P. lobata* and *M. capitata* across all treatment groups. Overall, the coral tissue color appeared to lighten independent of treatment group. Percentage estimates of corals with bleached tissue were <1% at the end of the 18-day exposure.

In both experiments, a proportion of *P. lobata* consistently produced visible mucus layers in all treatment groups receiving sediment; visible mucous was also observed on some corals in control tanks. Approximately two days after the first sediment dose in either experiment a mucus layer was detected for some *P. lobata* in treatment groups with sediment. The proportion of *P. lobata* with a mucus layer increased after each dose and by the end of either experiment, the proportion of corals with a mucus layer ranged from 18% at 6 mg cm^{-2} to as great as 50% at 60 mg cm^{-2}. Mucus layers for *M. capitata* and *P. meandrina* were more difficult to detect visually because the layer was not as well defined or visually distinguishable but were estimated to occur in 2%–12% of exposed corals.

Mucus production may have also occurred due to algal growth (McCook et al. 2001; O'brien and Scheibling 2018; Tebbett and Bellwood 2019). Growth of algae on the sides of the test tank and bottom grate increased over each 18-day experiment and was most noticeable in control tanks and the 6 mg cm^{-2} treatment group by day 9. In the fine grain experiment, by day 14, *P. lobata* in control tanks with a visible mucus layer increased to 44%. In the coarse grain experiment, formation of mucus layers by *P.*

lobata increased to as high as 57%. Introduced test sediments and other particles in the water could be trapped by algal filaments and could have potentially increase stress to coral tissue (McCook et al. 2001). However, because algal growth did not appear until day 9 in either experiment and because it was confined to the control and 6 mg cm^{-2} treatment group, the effect of algal during the 18-day experiment is believed to be minimal.

Figure 27. Mean of physiological conditions observed daily for *P. lobata* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every four days during an 18-day laboratory experiment performed with fine grain sediment. Observations were subject to sediment coverage.

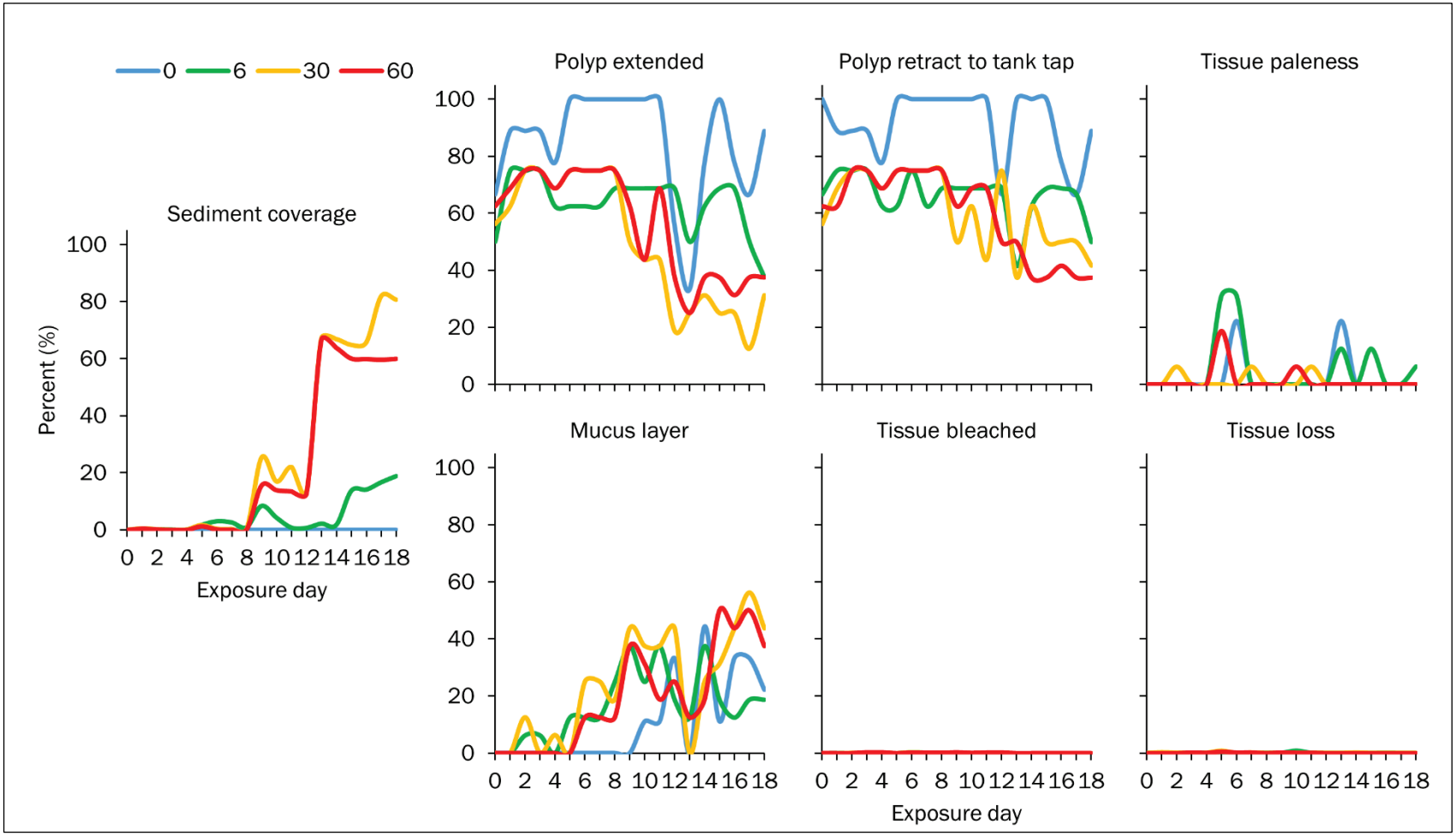


Figure 28. Mean of physiological conditions observed daily for *P. lobata* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every four days during an 18-day laboratory experiment with coarse grain sediment. Observations were subject to sediment coverage.

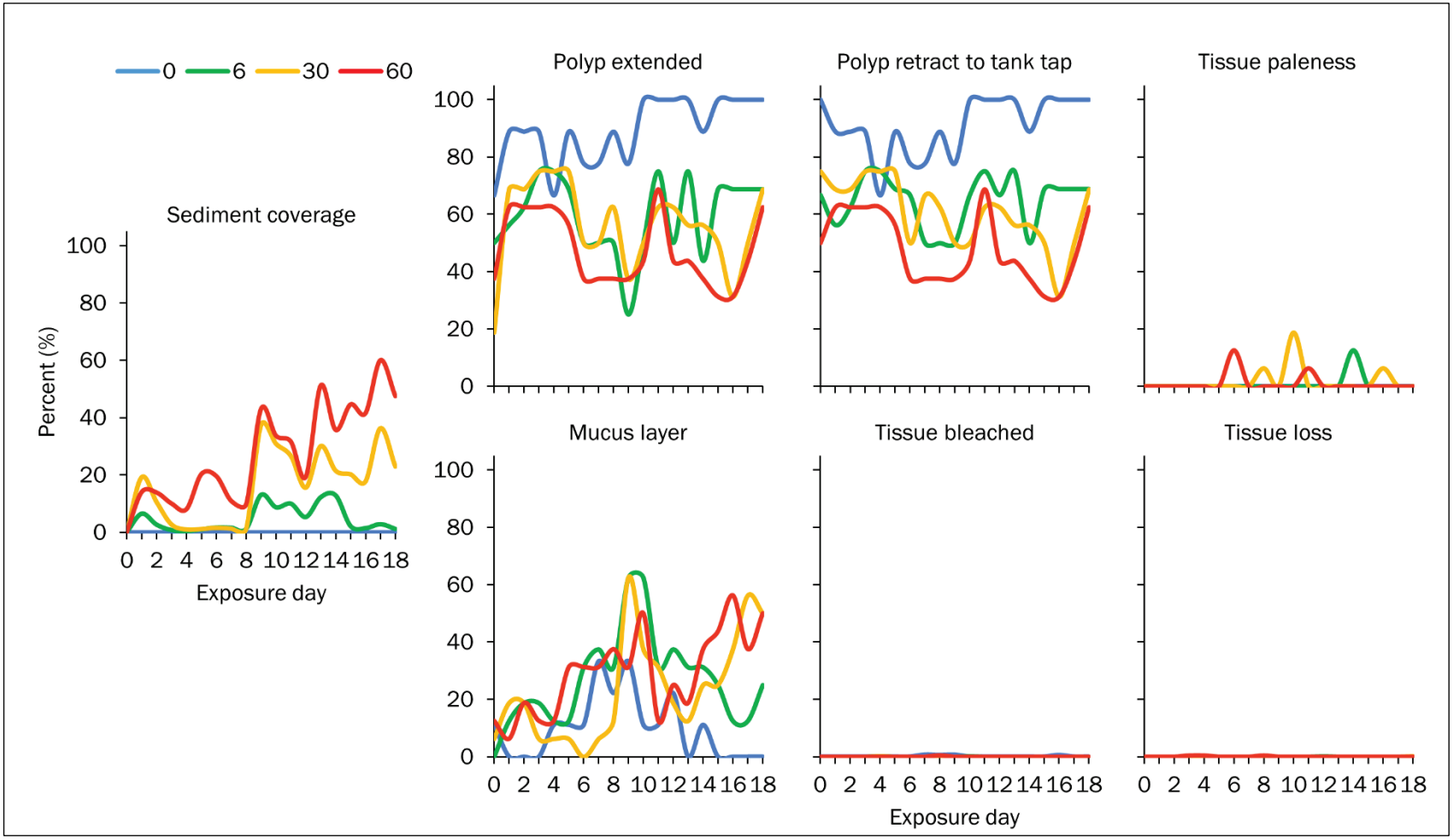


Figure 29. Mean of physiological conditions observed daily for *P. meandrina* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every 4 days during an 18-day laboratory experiment with fine grain sediment. Observations were subject to sediment coverage.

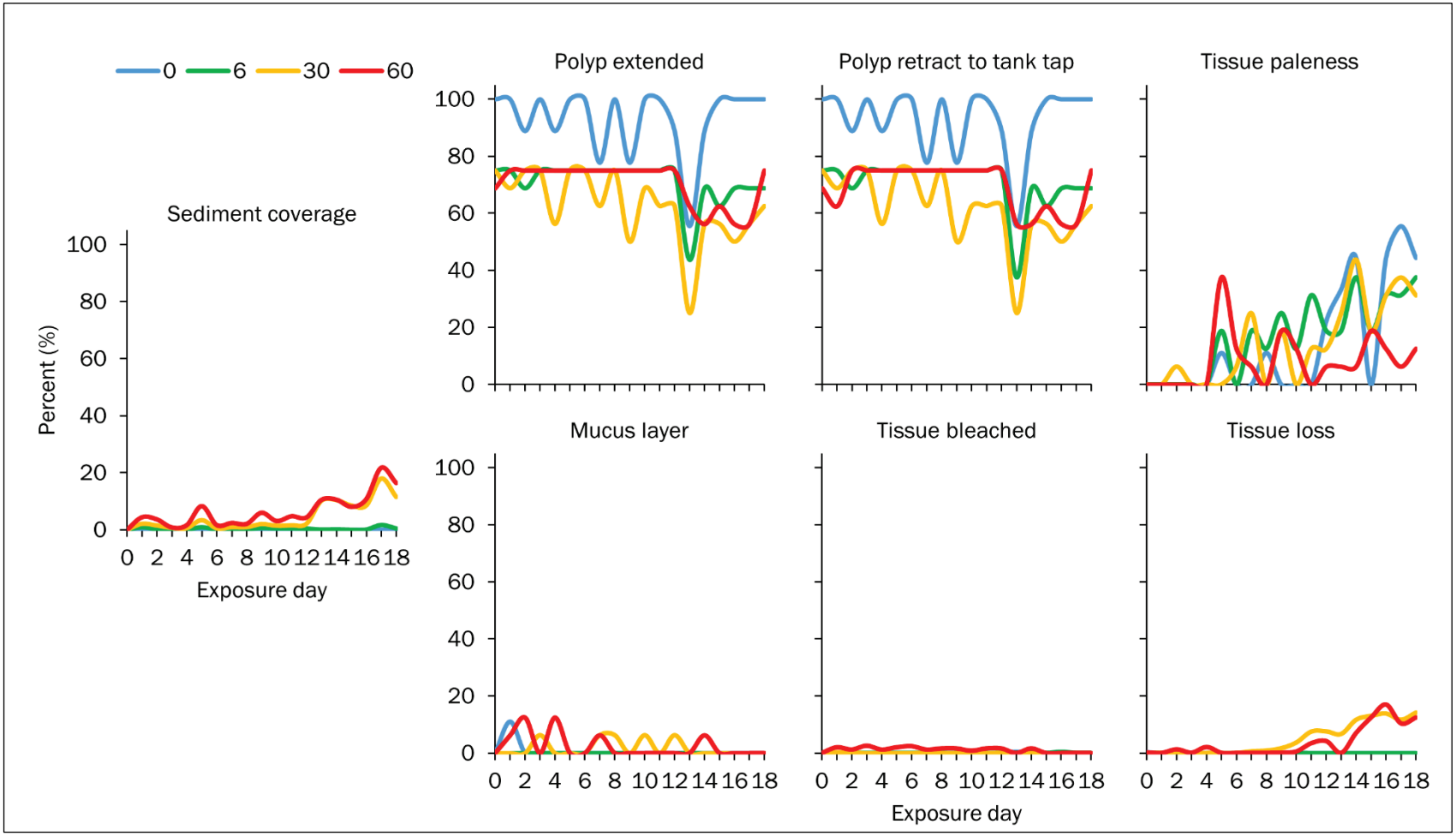


Figure 30. Mean of physiological conditions observed daily for *P. meandrina* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every 4 days during an 18-day laboratory experiment with coarse grain sediment. Observations were subject to sediment coverage.

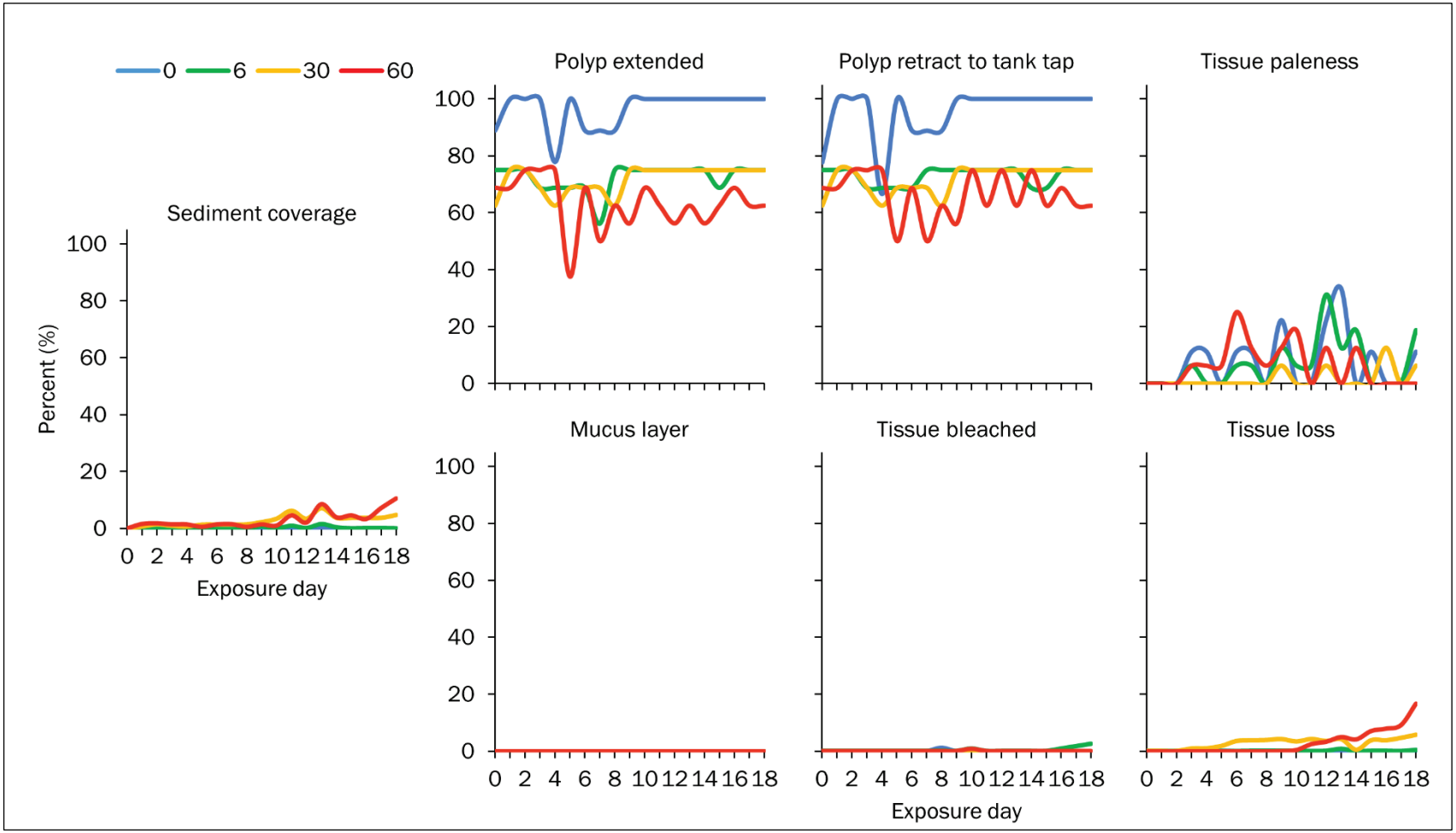


Figure 31. Mean of physiological conditions observed daily for *M. capitata* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every 4 days during an 18-day laboratory experiment with fine grain sediment. Observations were subject to sediment coverage.

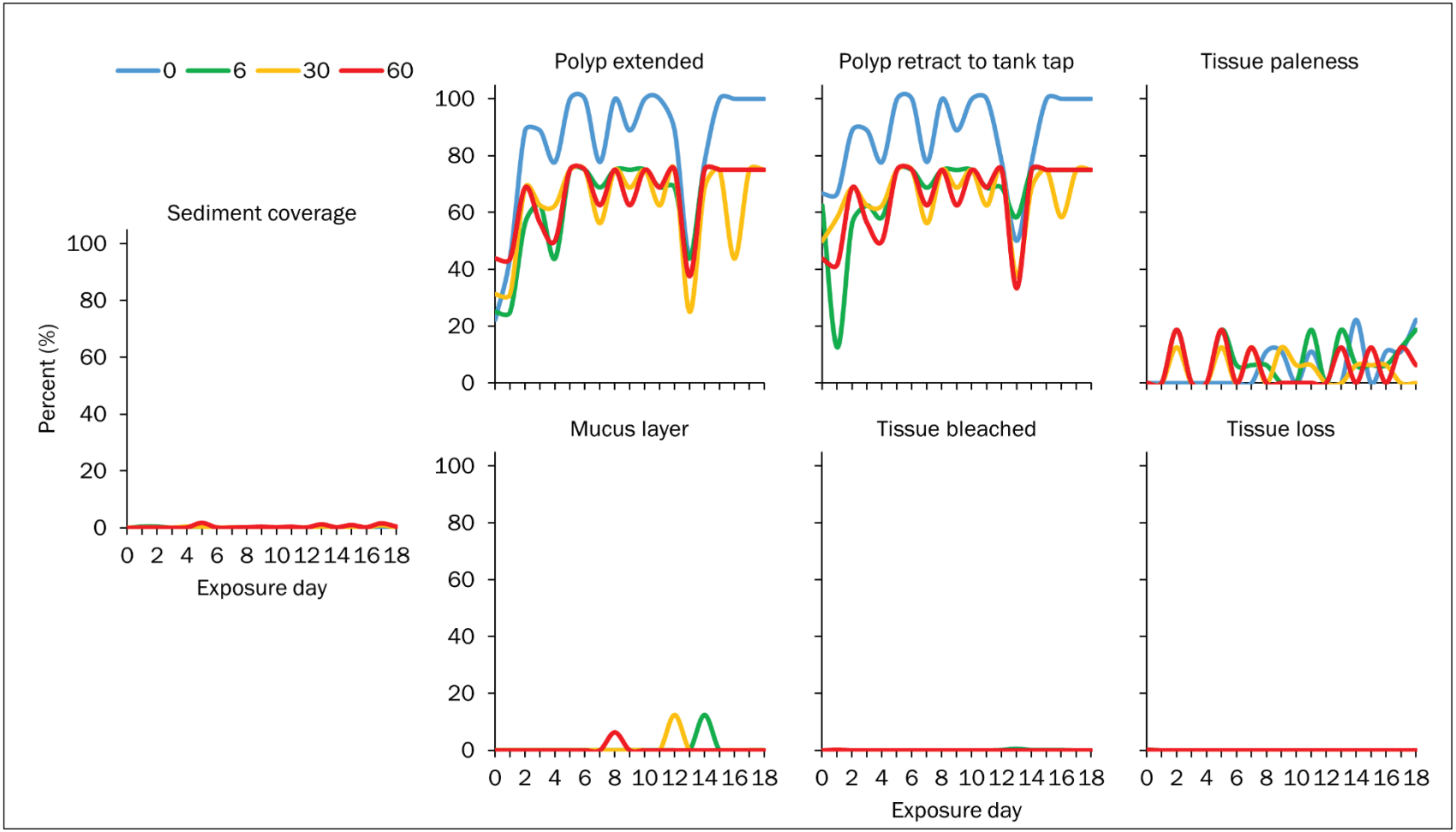
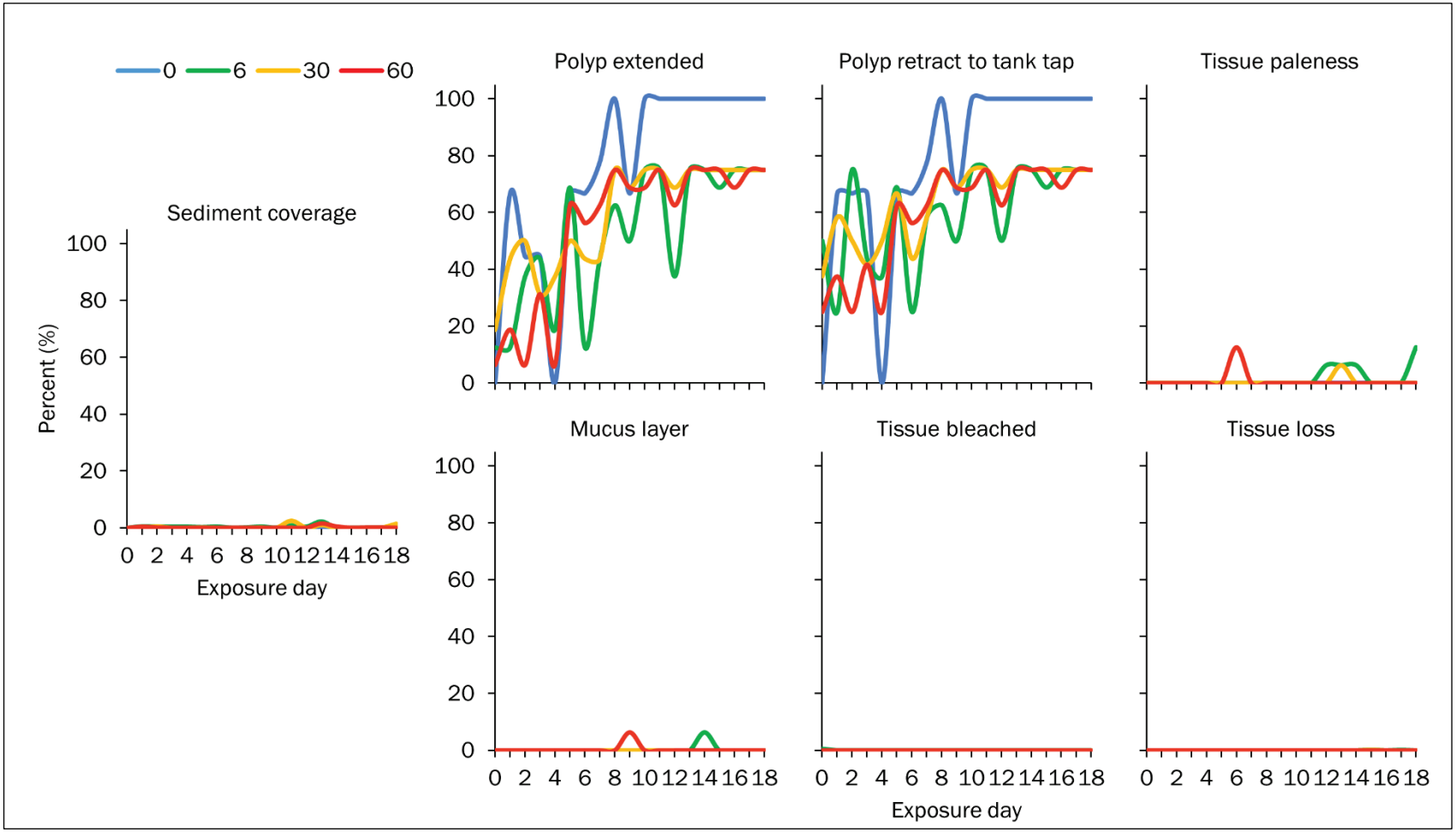


Figure 32. Mean of physiological conditions observed daily for *M. capitata* exposed to sedimentation (0-control to 60 mg cm^{-2}) introduced every 4 days during an 18-day laboratory experiment with coarse grain sediment. Observations were subject to sediment coverage.



3.5 Tissue loss

3.5.1 Tissue loss of corals exposed to fine grain sediment

All 135 corals survived the 18-day exposure period conducted with fine grain sediment (i.e., no complete loss of tissue), but partial tissue loss was observed for 32 of the 135 corals (24%) in an exposure dependent manner (Table 4; Figure 33 and 34). Of those, a single *P. meandrina* coral from a control tank experienced tissue loss of 11%, and a single *P. meandrina* and *P. lobata* coral in the 6 mg cm^{-2} treatment group experienced tissue loss (≤5%). The remaining coral (n =29) impacted by tissue loss were exposed in the 30 and 60 mg cm^{-2} sedimentation treatment groups. A one-way permutation test conducted by coral species compared the effect of treatment group means on tissue loss.

For *P. meandrina*, 8 of the 12 corals experienced tissue loss when exposed in either the 30 mg cm^{-2} (16% ±15% tissue loss) or 60 mg cm^{-2} (15% ±23%) treatment groups. Between these treatment groups, coral surface area impacted by tissue loss for individual corals ranged from 3% to as high as 73%. Due to high variability no statistically significant difference between treatment group means was detected however (F = 2.38, P =0.12). For *P. lobata,* 6 of 12 corals exposed to 30 mg cm^{-2} experienced a mean tissue loss of 3% (±3%) while 7 of 12 corals exposed to 60 mg cm^{-2} experienced a mean tissue loss of 9% (±6%). A statistically significant difference between the treatment group means (F = 4.75, P =0.02) was detected and a post hoc Dunn test showed corals in the 60 mg cm^{-2} treatment group had significantly (P =0.04) more tissues loss as compared to the control group. For *M. capitata* no tissue loss was detected, but there was some tissue paling that occurred near the base of the corals because of sediment accumulation on the tile.

All 90 corals survived the 30-day sediment free observation period, but partial tissue loss was still observed for 14 of the 90 corals (16%) observed. Of these, two *P. meandrina* corals from the control group experienced a 6% and 30% tissue loss while the remainder of corals (n =12) with tissue loss were from the 30 and 60 mg cm^{-2} treatment groups. For the 6 mg cm^{-2} treatment groups it was reported above that a single *P. meandrina* and *P. lobata* coral experienced tissue loss, but these corals were used for day 18 lipid analysis. During the 30-day observation period, no further tissue loss was observed for any coral species exposed in the 6 mg cm^{-2} treatment

group. The mean percent tissue loss continued to increase for *P. meandrina* previously exposed in the 30 and 60 mg cm^{-2} treatment groups where individual coral tissue loss ranged from 1% to as high as 84%. Again, due to high variability, no statistically significant differences between treatment group means (F = 0.91, P =0.47) was detected. For *P. lobata,* tissue loss was no longer detected in 30 mg cm^{-2} treatment group while mean tissue loss decreased from 9% at the end of the 18-day experiment to 2% by the end of the 30-day observation for corals in the 60 mg cm^{-2} treatment group. A statistically significant difference was detected between treatment groups (F = 6.48, P =0.002) in which it was further determined that corals in the 60 mg cm^{-2} treatment group were still significantly different (P =0.03) as compared to the control (Figure 33), albeit only 2% tissue loss. For *M. capitata,* tissue loss was not detected in any treatment group during the 30-day post-exposure period. The tissue paleness near the base of the coral caused by the accumulated sediment on top of the tile during the 18-day exposure had returned to normal color.

Table 4. Mean (standard deviation) and range (minimum-maximum) of percent sediment coverage and tissue loss of corals exposed to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during 18-day experiments performed once with fine grain sediment and again with coarse grain sediment, each followed by a 30-day sediment free observation period. Tissue loss means with an asterisk are significantly different from the control (P < 0.05).

			Sediment coverage (%)		Tissue loss (%)			
			18-day		18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	Mean (SD)	Range (min-max)	Mean (SD)	Range (min-max)	Mean (SD)	range (min-max)
Fine grain	*M. capitata*	0	NA	NA	0	0	0	0
		6	0.2 (0.4)	0-1	0	0	0	0
		30	0.1 (0.3)	0-1	0	0	0	0
		60	0.5 (1)	1-5	0	0	0	0
	P. meandrina	0	NA	NA	1.2 (2.1)	0-3.6	6.0 (7.9)	0-15
		6	0.5 (0.5)	0-1	0.3 (0.6)	0-1.2	0	0
		30	12 (16.8)	0-50	16.5 (14.8)	0.0-31.3	20.1 (23.3)	0-42.6
		60	16 (18.3)	0-50	14.9 (22.6)*	1.6-48.5	17.8 (33.4)*	0-67.9
	P. lobata	0	NA	NA	0	0	0	0
		6	19 (36)	0-95	0.4 (0.8)	0-1.5	0	0
		30	81 (38)	0-100	2.7 (2.8)	0-5.6	0	0
		60	60 (46)	0-100	8.7 (6.2)*	0-14.6	2.4 (2.2)*	0-5.2
Coarse grain	*M. capitata*	0	NA	NA	0	0	0	0
		6	0.1 (0.3)	0-1	0	0	0	0

			Sediment coverage (%)		Tissue loss (%)			
			18-day		18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	Mean (SD)	Range (min-max)	Mean (SD)	Range (min-max)	Mean (SD)	range (min-max)
		30	1 (5)	0-17	0.7 (1.4)	0-2.8	0	0
		60	0.1 (0.3)	0-1	0	0	0	0
	P. meandrina	0	NA	NA	0	0	0	0
		6	0.1 (0.3)	0-1	0	0	0	0
		30	5 (12)	0-40	4.6 (7.5)	0-15.7	13.3 (24.5)	0-50
		60	11 (24.7)	0-80	19.3 (20.7)	1.2-47.6	24.1 (42)	0-87
	P. lobata	0	NA	NA	0	0	0	0
		6	1 (3)	0-10	0	0	0	0
		30	23 (27)	0-80	0.7 (1.1)	0-2.2	0	0
		60	48 (41)	0-100	8.2 (4.7)*	1.9-12	5.2 (4.9)*	0-11.5

NA= Not applicable (i.e., no sediment was introduced).

Figure 33. Mean tissue loss (error bars represent 95% confidence intervals) for three coral species exposed for 18 days to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a fine grain sediment introduced every four days followed by a 30-day sediment free observation period. Means with an asterisk are significantly different from the control (P <0.05).

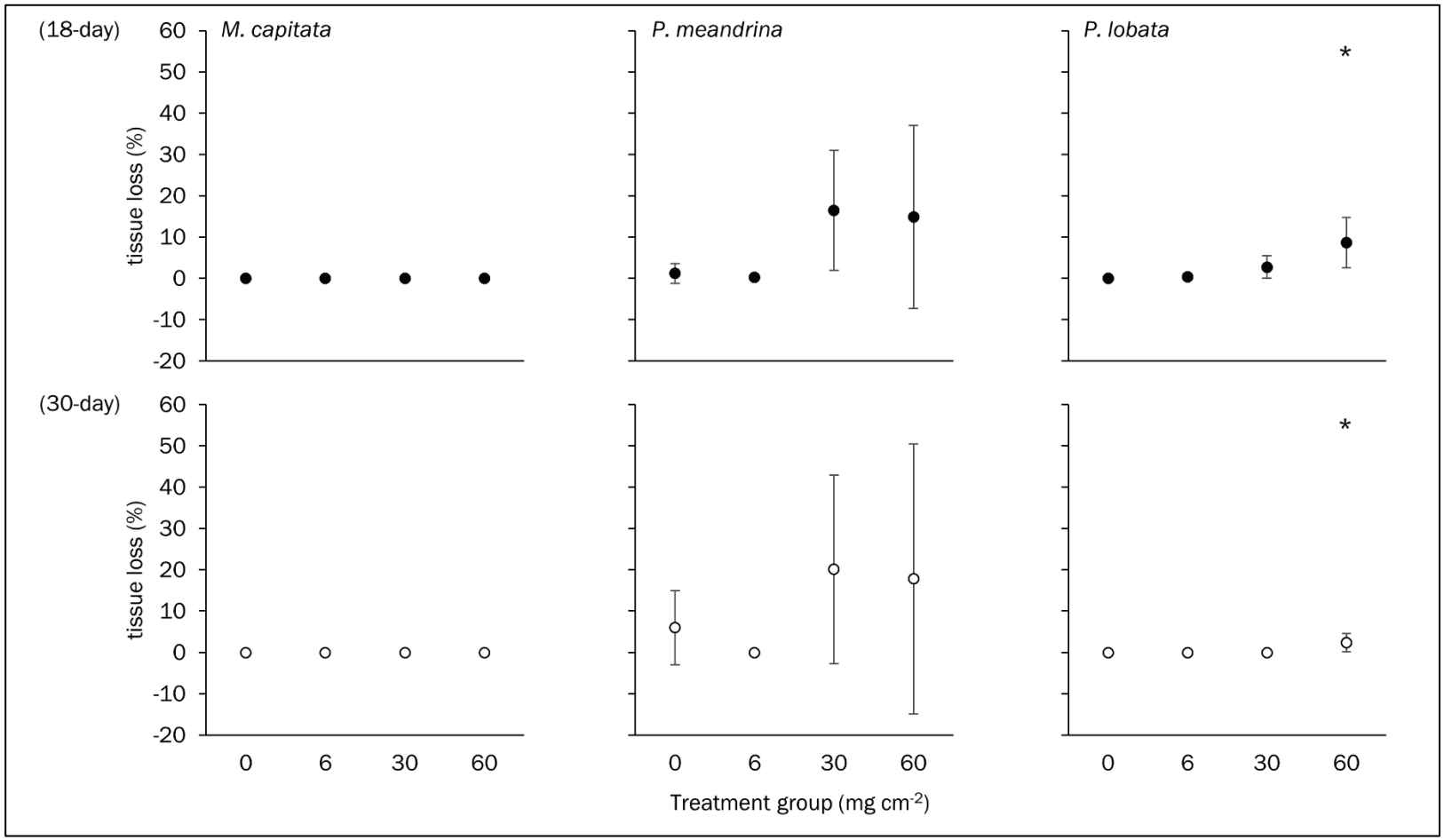
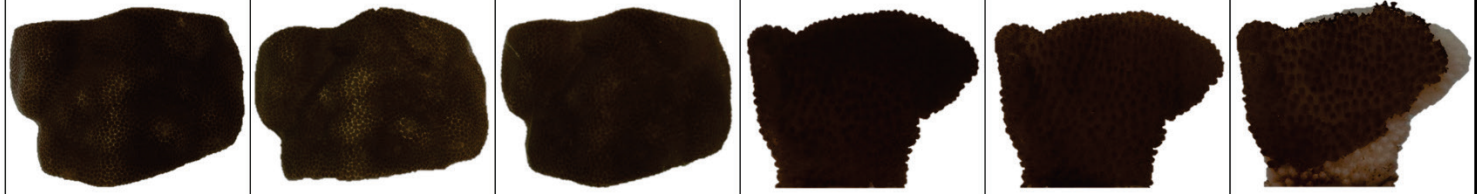
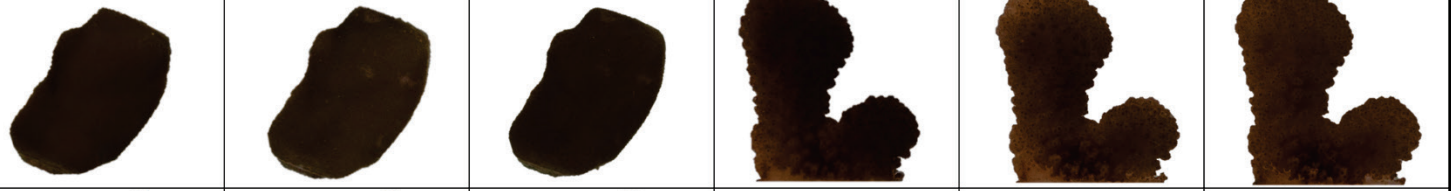
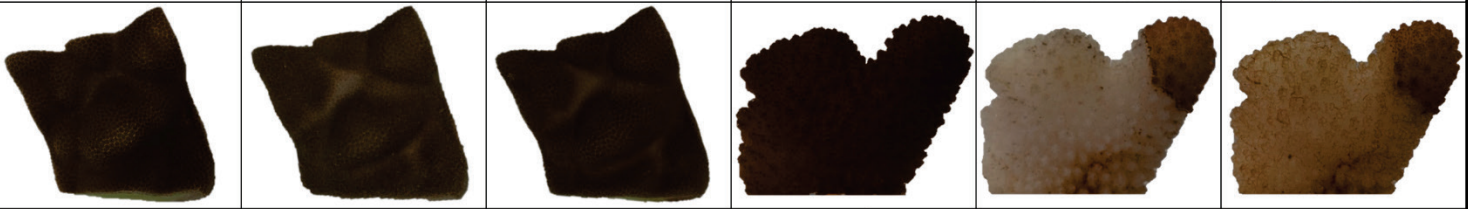
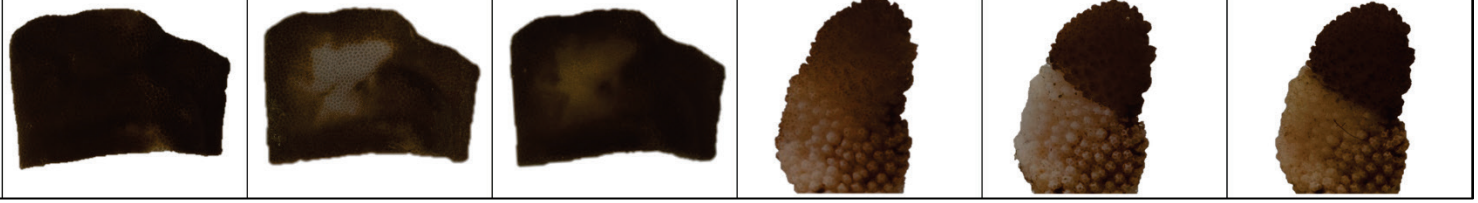


Figure 34. Photos of *P. lobata* and *P. meandrina* tissue loss after 18-day exposure to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a fine grain sediment introduced every four days followed by a 30-day sediment free observation period. No tissue loss was observed for *M. capitata* in any sedimentation treatment (Photos: Justin Wilkens).

	Porites lobata			*Pocillopora meandrina*		
Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
0						
6						
30						
60						

3.5.2 Tissue loss of corals exposed to coarse grain sediment

All 135 corals survived the 18-day exposure period conducted with coarse grain sediment (i.e., no complete loss of tissue), but partial tissue loss was observed for 22 of the 135 corals (16%) in an exposure dependent manner (Table 4; Figure 35 and 36). Of those, no tissue loss was observed for any coral species in the control group, or any coral species exposed in the 6 mg cm^{-2} treatment group. A one-way permutation test conducted by coral species compared the effect of treatment group means on tissue loss.

For *P. meandrina*, two of the 12 corals experienced tissue loss (4.6% ±7.5%) when exposed in the 30 mg cm^{-2} treatment group and eight of the 12 corals experienced tissue loss (19.3% ±20.7%) when exposed in the 60 mg cm^{-2} treatment group. Between these treatment groups, coral surface area impacted by tissue loss ranged from 4% to as high as 81%. A statistically significant difference between treatment groups means (F =4.36, P =0.02) was detected, where *P. meandrina* in the 60 mg cm^{-2} had significantly (P =0.02) more tissue loss as compared to the control group. For *P. lobata,* three of the 12 corals experienced tissue loss (0.7% ±1.1%) when exposed in the 30 mg cm^{-2} treatment group and eight of the 12 corals experienced tissue loss (8.2% ±4.7%) when exposed in the 60 mg cm^{-2} treatment group. A statistically significant difference between the treatment groups means (F =16.45, P =0.005) was detected and a post hoc test showed corals in the 60 mg cm^{-2} had significantly (P =0.01) more tissues loss as compared to the control group. For *M. capitata,* tissue loss (0.7 ±1.4%) was only detected for one of the 12 coral exposed in the 30 mg cm^{-2} treatment group, but no statistically significant difference was detected between treatment group means (F =0.89, P =0.19).

Of the 90 corals observed during the 30-day sediment free observation period, all survived except two *P. meandrina* coral (i.e., complete loss of tissue). Of those two *P. meandrina* corals, one was exposed to 30 mg cm^{-2} and the other to 60 mg cm^{-2}. The mean percent tissue loss continued to increase for *P. meandrina* previously exposed in 30 and 60 mg cm^{-2} treatment groups to as high as 13.3% (±24.5%) and 24.1% (±42.0%), respectively, but the permutation test detected no statistically significant differences between treatment groups (F =1.28, P =0.24) due to high variability. For *P. lobata,* a statistically significant difference between treatment groups was detected (F =6.34, P =0.002; Figure 35). Similar to the result at the end of day 18, corals in the 60 mg cm^{-2} treatment group

had significantly more tissue loss (P =0.03) as compared to the control. However, the area of tissue loss decreased from 8% at the end of the 18-day exposure to 5% after 30 days. Additionally, the area of tissue lost by *P. lobata* exposed in 30 mg cm^{-2} treatment group during the 18-day exposure had completely regrown by the end of the 30-day observation. For *M. capitata*, tissue loss was not detected in any treatment group during the 30-day observation period. The tissue paleness near the base of the coral caused by the accumulated sediment on top of the tile during the 18-day exposure had returned to normal color.

Figure 35. Mean tissue loss (error bars represent 95% confidence interval) for three coral species exposed for 18 days to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a coarse grain sediment introduced every four days followed by a 30-day sediment free observation period. Means with an asterisk are significantly different from the control (P<0.05).

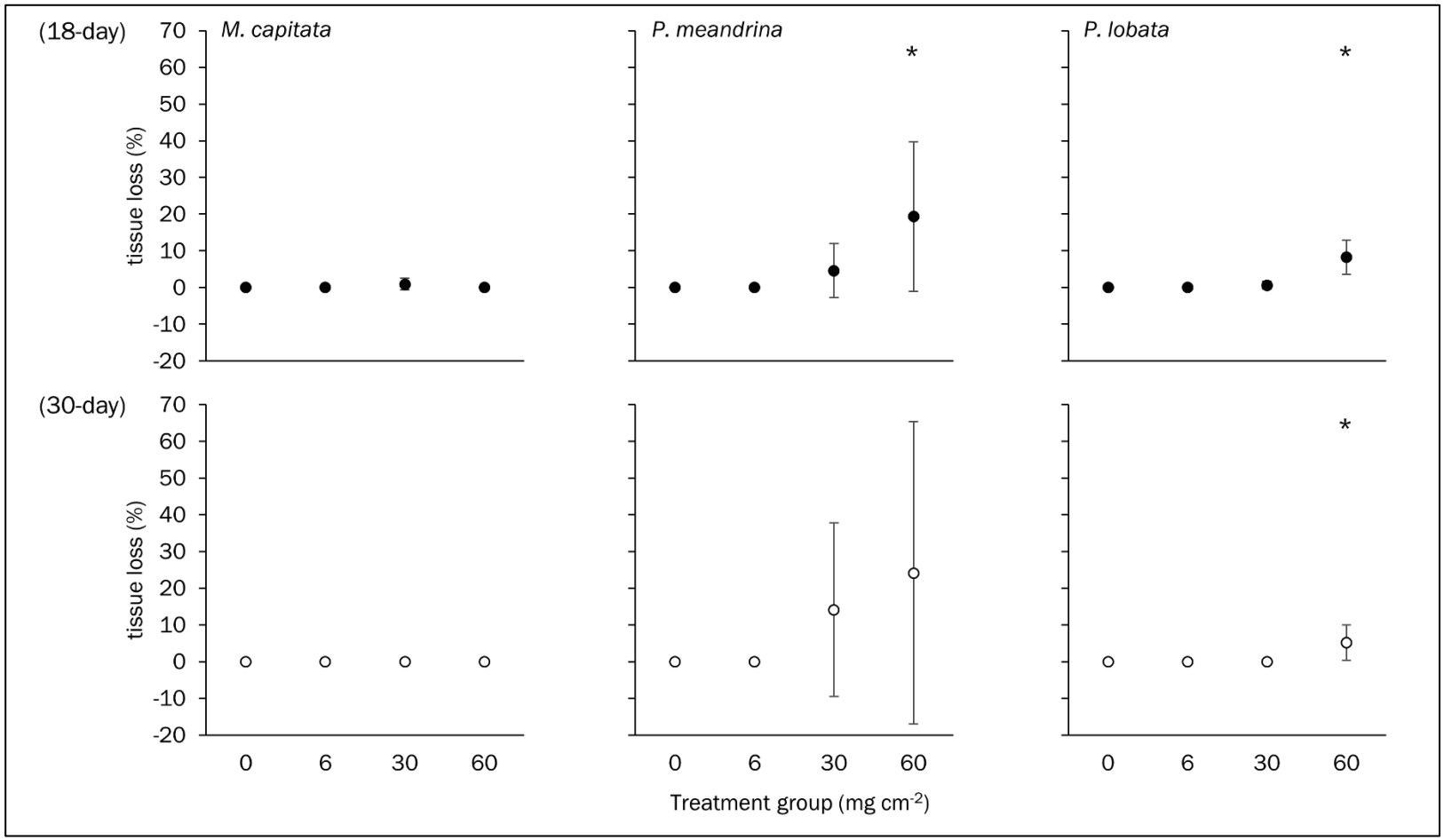
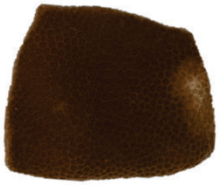
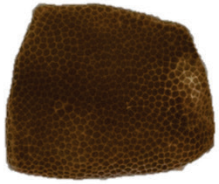
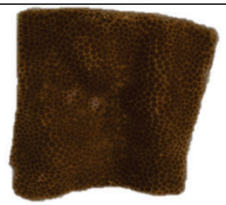
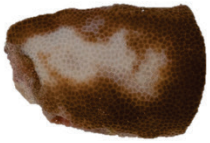


Figure 36. Photos of *P. lobata* and *P. meandrina* tissue loss at the end of an 18-day exposure to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a coarse grain sediment introduced every four days followed by a 30-day sediment free observation period. No tissue loss was observed for *M. capitata* (Photos: Justin Wilkens).

	Porites lobata			*Pocillopora meandrina*		
Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
0						
6						
30						
60						

3.5.3 Summary of tissue loss

Combined, all 270 corals survived (i.e., no complete loss of tissue) the 18-day exposures to sedimentation with fine and coarse grain sediment. Except for two *P. meandrina* corals, all corals survived (178 out of 180) the subsequent 30-day sediment free observation period. Of the two *P. meandrina* corals that died (i.e., complete loss of tissue), one was exposed in the 30 mg cm^{-2} and the other in the 60 mg cm^{-2} sedimentation treatment groups with coarse grain sediment. Although survival was high, partial tissue loss was observed for 32 of 135 corals (24%) exposed to sedimentation with fine grain sediment and 22 of 135 corals (16%) exposed to sedimentation with coarse grain sediment (54 of 270 total). Apart from three corals, the impacted corals were from exposures to 30 or 60 mg cm^{-2} sedimentation treatment groups with fine or coarse grain sediments. The tissues of *P. meandrina* and *P. lobata* corals were primarily impacted, while *M. capitata* experienced virtually no tissue loss. In both experiments, tissue loss varied substantially within species and within treatment groups. The variation in tissue loss and sediment coverage, or lack thereof, is attributed to differences in morphologies between species and morphological nuances within species (Duckworth et al. 2017). The morphological nuances within species should have made it more likely that some proportion of coral would accumulate sediment which was demonstrated for *P. meandrina* and *P. lobata* corals but not for *M. capitata*. In these experiments, the morphology of *M. capitata* coral appears quite resilient when exposed to sedimentation with either fine or coarse grain sediment as shown by virtually no sediment coverage and no tissue loss. Overall, percent sediment coverage and tissue loss were greatest for corals exposed to fine grain sediments. Although the fine grain sediment had a higher propensity to remain on the coral surface as compared to coarse grain sediment, if either fine or coarse grain sediment remained on the coral surface long enough the coral tissue was damaged, especially for *P. meandrina* and *P. lobata*.

In the 30-day sediment free observation period, *P. meandrina* corals previously exposed to 30 and 60 mg cm^{-2} sedimentation treatment groups with either fine or coarse grain sediment continued to lose tissue and there was no indication of tissue regrowth. Whereas *P. lobata* who experienced tissue loss when exposed to 30 and 60 mg cm^{-2} sedimentation treatment groups with either fine or coarse grain sediment resumed growth processes and regrew tissue in most impacted areas. *M. capitata* did not show any observable signs of lingering effects to sedimentation exposure.

3.6 Growth

3.6.1 Growth of corals exposed to fine grain sediment

3.6.1.1 Growth rate expressed as percent of initial buoyant weight

A statistically significant difference in growth rate expressed as a percentage of initial buoyant weight between treatment groups was not detected at the end of the 18-day exposure for *P. meandrina* (F =0.07, P =0.97), *M. capitata* (F =1.89, P =0.18), or *P. lobata* (F =1.79, P =0.21) (Table 5; Figure 37). Overall, the mean growth rate for combined treatment groups by species was greatest for *M. capitata* (1.69 ±0.41%) and *P. lobata* (1.56 ±0.38%), while *P. meandrina* (0.77 ±0.39%) had the slowest growth rate. After the 30-day observation, a statistically significant decline in growth rate between treatment groups was detected for *P. meandrina* (F =6.58, P =0.008). Further analysis showed growth rates for corals exposed in the 30 (0.22 ±0.09%; P =0.03) and 60 mg cm^{-2} (0.19 ±0.12%; P =0.03) treatment groups decreasing slightly, yet significantly, as compared to the control group (0.42 ±0.07%). There were no statistically significant differences in growth rates between treatment groups for *P. lobata* (F =1.38, P =0.29) or *M. capitata* (F =0.399, P =0.76). The mean growth rate for combined treatment groups by species after 30 days was greatest for *P. lobata* (1.08%), followed by *M. capitata* (0.81%) and *P. meandrina* (0.32%).

3.6.1.2 Growth rate expressed as percent of initial 2D surface area

A statistically significant difference in growth rate expressed as percent of initial 2D surface area between treatment groups was not detected for *P. meandrina* (F =0.19, P =0.89), *M. capitata* (F =0.53, P =0.66), or *P. lobata* (F =1.88, P =0.18) after the 18-day exposure to fine grain sediment (Figure 38). The 2D surface area growth rate averaged for combined treatment groups by species was greatest for *P. lobata* (2.44%) followed by *M. capitata* (1.46%) and *P. meandrina* (-0.31%) which followed the same trend as reported in the buoyant weight (section 3.6.1.1). After the 30-day observation, there was a borderline statistically significant difference in growth rate between treatment groups for *P. meandrina* (F =0.05, P =0.98), but post-hoc analysis did not detect the difference. There were also no statistically significant differences in growth rates between treatments for *M. capitata* (F =0.13, P =0.94) or *P. lobata* (F =2.46, P =0.12). The 2D surface area growth rate averaged for combined treatment groups by species after 30 days was still greatest for *P. lobata* (2.79%) followed by *M. capitata* (1.23%) and *P. meandrina* (0.48%).

3.6.1.3 Changes in tissue thickness

Changes in tissue thickness expressed as a percentage of initial tissue thickness varied considerably between treatment groups after the 18-day exposure for *P. lobata* where no statistically significant difference was detected (F =1.43, P =0.29; Table 5). Mean (SD) tissue thickness of corals in the control and 6 mg cm^{-2} treatment group decreased -7.4% (8.5%) and -13.9% (29.3%) respectively, while tissue thickness for corals exposed in 30 and 60 mg cm^{-2} treatment groups increased 16.9% (38.1%) and 27.9% (38.6%) respectively. After the 30-day observation, tissue thickness measurements displayed a more dose dependent response, but remained highly variable. Control corals mean tissue thickness increased 1.2% (25.2%) whereas tissue thickness decreased -23.2% (4.4%), -25.0% (24.4%), and -31.2% (16.7%) in the 6, 30, and 60 mg cm^{-2} treatment groups, respectively. However, there was no statistically significant difference between treatment groups (F =1.83, P =0.19) due in part to large variability within treatments for all species.

Table 5. Growth rate (buoyant weight), two-dimensional surface area (2-D), and tissue thickness expressed as mean percent (standard deviation) of initial measurement on day 0 and day 18 for corals exposed to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} introduced every four days during an 18-day experiment conducted once with a fine grain and again with a coarse grain sediment each followed by a 30-day sediment free observation period. Means with an asterisk are significantly different from the control (P <0.05).

			End of 18-day exposure expressed as % of measurement recorded on Day 0			End of 30-day observation expressed as % of measurement recorded on Day 18		
Sediment	Corals	Treatment (mg cm^{-2})	Buoyant weight	2-D	Tissue thickness	Buoyant weight	2-D	Tissue thickness
Fine grain	*M. capitata*	0	1.77 (0.38)	2.13 (0.97)	NA	0.84 (0.09)	1.46 (2.06)	NA
		6	1.63 (0.56)	1.27 (1.29)	NA	0.92 (0.38)	0.93 (0.84)	NA
		30	1.38 (0.28)	1.24 (0.27)	NA	0.75 (0.28)	1.14 (1.57)	NA
		60	2.00 (0.20)	1.38 (1.26)	NA	0.73 (0.22)	1.44 (0.98)	NA
	P. meandrina	0	0.80 (0.25)	-0.63 (0.58)	NA	0.42 (0.07)	0.48 (1.75)	NA
		6	0.77 (0.41)	0.06 (1.13)	NA	0.42 (0.08)	0.62 (1.12)	NA
		30	0.69 (0.58)	0.08 (3.69)	NA	0.22 (0.09)*	0.46 (0.26)	NA
		60	0.82 (0.40)	-0.81 (0.68)	NA	0.19 (0.12)*	0.33 (0.78)	NA
	P. lobata	0	1.88 (0.38)	2.18 (2.59)	-7.36 (8.48)	1.40 (0.25)	3.78 (2.25)	1.18 (25.18)
		6	1.67 (0.32)	1.56 (0.68)	-13.87 (29.34)	0.85 (0.11)	3.00 (2.22)	-23.17 (4.35)
		30	1.29 (0.37)	2.11 (1.17)	16.92 (38.05)	1.17 (0.49)	3.71 (1.31)	-25.02 (24.41)
		60	1.48 (0.34)	3.85 (1.14)	27.85 (38.57)	0.91 (0.54)	0.90 (0.60)	-31.24 (16.74)

			End of 18-day exposure expressed as % of measurement recorded on Day 0			End of 30-day observation expressed as % of measurement recorded on Day 18		
Sediment	Corals	Treatment (mg cm^{-2})	Buoyant weight	2-D	Tissue thickness	Buoyant weight	2-D	Tissue thickness
Coarse grain	*M. capitata*	0	0.23 (0.47)	0.97 (0.96)	NA	1.27 (0.66)	1.65 (0.97)	NA
		6	0.49 (0.54)	1.14 (1.50)	NA	1.02 (0.98)	2.28 (0.63)	NA
		30	0.38 (0.44)	1.79 (0.61)	NA	0.86 (0.70)	2.45 (0.89)	NA
		60	0.36 (0.29)	0.86 (0.39)	NA	0.86 (0.11)	0.42 (1.93)	NA
	P. meandrina	0	0.01 (0.55)	0.06 (0.32)	NA	0.31 (0.38)	0.24 (0.86)	NA
		6	0.29 (0.35)	0.19 (1.15)	NA	0.06 (0.60)	0.69 (0.53)	NA
		30	1.28 (2.97)	0.41 (0.71)	NA	-1.67 (3.62)	0.09 (1.20)	NA
		60	0.24 (0.31)	1.67 (1.17)	NA	-0.53 (0.38)	0.13 (0.82)	NA
	P. lobata	0	1.24 (0.17)	2.86 (0.65)	7.40 (12.56)	2.53 (0.21)	1.74 (1.33)	-31.58 (11.26)
		6	1.02 (0.35)	2.50 (0.69)	-7.44 (14.22)	3.03 (0.18)	2.30 (1.07)	-16.32 (26.58)
		30	1.05 (0.27)	2.91 (0.86)	8.60 (18.76)	3.12 (0.60)	2.36 (1.55)	-35.63 (4.87)
		60	0.69 (0.32)	1.63 (0.85)	9.41 (5.73)	2.34 (0.47)	1.46 (1.33)	-27.95 (13.13)

Figure 37. Mean growth rate (error bars represent 95% confidence interval) for three coral species exposed for 18 days to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a fine grain sediment introduced every four days followed by a 30-day sediment free observation period. Means with an asterisk are significantly different from the control (P<0.05).

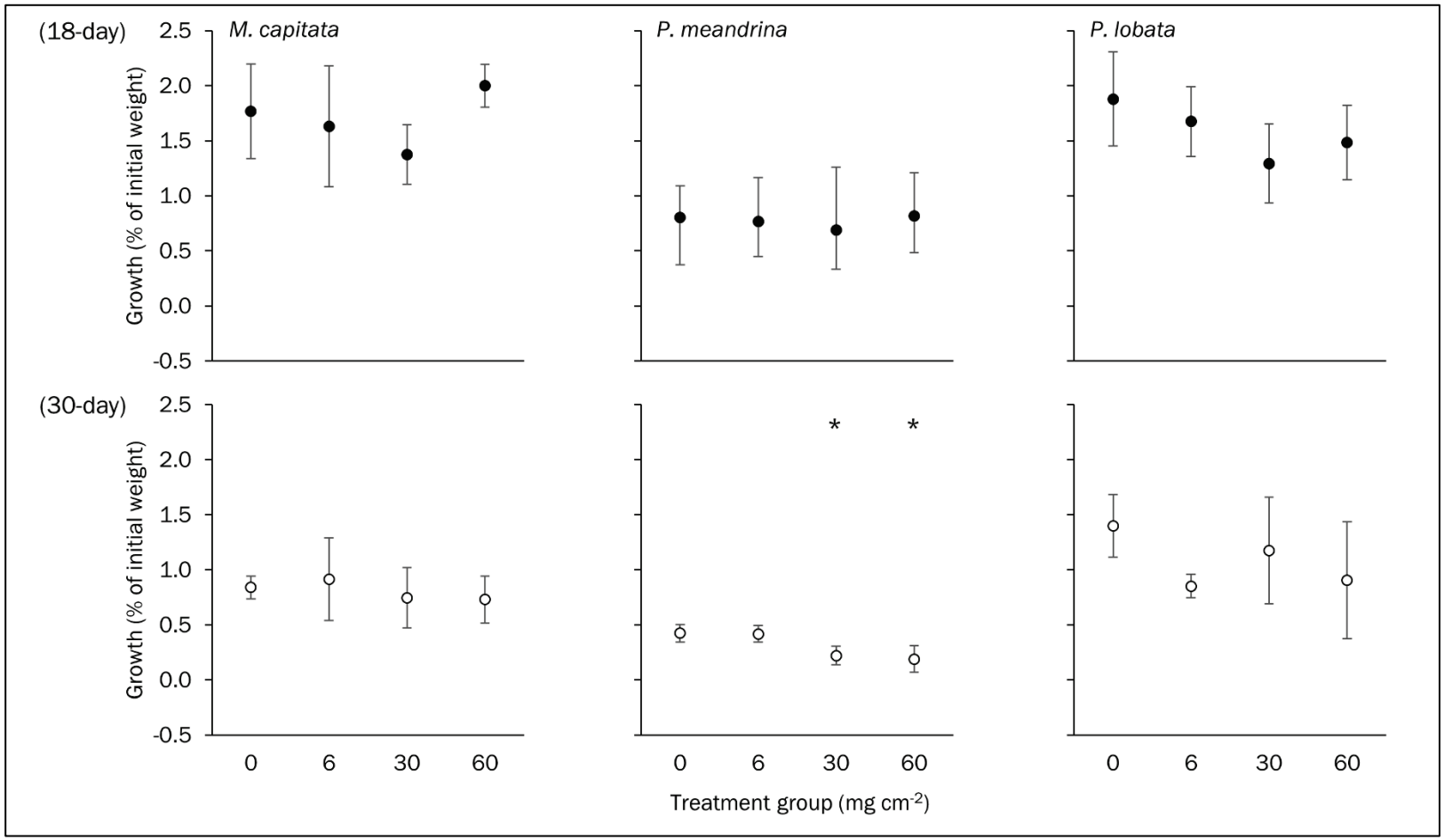
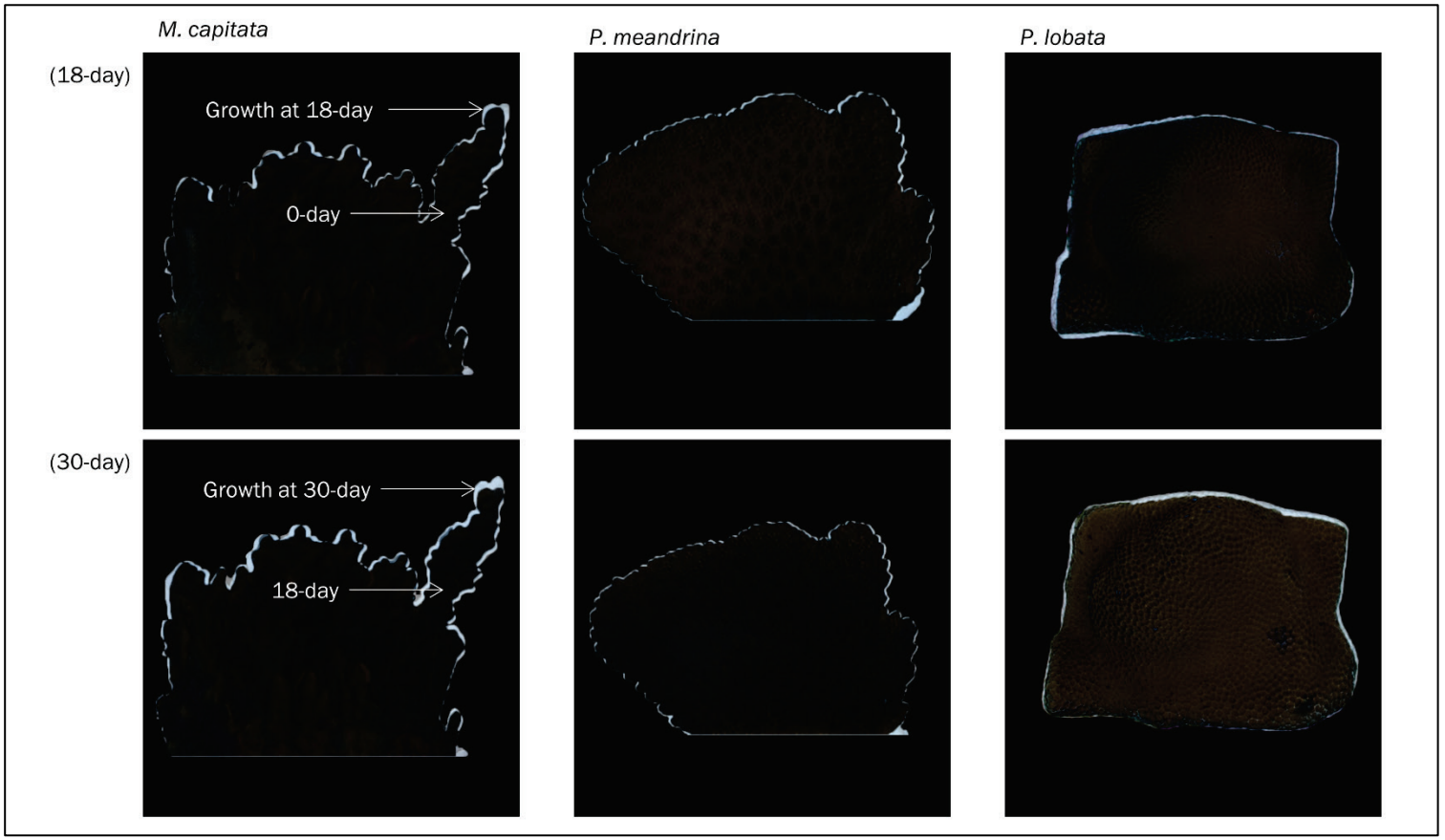


Figure 38. Growth measured as 2D surface area from photos of corals exposed for 18 days to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with fine grain sediment introduced every four days followed by a 30-day sediment free observation period. The difference blend mode in ImageJ analyzed color information in each channel and subtracted the blend color from the base color. The white margins represent where there is no overlap between photos (i.e., growth). If two pixels had the same value, the result was black.



3.6.2 Growth of corals exposed to coarse grain sediment

3.6.2.1 Growth rate expressed as percent of initial buoyant weight

At the end of the 18-day exposure there was minimal change in growth rate between treatment groups for all corals exposed to coarse grain sediment (Table 5; Figure 39). A permutation test did not detect a statistically significant difference in growth rates between treatment groups for *P. meandrina* (F =0.47, P =0.94), *M. capitata* (F =0.20, P =0.89), or *P. lobata* (F =2.14, P =0.16). Overall, the mean growth rate for combined treatment groups by species was greatest for *P. lobata* (0.98 ±0.33%), followed by *P. meandrina* (0.49 ±1.50%), and *M. capitata* (0.37 ±0.40%). After the 30-day observation, no statistically significant difference in growth rate between treatment groups was detected for *P. meandrina* (F =0.77, P =0.68) or *M. capitata* (F =0.26, P =0.86). A borderline statistically significant increase in growth rate between treatment groups was detected for *P. lobata* (F =3.20, P =0.05). The post hoc test did not detect a significant difference when treatment groups were compared to the control, but growth rates for corals exposed in the 6 (3.03%, P =0.066) and 30 mg cm^{-2} (3.11%; P =0.066) treatment groups increased as compared to the control group (2.52%). The mean growth rate for combined treatment groups by species after 30 days was greatest for *P. lobata* (2.77 ±0.51%), followed by *M. capitata* (0.99 ±0.63%), and *P. meandrina* (-0.51 ±1.89%).

3.6.2.2 Growth rate expressed as percent of initial 2D surface area

A statistically significant difference in growth rate expressed as a percentage of initial 2D surface area between treatment groups was not detected for *P. meandrina* (F =2.34, P =0.13), *M. capitata* (F =0.73, P =0.55), or *P. lobata* (F =2.23, P =0.14) after the 18-day exposure (Table 5). The 2D surface area growth rate averaged for combined treatments by species was greatest for *P. lobata* (2.45%) and *M. capitata* (1.21%), while *P. meandrina* (0.62%) had the slowest growth rate. After the 30-day observation, there were no statistically significant differences in growth rate between treatment groups for *P. meandrina* (F =0.39, P =0.79), *M. capitata* (F =2.25, P =0.10), or *P. lobata* (F =0.42, P =0.73). The 2D surface area growth rate averaged for combined treatments by species after 30 days was still greatest for *P. lobata* (1.97%) and *M. capitata* (1.70%), while *P. meandrina* (0.28%) had the slowest growth rate.

3.6.2.3 Changes in tissue thickness

Changes in tissue thickness, expressed as a percentage of initial tissue thickness, varied between treatments with generally no clear trend (Table 5). A one-way permutation test conducted for *P. lobata* tissue thickness data did not detect a statistically significant difference in thickness of live tissue between treatment groups (F =1.33, P =0.31). Mean tissue thickness of corals in the control, 30, and 60 mg cm^{-2} treatment groups increased 7.41%, 8.60%, and 9.41% respectively, while corals in the 6 mg cm^{-2} treatment group decreased by -7.44%. After the 30-day observation, tissue thickness for all treatment groups decreased slightly but not significantly (F =1.00, P =0.42). Mean tissue thickness for corals in the control, 6, 30, and 60 mg cm^{-2} treatment groups was -31.60%, -16.32%, -35.63% and -27.95% respectively.

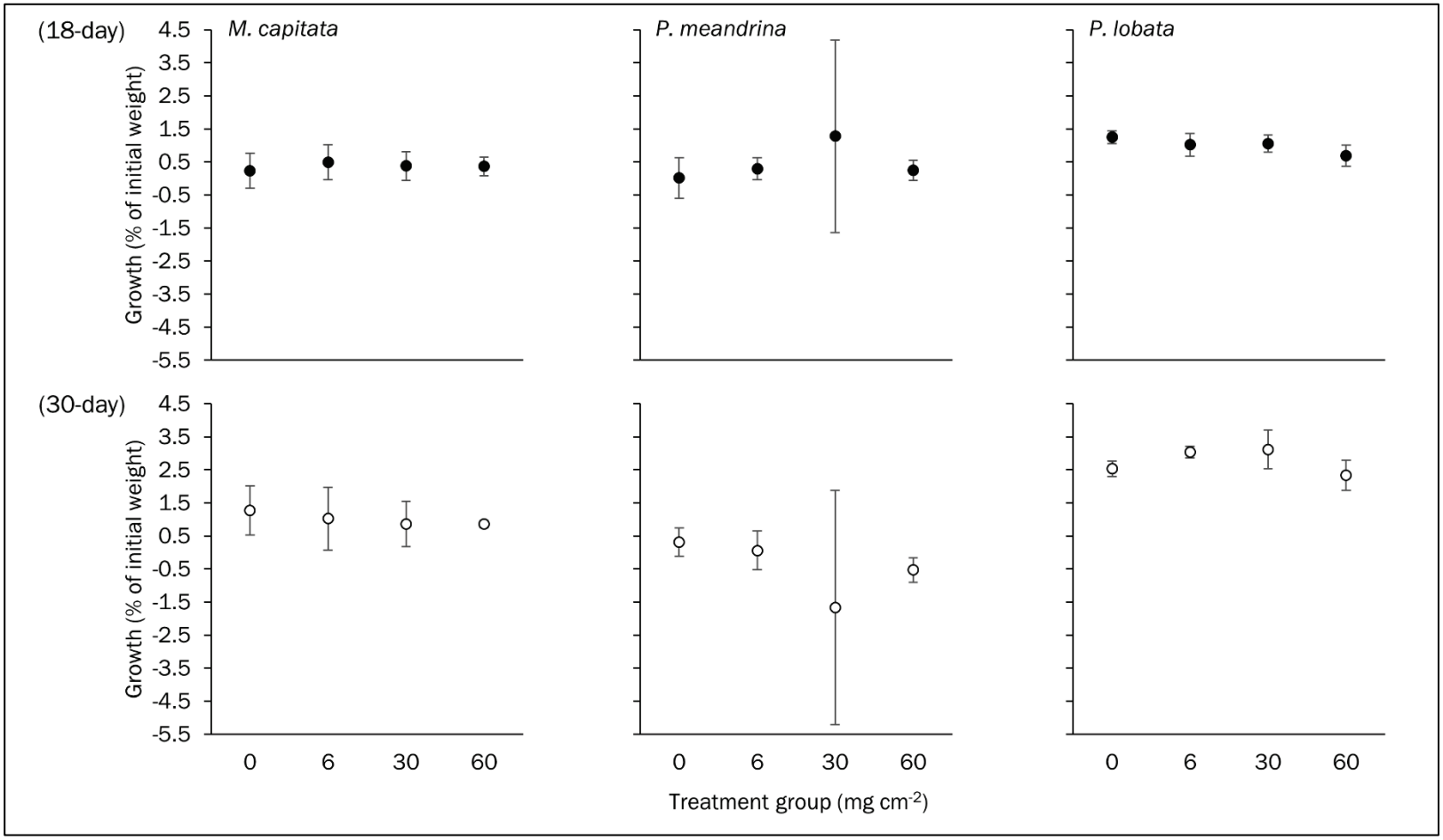
3.6.3 Summary of coral growth

Except for *P. meandrina* exposed in the 30 and 60 mg cm^{-2} sedimentation treatment groups with coarse grain sediment, all corals maintained an overall positive, albeit quite variable, growth rate over each 18-day experiment and each 30-day observation period. The 2D surface area measurements obtained from photo-documentation pre- and post-exposure provided further evidence of this growth. *P. lobata* exhibited the fastest growth rate followed by *M. capitata* and *P. meandrina*. During the 30-day grow out, growth of *P. meandrina* previously exposed in the 30 and 60 mg cm^{-2} sedimentation treatment groups with fine grain sediment, decreased slightly, yet significantly, as compared to the control group. There was also a decreasing trend in growth for *P. meandrina* exposed in the same sedimentation treatment groups with coarse grain sediment. *P. meandrina* in both experiments also continued to lose tissue during the 30-day observation period. These data show the sensitivity of *P. meandrina* to sedimentation and provide further evidence that sedimentation of fine grain sediment appears to be more impactful as compared to sedimentation of coarse grain sediment.

Tissue thickness, the depth of skeleton occupied by tissue, was another growth characteristic or indicator of stress that could potentially respond relatively rapidly to environmental conditions such as sedimentation (Barnes and Lough 1992, 1999). When measured for *P. lobata,* the results were variable and there were no pronounced changes or trends between treatment groups at the end of each 18-day experiment with fine or coarse

grain sediment. Control corals tissue decreased in one experiment and increased in the other, while corals exposed to the 30 and 60 mg cm^{-2} both experienced increased tissue thickness in either experiment. During the 30-day observation, all *P. lobata* experienced a decrease in tissue thickness except control corals in the fine grain experiment. It is not clear why this occurred, but it could possibly be related to changes in light intensity between the experiment (DLI =12.8 mol m^{-2} d^{-1}) and outdoor holding tanks (DLI =4.5 mol m^{-2} d^{-1}) which could have influenced photo-acclimation responses including changes in tissue thickness. *P. lobata* color also darkened during the 30-day observation period as reported in section 3.7. Together, these data suggest that corals were acclimating to produce more favorable conditions for symbionts in their tissues once back in the outdoor tanks exposed to lower light intensities (Kaniewska et al. 2011).

Figure 39. Mean growth rate (error bars represent 95% confidence interval) for three coral species exposed for 18 days to sedimentation concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} made with a coarse grain sediment introduced every 4 days followed by a 30-day sediment free observation period. No significant difference (P<0.05) was detected for a treatment group as compared to the control group.



3.7 Color

Grayscale values from photos acquired of corals one day prior to the start of each experiment, at the end of the 18-day exposure, and again after the 30-day observation period were compared for each species to detect differences in color between treatment groups (Table 6 and Figures 40–43).

3.7.1 Color of coral tissue exposed to fine grain sediment

A one-way permutation test was used to compare the effect of treatment group on mean grayscale color changes. This test indicated there were no statistically significant differences in mean grayscale values between treatment groups for any coral species at the end of either the 18-day exposure or 30-day observation period (Table 6). All coral species within each treatment group did, however, generally appear darker at the beginning of the experiment, then lightened slightly during exposure, and then darkened again during the 30-day sediment free observation period.

3.7.2 Color of coral tissue exposed to coarse grain sediment

A one-way permutation test was used to compare the effect of treatment group on mean grayscale color changes; the results of this test detected no statistically significant differences in mean grayscale values between treatment groups at the end of either the 18-day exposure or 30-day observation period for *M. capitata* (18-d: F =0.36, P =0.78; 30-d: F =0.29, P =0.82) or *P. lobata* (18-d: F =2.51, P =0.12; 30-d: F =0.54, P =0.67; Table 6). For *P. meandrina*, a statistically significant change in color between treatment groups was detected at the end of the 18-day exposure (F =4.16, P =0.04). Further statistical testing indicated that color for corals exposed in the 30 (33.0 ±6.3 grayscale; P =0.008) and 60 mg cm^{-2} (31.4 ±4.7 grayscale; P =0.008) treatment groups darkened as compared to the control group corals whose color lightened (40.9 ±0.5 grayscale). A statistically significant change in color between treatment groups was also detected at the end of the 30-day observation (F =3.81, P =0.02) for *P. meandrina*, but the post hoc test did not detect a significant difference when treatment groups were compared to the control. Color for corals previously exposed in the 30 (31.1 ±1.5 grayscale; P =0.07) and 60 mg cm^{-2} (29.4 ±3.7 grayscale; P =0.07) treatment groups remained slightly darker than the control group (33.9 ±2.2 grayscale) at the end of 30 days. Similar to the color results observed during the fine grain experiment, all coral species within each treatment group generally appeared darker at the beginning of the

experiment, then lightened slightly during exposure, and then darkened again during the 30-day sediment free observation period. The change in color was not as noticeable as compared to the fine grain experiment.

3.7.3 Summary coral tissue color

There were no pronounced color changes between sedimentation treatment groups for any coral species in either experiment with fine or coarse grain sediment. The photos corroborate the daily visual assessment that corals experienced slightly lightened tissue colors over each 18-day experiment and then appeared to darken over the 30-day grow out period. An explanation for the differences in tissue color between the experiment and outdoor tanks is likely due to the differences in DLI which was 12.8 mol m^{-2} d^{-1} when corals were exposed in 18-day experiments and 4.5 mol m^{-2} d^{-1} while corals were held in outdoor tanks. Photo-acclimation responses described in other studies indicate the explanation for darker tissue color in outdoor tanks could be attributed to a response by the corals to increase light absorptivity under lower light intensities by increasing pigment concentration per algal cell or higher symbiont density (Anthony and Hoegh-Guldberg 2003; Falkowski and Dubinsky 1981; Jones et al. 2020).

Table 6. Mean (standard deviation) grayscale and RGB visualization of corals tissue color measured in photos acquired on day 0 and after day 18 exposure to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during the 18-day experiments performed once with fine grain sediment and again with coarse grain sediment, each followed by a 30-day sediment free observation period. Means accompanied by an asterisk are significantly different (P <0.05) as compared to the control for each time period.

		Montipora capitata						*Pocillopora meandrina*						*Porites lobata*					
		Grayscale			RGB color			Grayscale			RGB color			Grayscale			RGB color		
Sediment	Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
Fine grain	0	33.7 (1.0)	35.9 (1.1)	32.9 (3.8)				34.4 (4.9)	40.9 (4.0)	38.1 (3.2)				35.8 (3.5)	43.3 (2.4)	35.0 (2.0)			
	6	35.5 (2.6)	35.2 (3.3)	30.3 (3.9)				32.3 (3.0)	39.7 (7.8)	36.2 (7.8)				34.4 (2.6)	43.7 (4.7)	34.4 (3.5)			
	30	33.4 (3.0)	34.7 (1.5)	30.8 (2.5)				33.9 (5.4)	40.0 (4.2)	36.6 (2.8)				38.0 (2.8)	45.0 (5.7)	35.4 (2.1)			
	60	35.7 (3.1)	35.1 (2.0)	30.4 (2.0)				37.4 (6.4)	39.3 (4.8)	33.6 (4.7)				36.4 (2.9)	43.9 (3.1)	32.7 (0.9)			
Coarse grain	0	37.2 (4.3)	36.6 (4.7)	33.0 (3.4)				31.7 (3.0)	40.9 (0.5)	33.9 (2.2)				50.6 (1.9)	55.5 (2.1)	37.1 (2.3)			
	6	39.4 (6.1)	36.3 (4.3)	31.5 (4.5)				34.1 (1.7)	38.7 (1.7)	35.4 (3.1)				49.9 (4.4)	56.6 (2.3)	35.6 (2.5)			
	30	37.3 (5.5)	36.1 (6.4)	32.4 (3.6)				33.1 (2.9)	33.0 (6.3)*	31.1 (1.5)				54.0 (3.3)	53.1 (1.7)	35.1 (2.1)			
	60	35.5 (4.8)	33.2 (4.8)	30.5 (3.6)				34.5 (1.5)	31.4 (4.7)*	29.4 (3.7)				53.4 (0.6)	54.8 (1.4)	35.8 (1.4)			

Figure 40. Mean grayscale (error bars represent standard error) of coral tissue color photo-documented on day 0 and after day 18 exposure to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during the 18-day experiments performed once with fine grain sediment and again with coarse grain sediment, each followed by a 30-day sediment free observation period. Means with an asterisk above the bar are significantly different (P <0.05) as compared to the control within each timeline category.

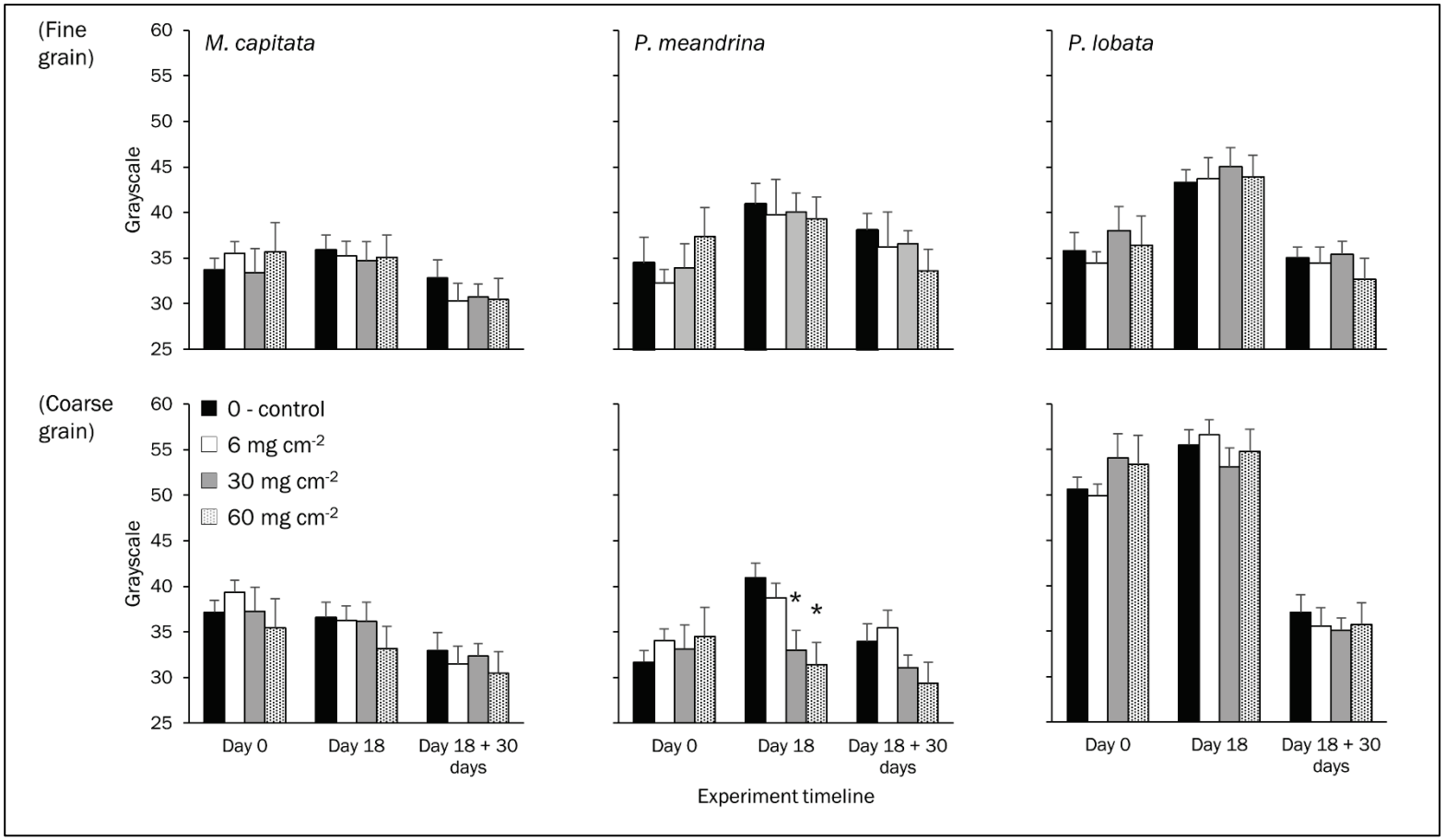


Figure 41. Photos of *M. capitata* prior to exposure, at the end of the 18-day exposure to sediment concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} created with a fine or coarse grain sediment dosed every 4 days and after a 30-day sediment free observation period (Photos: Justin Wilkens).

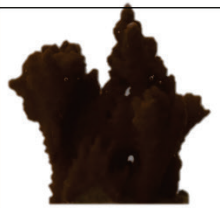
	Exposure to fine grain sediment			Exposure to coarse grain sediment		
Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
0						
6						
30						
60						

Figure 42. Photos of *P. meandrina* prior to exposure, at the end of the 18-day exposure to sediment concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} created with a fine or coarse grain sediment dosed every 4 days and after a 30-day sediment free observation period (Photos: Justin Wilkens).

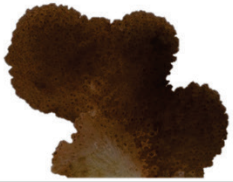
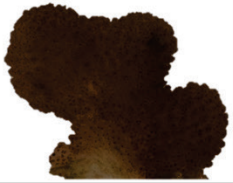
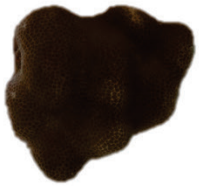
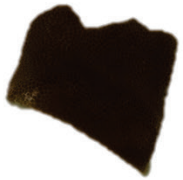
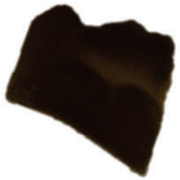
	Exposure to fine grain sediment			Exposure to coarse grain sediment		
Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
0						
6						
30						
60						

Figure 43. Photos of *P. lobata* prior to exposure, at the end of the 18-day exposure to sediment concentrations of 0 (control), 6, 30, and 60 mg cm^{-2} created with a fine or coarse grain sediment dosed every 4 days and after a 30-day sediment free observation period (Photos: Justin Wilkens).

	Exposure to fine grain sediment			Exposure to coarse grain sediment		
Treatment (mg cm^{-2})	Day 0	Day 18	Day 30	Day 0	Day 18	Day 30
0						
6						
30						
60						

3.8 Photosynthetic efficiency

Dark adapted quantum yield (*Fv/Fm*) and maximum electron transport rate (*ETRm*) were measured at day 0 and at the end of 18-day experiment and expressed as a percentage change of initial measurement on day 0. The permutation test was subject to outliers; thus, the data were transformed to stabilize variance. Because some of the values were negative, a constant value was added to the data prior to a log transform (Log10[Y + 1−−min(Y)]).

3.8.1 Photosynthetic efficiency of corals exposed to fine grain sediment

A statistically significant difference in *Fv/Fm* between treatment groups was not detected at the end of the 18-day exposure for *M. capitata* (F = 0.17, P =0.91), *P. meandrina* (F =1.13, P =0.38), or *P. lobata* (F =2.41, P = 0.11; Figure 44). A statistically significant decrease in *ETRm* was detected for *M. capitata* (F =3.67, P =0.04) and *P. lobata* (F =5.00, P =0.02) between treatment groups (Figure 45). Post hoc tests showed *ETRm* decreased for *M. capitata* exposed in the 60 mg cm^{-2} treatment group (P = 0.02) while for *P. lobata* a decrease occurred in both the 30 mg cm^{-2} (P = 0.05) and 60 mg cm^{-2} (P =0.03) treatment groups as compared to the control group. No statistically significant differences in *ETRm* were detected between treatment groups for *P. meandrina* (F =0.079, P =0.97).

3.8.2 Photosynthetic efficiency of corals exposed to coarse grain sediment

A statistically significant difference in *Fv/Fm* or *ETRm* between treatment groups was not detected at the end of the 18-day exposure to coarse grain sediment for *M. capitata* (*Fv/Fm* F =0.48, P =0.73, *ETRm:* F =0.21, P =0.88), *P. meandrina* (*Fv/Fm* F =3.32, P =0.07, *ETRm* F =0.24, P =0.86), or *P. lobata* (*Fv/Fm* F =1.22, P =0.35, *ETRm* F =1.88, P =0.19).

3.8.3 Summary of photosynthetic efficiency

Changes in quantum yields (*Fv/Fm*) between sedimentation treatment groups was not detected for any coral species at the end of the 18-day exposure to either fine or coarse grain sediment, but changes in *ETRm* were detected. *P. lobata* experienced some of the highest sediment coverage of tissue as well as tissue loss in both experiments, but *ETRm* was most impacted by fine grain sediment for corals exposed in the 30 and

60 mg cm^{-2} sedimentation treatment groups. Interestingly, *M. capitata* which was the most resilient coral species tested in terms of lack of sediment coverage and relatively no tissue loss, experienced a decrease in *ETRm* for corals exposed in the 60 mg cm^{-2} sedimentation treatment group with fine grain sediment. This observation highlights the importance and sensitivity of sublethal measurements such as photosynthetic yield especially for corals who by visual observations appear to be relatively unaffected. Also notable, the changes in *ETRm* were only observed for corals exposed to fine grain sediment.

Figure 44. Mean of dark-adapted quantum yield (*Fv/Fm;* error bars represent 95% confidence intervals) for corals exposed for 18 days to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during 18-day experiments performed once with fine grain sediment and again with coarse grain sediment. *Fv/Fm* was measured after each 18-day experiment and expressed as percent change of initial measurement (0-day). No statistically significant difference (P <0.05) as compared to the control (0 mg cm^{-2}) was detected.

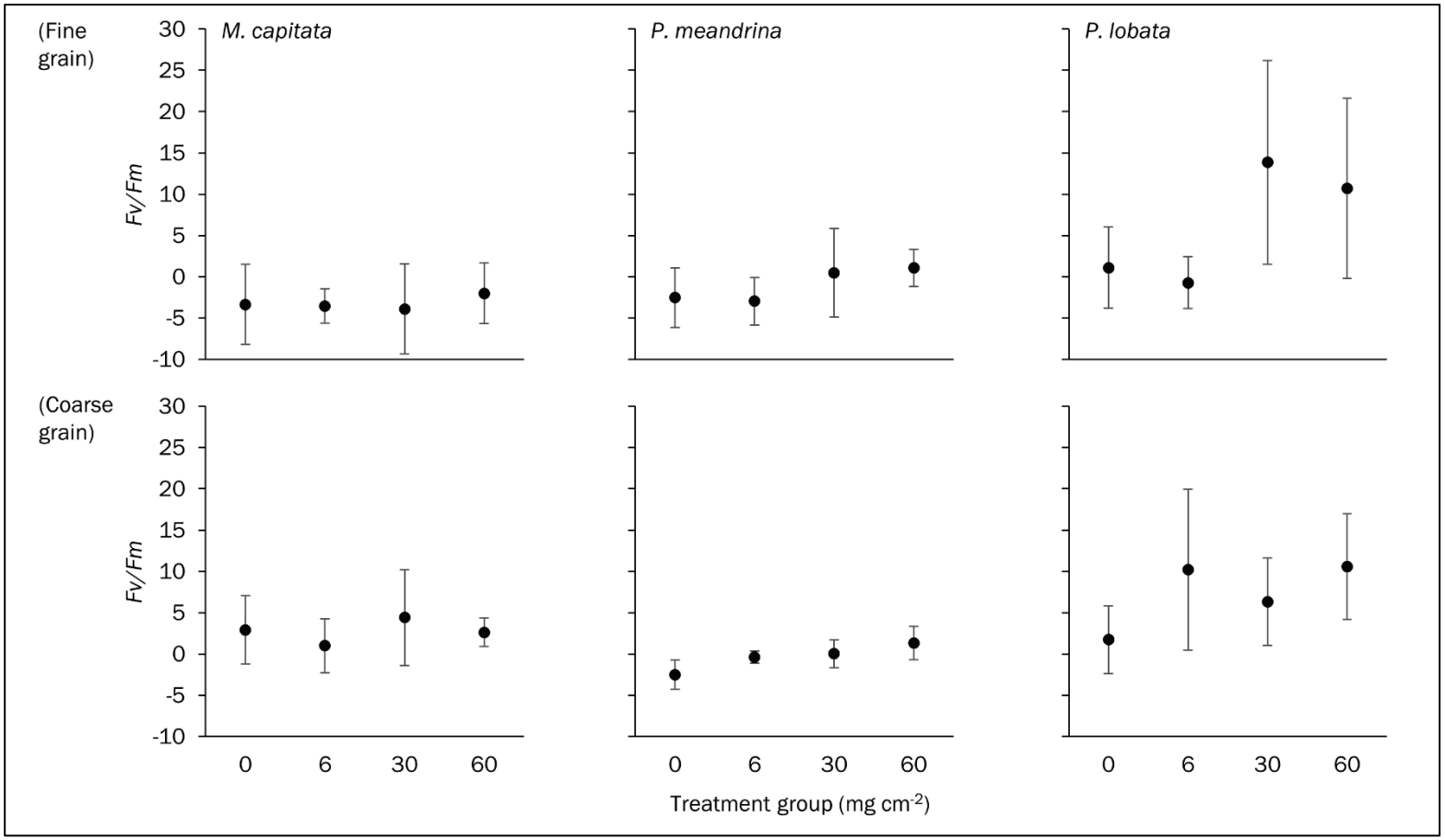
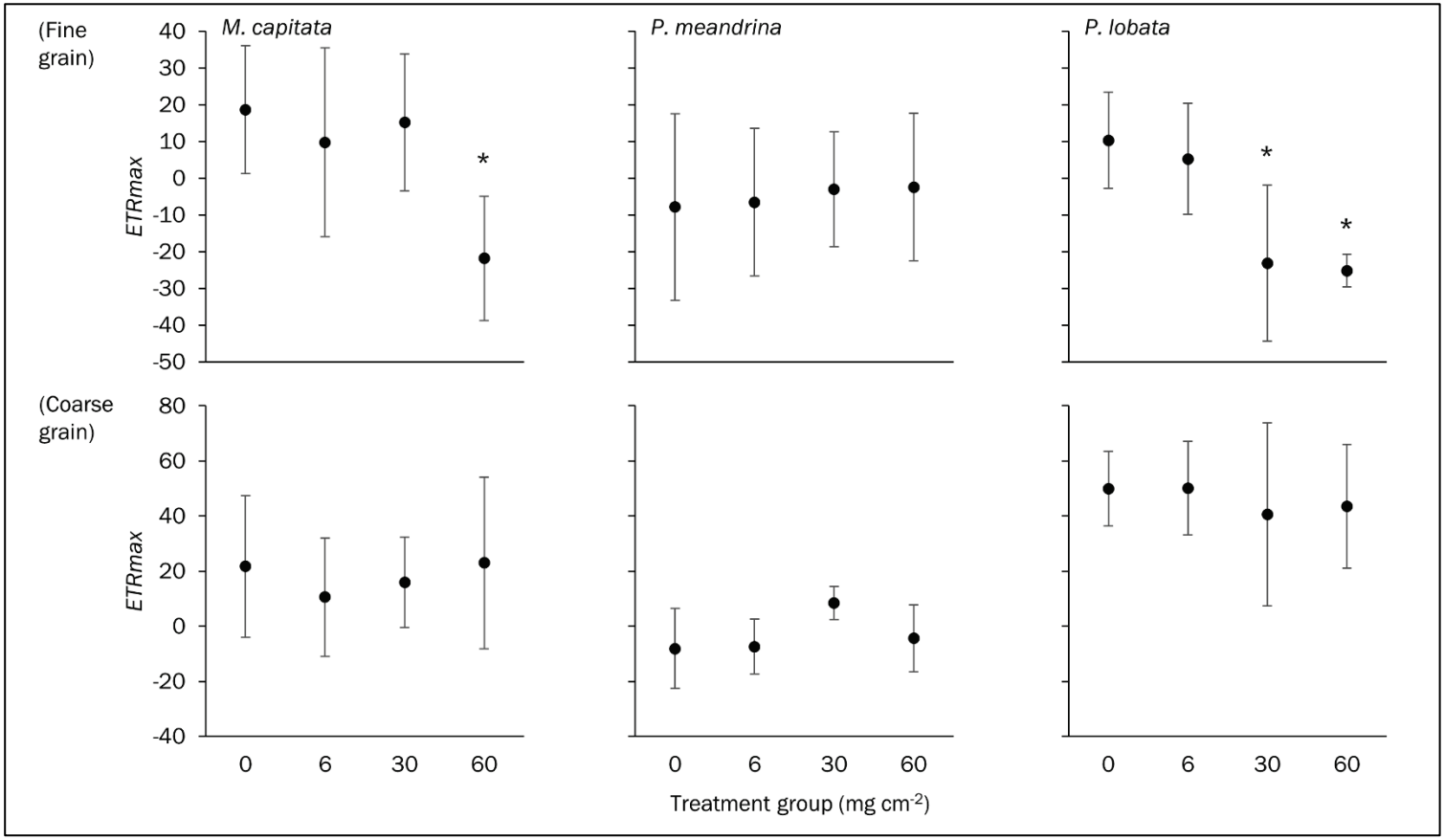


Figure 45. Mean of dark-adapted maximum electron transport rate (*ETRm;* error bars represent 95% confidence intervals) for corals exposed for 18 days to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during 18-day experiments performed once with fine grain sediment and again with coarse grain sediment. *ETRm* was measured at the end of each 18-day experiment and expressed as percent change of initial measurement (0-day). Means with an asterisk are significantly different (P <0.05) as compared to the control.



3.9 Lipid to protein ratio

Coral lipids and proteins were measured in three groups of corals. For unexposed corals, before each experiment extra corals of each species not used in the experiments were sacrificed to determine lipid to protein ratios. For exposed corals, at the end of each 18-day experiment the ratio was determined and expressed as a percentage change of the initial measurement from day 0. A third group of corals was examined after the 30-day post exposure sediment free observation period, where the lipid measurement was expressed as percent change of the lipid measurement from day 18.

3.9.1 Lipid to protein ratio for corals exposed to fine grain sediment

The lipid to protein ratio results were highly variable for corals exposed to fine grain sediments (Tables 7 and 8). No statistically significant difference in the percentage change of the lipid to protein ratio at the end of the 18-day experiment and after the 30-day sediment free observation period was detected between treatment groups for *M. capitata* (18-d: F =0.62, P =0.60; 30-d: F =1.07, P =0.40), *P. meandrina* (18-d: F =0.39, P =0.76; 30-d: F =0.26, P =0.88), or *P. lobata* (18-d: F =0.70, P =0.69; 30-d: F =0.96, P =0.43) (Tables 7 and 8). Although there was no statistically significant difference between treatment groups, the overall mean lipid to protein ratio decreased from 9.95 on day 0 for *M. capitata* corals to 5.89 by day 18 and then 4.67 by day 30 which reflects a decrease in lipid content and concomitant increase in protein (Table 8). A similar trend appeared for *P. lobata* and P. meandrina whose day 0 lipid to protein ratios declined slightly from 5.12 and 4.12 to 3.97 and 3.54 respectively by the end of the 30-day observation.

3.9.2 Lipid to protein ratio for corals exposed to coarse grain sediment

Lipid to protein ratio results were also highly variable for corals exposed to coarse grain sediment (Tables 7 and 8). No statistically significant difference in the percentage change of the lipid to protein ratio at the end of the 18-day experiment and after the 30-day sediment free observation period was detected between treatment groups for *M. capitata* (18-d: F =1.23, P =0.31; 30-d: F =1.03, P =0.40), *P. meandrina* (18-d: F =2.05, P =0.14; 30-d: F =1.22, P =0.34), or *P. lobata* (18-d: F =2.74, P =0.09; 30-d: F =0.89, P =0.48). The overall mean lipid to protein ratio increased for all coral species at the end of day 18, but then decreased in many cases by

50% or more at the end of the 30-day post exposure observation period reducing to or below day 0 lipid to protein ratios (Table 8).

3.9.3 Summary of lipid and protein measurements

There were no statistically significant differences in lipid to protein ratios between sedimentation treatment groups for any coral species in either experiment with fine or coarse grain sediment. However, there was an overall decline in lipid to protein ratios from day 0 through the 30-day sediment free observation period for all coral species in either experiment which reflects a decrease in lipid content and concomitant increase in protein. Although not statistically significant, several control corals had a higher lipid to protein ratio at the end of the 18-day experiments. The lipid analysis could not consistently demonstrate changes in the biochemical composition of the coral's tissues, but overall, the conditions were such that autotrophy did appear to be reduced and some lipid resources were likely expended, but not in dose dependent manner (Rodrigues et al. 2008). Besides the lipid analysis being constrained by a low sample size, the lack of a dose dependent response could be attributable to possible ingestion of sediments as has been observed in other studies (Houlbrèque and Ferrier-Pagès 2009; Lewis and Price 1975; Stafford-Smith 1993). Sediments contain a variety of particulates that when suspended could make food items, such as organic matter, available to the exposed corals (Wild et al. 2004; Mills et al. 2004).

Table 7. Mean (standard deviation) protein and lipid composition of tissue from corals exposed for 18 days to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during 18-day experiments performed once with fine grain sediment and again with coarse grain sediment followed by a 30-day sediment free observation period.

			Starting		18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	Protein (µg/ml)	Lipids (µg)	Protein (µg/ml)	Lipids (µg)	Protein (µg/ml)	Lipids (µg)
Fine grain	*M. capitata*	0	312 (6) *n =4*	3,100 (400)	310 (81)	2067 (451)	411 (90)	2000 (721)
		6			368 (10)	1625 (1159)	359 (29)	1500 (845)
		30			409 (71)	2100 (829)	434 (111)	2250 (772)
		60			372 (87)	2275 (544)	419 (55)	1550 (370)
	P. meandrina	0	285 (40) *n =4*	1,150 (191)	213 (129)	1233 (493)	311 (37)	1100 (854)
		6			259 (89)	975 (512)	313 (48)	775 (763)
		30			246 (156)	1075 (492)	266 (97)	1025 (568)
		60			275 (97)	1475 (330)	286 (138)	1025 (150)

			Starting		18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	Protein (µg/ml)	Lipids (µg)	Protein (µg/ml)	Lipids (µg)	Protein (µg/ml)	Lipids (µg)
	P. lobata	0	259 (31) *n =4*	1,300 (316)	316 (58)	1400 (458)	331 (37)	1033 (513)
		6			323 (51)	1500 (408)	371 (89)	1500 (294)
		30			264 (86)	1125 (512)	392 (33)	1375 (618)
		60			205 (94)	1350 (723)	248 (71)	1175 (624)
Coarse grain	*M. capitata*	0	400 (81) *n =7*	2,057 (270)	302 (55)	2100 (700)	400 (14)	1267 (351)
		6			304 (18)	2025 (597)	420 (41)	875 (126)
		30			371 (34)	1775 (411)	442 (69)	1000 (258)
		60			378 (49)	1980 (614)	480 (109)	1475 (907)
	P. meandrina	0	277 (29) *n =4*	450 (238)	355 (57)	1167 (503)	273 (74)	567 (351)
		6			226 (141)	940 (498)	223 (69)	1075 (750)
		30			270 (61)	825 (250)	269 (43)	875 (435)
		60			253 (46)	825 (403)	232 (16)	1175 (732)
	P. lobata	0	360 (22) *n =4*	725 (206)	262 (6)	2633 (551)	356 (23)	833 (666)
		6			225 (38)	1450 (545)	356 (38)	300 (82)
		30			251 (52)	2000 (942)	296 (36)	600 (216)
		60			297 (40)	1725 (629)	290 (62)	475 (350)

Table 8. Mean (standard deviation) ratio of lipid to protein in coral tissue expressed for day 18 as a percentage change of initial ratio on day 0 and for day 30 as a percentage change of ratio on day 18 for corals exposed to sedimentation concentrations of 0, 6, 30, and 60 mg cm^{-2} introduced every four days during 18-day experiments performed once with fine grain sediment and again with coarse grain sediment followed by a 30-day sediment free observation period. No statistically significant difference (P <0.05) as compared to the control was detected.

			Starting	18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	lipid/protein	lipid/protein	% change	lipid/protein	% change
Fine grain	*M. capitata*	0	9.95 (1.4) *n =4*	7.10 (2.7)	-29 (27)	5.10 (2.2)	-28 (31)
		6		4.47 (3.2)	-55 (33)	4.10 (2.1)	-8 (47)
		30		5.33 (2.3)	-46 (23)	5.77 (3.5)	8 (65)
		60		6.66 (3.3)	-33 (34)	3.69 (0.7)	-45 (11)
	P. meandrina	0	4.12 (1.0) *n =4*	8.17 (5.9)	98 (144)	3.40 (2.4)	-58 (30)
		6		4.39 (3.4)	7 (83)	2.66 (2.8)	-39 (63)
		30		6.25 (5.3)	52 (128)	3.69 (1.2)	-41 (20)
		60		6.31 (3.9)	53 (94)	4.40 (2.5)	-30 (40)
	P.	0	5.12 (1.4)	4.66 (2.3)	-9 (45)	3.07 (1.4)	-34 (29)

			Starting	18-day		30-day	
Sediment	Corals	Treatment (mg cm^{-2})	lipid/protein	lipid/protein	% change	lipid/protein	% change
	lobata	6	*n =4*	4.58 (0.6)	-11 (11)	4.30 (1.4)	-6 (32)
		30		4.72 (2.7)	-8 (53)	3.51 (1.6)	-26 (34)
		60		8.61 (8.3)	68 (162)	4.99 (2.4)	-42 (28)
Coarse grain	*M. capitata*	0	5.35 (1.4) *n =7*	7.29 (3.5)	36 (66)	3.15 (0.8)	-57 (11)
		6		6.69 (2.1)	25 (39)	2.10 (0.4)	-69 (6)
		30		4.77 (0.9)	-11 (17)	2.31 (0.7)	-52 (15)
		60		5.36 (1.9)	-1 (23)	3.09 (2.0)	-41 (38)
	P. meandrina	0	1.7 (1.0) *n =4*	3.44 (1.7)	102 (102)	1.92 (0.8)	-44 (24)
		6		6.46 (5.2)	354 (291)	5.80 (5.2)	-25 (68)
		30		3.03 (0.5)	77 (27)	3.32 (1.6)	10 (52)
		60		3.62 (2.7)	113 (158)	4.94 (2.8)	36 (78)
	P. lobata	0	2.0 (0.5) *n =4*	10.08 (2.2)	403 (112)	2.34 (1.9)	-77 (19)
		6		6.29 (1.7)	214 (86)	0.86 (0.3)	-86 (5)
		30		7.89 (2.9)	294 (144)	2.03 (0.7)	-74 (9)
		60		5.68 (1.7)	184 (83)	1.68 (1.1)	-70 (20)

4 Summary and Conclusions

The presence of anthropic activities (e.g., daily commercial shipping sediment plumes) and designs (e.g., cityscapes, channelized streams) as well as natural causes (e.g., storms, climate change) impact the sources, sinks, and redistribution pathways of sediment in the Honolulu Harbor Federal Navigation Project. As part of maintaining a federal navigation project, dredging activities are usually required to maintain channels to an authorized depth to allow for safe navigation of commercial vessels. On average, dredging of Honolulu Harbor occurs once every five years. When there is dredging, suspended sediment generated by the event can potentially impact coral health for corals located near the dredging activities (e.g., Jones et al. 2016; Bak 1978). Dredging is a concern because the activities can generate suspended sediment plumes many times greater than natural resuspension especially at the site of excavation and potentially extending several hundred meters from the dredge. There are many factors that influence the extent of such an event including sediment characteristics (e.g., settling capacity of coarse or fine grain sediment), hydrodynamics which are the primary driving forces of sediment dynamics (e.g., low energy water column [inner harbor] versus higher energy water column [entrance channel]), and best management dredging practices.

The potential impacts of sedimentation from dredging have previously been investigated but are commonly based on studies where corals are continuously exposed (e.g., Browne et al. 2015). In Honolulu Harbor, exposure near dredging operations can occur as a series of pulses influenced by movement of the dredge from one location to the next or to avoid vessel traffic. In this study, two experiments were conducted under controlled laboratory conditions, one with locally collected fine grain sediment and a second with coarse grain sediment, to assess the effects of pulsed sediment concentrations ranging from 0 to 60 mg cm^{-2} dosed on days 0, 4, 8, 12 and 16 of an 18-day exposure on three common endemic Hawaiian coral species (*P. meandrina* [branching growth form]; *P. lobata* [massive growth form]; *M. capitata* [branching growth form]). Experimental conditions spanned a range of exposures that could potentially be created by a dredging event in the Honolulu Harbor. A 30-day sediment free observation period followed each experiment to determine any lingering effects. The following bullets highlight the experimental results.

- On a typical experimental dosing day, the sedimentation treatment groups of 0 (control), 6, 30 and 60 mg cm^{-2} were associated with turbidity levels of <2, 60, 249, and 446 NTU, respectively, after the initial introduction of fine grain sediment and <2, 6, 20, and 50 NTU, respectively, after introduction of coarse grain sediment. For each sediment type, turbidity levels reduced to nearly half of the initial level by the end of the 15 min settling period and 1-4 hr later returned to reference (control) conditions (<1.92 NTU).
- During exposure to sedimentation created with either fine or coarse grain sediment, test corals were able to shed most sediment after the first two doses (day 0 and 4 doses) but accumulated more sediment after successive doses (3rd dose on day 8 and 4th dose on day 12) over the 18-day period. Sedimentation concentrations created with fine grain sediment had a higher propensity to remain on the coral surface as compared to sedimentation created with coarse grain sediment.
- Sediment accumulation was highest on the massive form, *P. lobata*. Contrary to other studies that observed branching coral morphologies being more resilient to sediment smothering (e.g., Jones et al. 2019), the branching *P. meandrina* corals did not easily shed sediment, likely due to the evenly spaced verrucae which are small but distinctive protrusions covering the coral that retained and accumulated sediment. The branching form of *M. capitata* corals, however, easily shed sediment likely due to less numerous and irregularly spaced verrucae and larger area of smooth surface.
- In either experiment, the response of corals varied substantially, but corals displayed physiological effects and, in some cases, partial tissue loss at sediment concentrations of 30 and 60 mg cm^{-2}, except *M. capitata*, which experienced no tissue loss. *M. capitata* did, however, experience a reduction in photosynthetic yield at 60 mg cm^{-2} fine grain sediment.
- During the 30-day post-exposure sediment free observation period, *P. meandrina* tissue loss continued, *P. lobata* tissue nearly completely regrew, while *M. capitata* showed no lingering effects.
- Except for *P. meandrina* exposed in the 30 and 60 mg cm^{-2} coarse grain sediment treatment groups, all corals maintained an overall positive, albeit quite variable, growth rate over each 18-day experiment and each 30-day observation period.
- These results indicate the branching *M. capitata* are potentially able to endure several sediment pulses, but successive sediment pulses occurring every four days for growth forms at higher risk of

accumulating sediment such as *P. meandrina* and *P. lobata*, may result in a cumulative effect on coral health.

- Although the fine grain sediment had a higher propensity to remain on the coral surface as compared to coarse grain sediment, if either fine or coarse grain sediment remained on the coral surface long enough the coral tissue was damaged, especially for *P. meandrina* and *P. lobata*.
- These data improve capabilities to estimate the potential impacts of dredging and other sources of suspended sediments on coral reef ecosystems.

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Appendix A: Water Chemistry

Table 9. Water chemistry for Kewalo Basin water (sourced approximately 500 m seaward of the Kewalo Marine Laboratory, Honolulu, HI, USA). Sea water used in the outdoor acclimation/quarantine tanks and in the laboratory, experiments was filtered through a 5 µm filter prior to use. For water analysis, a 5 µm filtered water sample was collected prior to introduction into an experimental tank.

Analyte	CAS	Method	Units	Result	DL	RL	Note
1,2,4-Trichlorobenzene	120-82-1	SW 846 8270E	ug L^{-1}	ND	0.051	0.99	H,H3
1,2-Diphenylhydrazine(as Azobenzene)	122-66-7	SW 846 8270E	ug L^{-1}	ND	0.049	0.99	H,H3
2,2'-oxybis[1-chloropropane]	108-60-1	SW 846 8270E	ug L^{-1}	ND	0.057	0.19	H,H3
2,4,6-Trichlorophenol	88-06-2	SW 846 8270E	ug L^{-1}	ND	0.067	0.99	H,H3
2,4-Dichlorophenol	120-83-2	SW 846 8270E	ug L^{-1}	ND	0.050	0.19	H,H3
2,4-Dimethylphenol	105-67-9	SW 846 8270E	ug L^{-1}	ND	0.041	0.99	H,H3,F1
2,4-Dinitrophenol	51-28-5	SW 846 8270E	ug L^{-1}	ND	1.5	9.9	H,H3
2,4-Dinitrotoluene	121-14-2	SW 846 8270E	ug L^{-1}	ND	0.050	0.99	H,H3
2,6-Dinitrotoluene	606-20-2	SW 846 8270E	ug L^{-1}	ND	0.059	0.99	H,H3
2-Chloronaphthalene	91-58-7	SW 846 8270E	ug L^{-1}	ND	0.058	0.19	H,H3
2-Chlorophenol	95-57-8	SW 846 8270E	ug L^{-1}	ND	0.063	0.99	H,H3,F1
2-Nitrophenol	88-75-5	SW 846 8270E	ug L^{-1}	ND	0.060	0.99	H,H3
3,3'-Dichlorobenzidine	91-94-1	SW 846 8270E	ug L^{-1}	ND	0.58	0.99	H,H3
4,6-Dinitro-2-methylphenol	534-52-1	SW 846 8270E	ug L^{-1}	ND	1.5	5.0	H,H3
4-Bromophenyl phenyl ether	101-55-3	SW 846 8270E	ug L^{-1}	0.42	0.062	0.99	J,H,H3
4-Chloro-3-methylphenol	59-50-7	SW 846 8270E	ug L^{-1}	ND	0.060	0.99	H,H3
4-Chlorophenyl phenyl ether	7005-72-3	SW 846 8270E	ug L^{-1}	ND	0.060	0.99	H,H3
4-Nitrophenol	100-02-7	SW 846 8270E	ug L^{-1}	ND	0.14	5.0	H,H3
Acenaphthene	83-32-9	SW 846 8270E	ug L^{-1}	ND	0.064	0.19	H,H3
Acenaphthylene	208-96-8	SW 846 8270E	ug L^{-1}	ND	0.064	0.19	H,H3
Anthracene	120-12-7	SW 846 8270E	ug L^{-1}	ND	0.049	0.19	H,H3
Benzidine	92-87-5	SW 846 8270E	ug L^{-1}	ND	9.0	20	H,H3,F1

Analyte	CAS	Method	Units	Result	DL	RL	Note
Benzo[a]anthracene	56-55-3	SW 846 8270E	ug L^{-1}	ND	0.074	0.19	H,H3
Benzo[a]pyrene	50-32-8	SW 846 8270E	ug L^{-1}	ND	0.052	0.19	H,H3
Benzo[b]fluoranthene	205-99-2	SW 846 8270E	ug L^{-1}	ND	0.096	0.19	H,H3
Benzo[g,h,i]perylene	191-24-2	SW 846 8270E	ug L^{-1}	ND	0.068	0.19	H,H3
Benzo[k]fluoranthene	207-08-9	SW 846 8270E	ug L^{-1}	ND	0.087	0.19	H,H3
Bis(2-chloroethoxy)methane	111-91-1	SW 846 8270E	ug L^{-1}	ND	0.066	0.99	H,H3
Bis(2-chloroethyl)ether	111-44-4	SW 846 8270E	ug L^{-1}	ND	0.040	0.19	H,H3,F1
Bis(2-ethylhexyl) phthalate	117-81-7	SW 846 8270E	ug L^{-1}	ND	6.2	9.9	H,H3
Butyl benzyl phthalate	85-68-7	SW 846 8270E	ug L^{-1}	ND	0.46	0.99	H,H3
Chrysene	218-01-9	SW 846 8270E	ug L^{-1}	ND	0.080	0.19	H,H3
Dibenz(a,h)anthracene	53-70-3	SW 846 8270E	ug L^{-1}	ND	0.071	0.19	H,H3
Diethyl phthalate	84-66-2	SW 846 8270E	ug L^{-1}	ND	0.56	0.99	H,H3
Dimethyl phthalate	131-11-3	SW 846 8270E	ug L^{-1}	ND	0.055	0.99	H,H3
Di-n-butyl phthalate	84-74-2	SW 846 8270E	ug L^{-1}	ND	0.74	0.99	H,H3
Di-n-octyl phthalate	117-84-0	SW 846 8270E	ug L^{-1}	ND	0.68	0.99	H,H3
Fluoranthene	206-44-0	SW 846 8270E	ug L^{-1}	ND	0.059	0.19	H,H3
Fluorene	86-73-7	SW 846 8270E	ug L^{-1}	ND	0.068	0.19	H,H3
Hexachlorobenzene	118-74-1	SW 846 8270E	ug L^{-1}	ND	0.055	0.19	H,H3
Hexachlorobutadiene	87-68-3	SW 846 8270E	ug L^{-1}	ND	0.068	0.19	H,H3
Hexachlorocyclopentadiene	77-47-4	SW 846 8270E	ug L^{-1}	ND	0.49	0.99	H,H3
Hexachloroethane	67-72-1	SW 846 8270E	ug L^{-1}	ND	0.061	0.99	H,H3,F1
Indeno[1,2,3-cd]pyrene	193-39-5	SW 846 8270E	ug L^{-1}	ND	0.084	0.19	H,H3
Isophorone	78-59-1	SW 846 8270E	ug L^{-1}	ND	0.053	0.99	H,H3
Naphthalene	91-20-3	SW 846 8270E	ug L^{-1}	ND	0.058	0.19	H,H3,F1
Nitrobenzene	98-95-3	SW 846 8270E	ug L^{-1}	ND	0.50	2.0	H,H3
N-Nitrosodimethylamine	62-75-9	SW 846 8270E	ug L^{-1}	ND	0.066	0.99	H,H3,F1

Analyte	CAS	Method	Units	Result	DL	RL	Note
N-Nitrosodi-n-propylamine	621-64-7	SW 846 8270E	ug L^{-1}	ND	0.070	0.19	H,H3,F1
N-Nitrosodiphenylamine	86-30-6	SW 846 8270E	ug L^{-1}	ND	0.12	0.99	H,H3,F1
Pentachlorophenol	87-86-5	SW 846 8270E	ug L^{-1}	ND	0.84	5.0	H,H3
Phenanthrene	85-01-8	SW 846 8270E	ug L^{-1}	ND	0.054	0.19	H,H3
Phenol	108-95-2	SW 846 8270E	ug L^{-1}	ND	0.48	0.99	H,H3,F1
Pyrene	129-00-0	SW 846 8270E	ug L^{-1}	ND	0.053	0.19	H,H3
2,4,6-Tribromophenol (Surr)	118-79-6	SW 846 8270E	ug L^{-1}	13			
2-Fluorobiphenyl	321-60-8	SW 846 8270E	ug L^{-1}	14			
2-Fluorophenol (Surr)	367-12-4	SW 846 8270E	ug L^{-1}	13			
Nitrobenzene-d5 (Surr)	4165-60-0	SW 846 8270E	ug L^{-1}	16			
Phenol-d5 (Surr)	4165-62-2	SW 846 8270E	ug L^{-1}	14			
Terphenyl-d14 (Surr)	1718-51-0	SW 846 8270E	ug L^{-1}	13			
Total Solids	STL00291	SM2540B	mg L^{-1}	40000	500	500	H,H3
Total Volatile Solids	STL00236	SM2540E	mg L^{-1}	11000	500	500	H,H3
Chlorophyll a	479-61-8	SM 10200H-2	mg m^{-3}	ND	0.86	1.6	Ua
pH	NA	EPA 150.1	pH Units	8.27			HTR
Total Suspended Solids	NA	EPA 160.2	mg L^{-1}	2.00	2.00	10.0	J
Ammonia as N	7664-41-7	EPA 350.1	mg L^{-1}	0.147	0.0100	0.0200	
Total Kjeldahl Nitrogen as N		EPA 351.2	mg L^{-1}	ND	0.100	0.200	Ha, U
Nitrate + Nitrite as N		EPA 353.1	mg L^{-1}	ND	0.0100	0.0200	U
Total Nitrogen	NA	EPA 353.1/351.2	mg L^{-1}	ND	0.110	0.220	U
Orthophosphate as P	1426-54-42	EPA 365.1	mg L^{-1}	0.00522	0.00326	0.00978	J
Calcium	7440-70-2	EPA 6010	mg L^{-1}	405	0.0400	0.200	
Phosphorus	7723-14-0	EPA 6010	mg L^{-1}	1.63	0.0400	0.200	
Arsenic-75 [1]	7440-38-2	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Barium-135 [1]	7440-39-3	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U

Analyte	CAS	Method	Units	Result	DL	RL	Note
Cadmium-114 [2]	7440-43-9	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Chromium-52 [1]	7440-47-3	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Copper-63 [2]	7440-50-8	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Lead-208 [1]	7439-92-1	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Nickel-62 [2]	7440-02-0	EPA 6020	mg L^{-1}	ND	0.0040	0.0080	U
Zinc-66 [2]	7440-66-6	EPA 6020	mg L^{-1}	0.0076	0.0040	0.0080	J
Selenium-78 [1]	7782-49-2	EPA 6020	mg L^{-1}	0.0102	0.0040	0.0080	
Mercury	7439-97-6	EPA 7474	mg L^{-1}	ND	0.00001	0.00002	U
2,4´-DDD	53-19-0	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
2,4´-DDE	3424-82-6	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
2,4´-DDT	789-02-6	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
4,4´-DDD	72-54-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
4,4'-DDE [2C]	72-55-9	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
4,4´-DDT	50-29-3	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Aldrin	309-00-2	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
alpha-BHC	319-84-6	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
alpha-Chlordane [2C]	5103-71-9	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
beta-BHC	319-85-7	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
cis-Nonachlor	510-37-31	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
delta-BHC	319-86-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Dieldrin	60-57-1	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
EndoSulfan I [2C]	959-98-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Endosulfan II	33213-65-9	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Endosulfan sulfate	1031-07-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Endrin	72-20-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Endrin aldehyde	7421-93-4	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U

Analyte	CAS	Method	Units	Result	DL	RL	Note
Endrin ketone	53494-70-5	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
gamma-BHC (Lindane)	58-89-9	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
gamma-Chlordane	5566-34-7	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Heptachlor	76-44-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Heptachlor epoxide	1024-57-3	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Methoxychlor	72-43-5	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Oxychlordane	26880-48-8	EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
Toxaphene	8001-35-2	EPA 8081A	ug L^{-1}	ND	0.015	0.050	U
trans-Nonachlor [2]		EPA 8081A	ug L^{-1}	ND	0.0004	0.001	U
2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA 8081A	ug L^{-1}	0.0140	0.0004	0.001	
PCB 198	68194-17-2	EPA 8081A	ug L^{-1}	0.0257	0.0004	0.001	
Total Organic Carbon	NA	EPA 9060	mg L^{-1}	0.843	0.500	1.00	J
PCB-1016	12674-11-2	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1221	11104-28-2	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1232	11141-16-5	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1242	53469-21-9	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1248	12672-29-6	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1254	11097-69-1	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB-1260	11096-82-5	EPA8082	ug L^{-1}	ND	0.007	0.020	U
PCB 198 (2C)	68194-17-2	EPA8082	ug L^{-1}	0.0321	0.0004	0.002	
2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA8082	ug L^{-1}	0.0143			
Hardness	NA	SM 2340B	mg equil CaC03 L^{-1}	6420	0.265	1.32	
Calcium	7440-70-2	SW 846/6010	mg L^{-1}	405	0.0400	0.200	
Magnesium	7439-95-4	SW 846/6010	mg L^{-1}	1310	0.0400	0.200	
Total Solids	STL00291	SM 2540B	mg L^{-1}	40000	500	500	H, H3
Total Volatile Solids	STL00236	SM 2540E	mg L^{-1}	11000	500	500	H, H3

Analyte	CAS	Method	Units	Result	DL	RL	Note
1,2,4-Trichlorobenzene	120-82-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.051	0.99	H, H3
1,2-Diphenylhydrazine(as Azobenzene)	122-66-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.049	0.99	H, H3
2,2'-oxybis[1-chloropropane]	108-60-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.057	0.19	H, H3
2,4,6-Trichlorophenol	88-06-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.067	0.99	H, H3
2,4-Dichlorophenol	120-83-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.050	0.19	H, H3
2,4-Dimethylphenol	105-67-9	SW 846 EPA 8270E	ug L^{-1}	ND	0.041	0.99	H, H3, F1
2,4-Dinitrophenol	51-28-5	SW 846 EPA 8270E	ug L^{-1}	ND	1.5	9.9	H, H3
2,4-Dinitrotoluene	121-14-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.050	0.99	H, H3
2,6-Dinitrotoluene	606-20-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.059	0.99	H, H3
2-Chloronaphthalene	91-58-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.058	0.19	H, H3
2-Chlorophenol	95-57-8	SW 846 EPA 8270E	ug L^{-1}	ND	0.063	0.99	H, H3, F1
2-Nitrophenol	88-75-5	SW 846 EPA 8270E	ug L^{-1}	ND	0.060	0.99	H, H3
3,3'-Dichlorobenzidine	91-94-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.58	0.99	H, H3
4,6-Dinitro-2-methylphenol	534-52-1	SW 846 EPA 8270E	ug L^{-1}	ND	1.5	5.0	H, H3
4-Bromophenyl phenyl ether	101-55-3	SW 846 EPA 8270E	ug L^{-1}	0.42	0.062	0.99	Ja, H, H3
4-Chloro-3-methylphenol	59-50-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.060	0.99	H, H3
4-Chlorophenyl phenyl ether	7005-72-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.060	0.99	H, H3
4-Nitrophenol	100-02-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.14	5.0	H, H3
Acenaphthene	83-32-9	SW 846 EPA 8270E	ug L^{-1}	ND	0.064	0.19	H, H3
Acenaphthylene	208-96-8	SW 846 EPA 8270E	ug L^{-1}	ND	0.064	0.19	H, H3
Anthracene	120-12-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.049	0.19	H, H3
Benzidine	92-87-5	SW 846 EPA 8270E	ug L^{-1}	ND	9.0	20	H, H3, F1
Benzo[a]anthracene	56-55-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.074	0.19	H, H3
Benzo[a]pyrene	50-32-8	SW 846 EPA 8270E	ug L^{-1}	ND	0.052	0.19	H, H3
Benzo[b]fluoranthene	205-99-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.096	0.19	H, H3
Benzo[g,h,i]perylene	191-24-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.068	0.19	H, H3

Analyte	CAS	Method	Units	Result	DL	RL	Note
Benzo[k]fluoranthene	207-08-9	SW 846 EPA 8270E	ug L^{-1}	ND	0.087	0.19	H, H3
Bis(2-chloroethoxy)methane	111-91-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.066	0.99	H, H3
Bis(2-chloroethyl)ether	111-44-4	SW 846 EPA 8270E	ug L^{-1}	ND	0.040	0.19	H, H3, F1
Bis(2-ethylhexyl) phthalate	117-81-7	SW 846 EPA 8270E	ug L^{-1}	ND	6.2	9.9	H, H3
Butyl benzyl phthalate	85-68-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.46	0.99	H, H3
Chrysene	218-01-9	SW 846 EPA 8270E	ug L^{-1}	ND	0.080	0.19	H, H3
Dibenz(a,h)anthracene	53-70-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.071	0.19	H, H3
Diethyl phthalate	84-66-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.56	0.99	H, H3
Dimethyl phthalate	131-11-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.055	0.99	H, H3
Di-n-butyl phthalate	84-74-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.74	0.99	H, H3
Di-n-octyl phthalate	117-84-0	SW 846 EPA 8270E	ug L^{-1}	ND	0.68	0.99	H, H3
Fluoranthene	206-44-0	SW 846 EPA 8270E	ug L^{-1}	ND	0.059	0.19	H, H3
Fluorene	86-73-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.068	0.19	H, H3
Hexachlorobenzene	118-74-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.055	0.19	H, H3
Hexachlorobutadiene	87-68-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.068	0.19	H, H3
Hexachlorocyclopentadiene	77-47-4	SW 846 EPA 8270E	ug L^{-1}	ND	0.49	0.99	H, H3
Hexachloroethane	67-72-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.061	0.99	H, H3, F1
Indeno[1,2,3-cd]pyrene	193-39-5	SW 846 EPA 8270E	ug L^{-1}	ND	0.084	0.19	H, H3
Isophorone	78-59-1	SW 846 EPA 8270E	ug L^{-1}	ND	0.053	0.99	H, H3
Naphthalene	91-20-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.058	0.19	H, H3, F1
Nitrobenzene	98-95-3	SW 846 EPA 8270E	ug L^{-1}	ND	0.50	2.0	H, H3
N-Nitrosodimethylamine	62-75-9	SW 846 EPA 8270E	ug L^{-1}	ND	0.066	0.99	H, H3, F1
N-Nitrosodi-n-propylamine	621-64-7	SW 846 EPA 8270E	ug L^{-1}	ND	0.070	0.19	H, H3, F1
N-Nitrosodiphenylamine	86-30-6	SW 846 EPA 8270E	ug L^{-1}	ND	0.12	0.99	H, H3, F1
Pentachlorophenol	87-86-5	SW 846 EPA 8270E	ug L^{-1}	ND	0.84	5.0	H, H3
Phenanthrene	85-01-8	SW 846 EPA 8270E	ug L^{-1}	ND	0.054	0.19	H, H3

Analyte	CAS	Method	Units	Result	DL	RL	Note
Phenol	108-95-2	SW 846 EPA 8270E	ug L^{-1}	ND	0.48	0.99	H, H3, F1
Pyrene	129-00-0	SW 846 EPA 8270E	ug L^{-1}	ND	0.053	0.19	H, H3
2,4,6-Tribromophenol (Surr)	118-79-6	SW 846 EPA 8270E	ug L^{-1}	13			
2-Fluorobiphenyl	321-60-8	SW 846 EPA 8270E	ug L^{-1}	14			
2-Fluorophenol (Surr)	367-12-4	SW 846 EPA 8270E	ug L^{-1}	13			
Nitrobenzene-d5 (Surr)	4165-60-0	SW 846 EPA 8270E	ug L^{-1}	16			
Phenol-d5 (Surr)	4165-62-2	SW 846 EPA 8270E	ug L^{-1}	14			
Terphenyl-d14 (Surr)	1718-51-0	SW 846 EPA 8270E	ug L^{-1}	13			

F1, MS and/or MSD recovery exceeds control limits.

H, Sample was prepped or analyzed beyond the specified holding time

H3, Sample was received and analyzed past holding time.

Ha, This sample was extracted and/or analyzed outside of the EPA recommended holding time.

HTR, Sample was received outside of EPA recommended holding time.

J, Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Jb, Detected but below the Reporting Limit (Limit of Quantitation); therefore, result is an estimated concentration.

Ja, Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

QM-07, The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS recovery.

RPD-02, The RPD result exceeded the QC control limits; however, both percent recoveries were acceptable. Sample results for the QC batch were accepted based on percent recoveries and completeness of QC data.

S-GC, Surrogate recovery outside of control limits. The data was accepted based on valid recovery of the remaining surrogate/s.

U, Analyte included in the analysis, but not detected

Ua, This compound was analyzed for, but not detected above the associated detection limit.

Appendix B: Sediment Chemistry

Table 10. Chemistry for fine grain sediment collected from inner Honolulu Harbor (Inner Harbor) and a coarse grain sediment collected from Kuli‘ou‘ou Beach Park (Kuli‘ou‘ou), Hawai‘i, USA, used to expose corals in a laboratory to a range of sedimentation concentrations. Test sediments were wet sieved through 1 mm sieve to remove debris prior to the experiments and chemistry.

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	% Solids	NA	ASTM D2216-98	% Solids	48.9	0.500	0.500	
Inner Harbor	4,4´-DDD	72-54-8	EPA 8081A	ug kg^{-1} dry	0.829	0.109	0.341	
Inner Harbor	4,4´-DDE	72-55-9	EPA 8081A	ug kg^{-1} dry	0.779	0.109	0.341	RPD-04
Inner Harbor	4,4´-DDT	50-29-3	EPA 8081A	ug kg^{-1} dry	1.37	0.109	0.341	RPD-04
Inner Harbor	Aldrin	309-00-2	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	alpha-BHC	319-84-6	EPA 8081A	ug kg^{-1} dry	0.220	0.109	0.341	J
Inner Harbor	alpha-Chlordane [2C]	5103-71-9	EPA 8081A	ug kg^{-1} dry	0.747	0.109	0.341	RPD-04
Inner Harbor	beta-BHC	319-85-7	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	cis-Nonachlor	510-37-31	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Dieldrin	60-57-1	EPA 8081A	ug kg^{-1} dry	0.693	0.109	0.341	RPD-04
Inner Harbor	EndoSulfan I [2C]	959-98-8	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Endosulfan II	33213-65-9	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Endosulfan sulfate [2C]	1031-07-8	EPA 8081A	ug kg^{-1} dry	2.62	0.109	0.341	RPD-04
Inner Harbor	Endrin	72-20-8	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Endrin aldehyde	7421-93-4	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Endrin ketone	53494-70-5	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	gamma-BHC (Lindane)	58-89-9	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	gamma-Chlordane	5566-34-7	EPA 8081A	ug kg^{-1} dry	1.27	0.109	0.341	
Inner Harbor	Heptachlor	76-44-8	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Heptachlor epoxide	1024-57-3	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U
Inner Harbor	Methoxychlor	72-43-5	EPA 8081A	ug kg^{-1} dry	ND	0.109	0.341	U

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	Oxychlordane	26880-48-8	EPA 8081A	ug kg^{-1} dry	0.431	0.109	0.341	
Inner Harbor	trans-Nonachlor [2]		EPA 8081A	ug kg^{-1} dry	0.890	0.109	0.341	
Inner Harbor	Toxaphene	8001-35-2	EPA 8081A	ug kg^{-1} dry	ND	4.09	13.6	U
Inner Harbor	2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA 8081A	ug kg^{-1} dry	3.84	0.109	0.341	
Inner Harbor	PCB 198	68194-17-2	EPA 8081A	ug kg^{-1} dry	7.32	0.109	0.341	
Inner Harbor	Nitrate + Nitrite as N		EPA 300.0	mg kg^{-1}	0.211	0.0110	0.0230	H
Inner Harbor	Ammonia as N	7664-41-7	EPA 350.1	mg kg^{-1}	11.0	0.149	0.498	
Inner Harbor	Orthophosphate as P	1426-54-42	EPA 365.1	mg kg^{-1}	1.23	0.300	1.00	H
Inner Harbor	Mercury	7439-97-6	EPA 7474	mg kg^{-1}	0.440	0.00494	0.00987	
Inner Harbor	pH	NA	EPA 9045C	pH Units	8.13	1.00	1.00	HTR
Inner Harbor	PCB-1016	12674-11-2	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1221	11104-28-2	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1232	11141-16-5	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1242	53469-21-9	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1248	12672-29-6	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1254	11097-69-1	EPA8082	ug kg^{-1} dry	ND	1.15	3.48	U
Inner Harbor	PCB-1260	11096-82-5	EPA8082	ug kg^{-1} dry	40.2	1.15	3.48	Z-03
Inner Harbor	2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA8082	ug kg^{-1} dry	4.59			
Inner Harbor	PCB 198 (2C)	68194-17-2	EPA8082	ug kg^{-1} dry	9.55	0.16	0.51	
Inner Harbor	Barium	7440-39-3	SW 846/6010	mg kg^{-1}	26.1	0.999	5.00	
Inner Harbor	Calcium	7440-70-2	SW 846/6010	mg kg^{-1}	239000	20.0	99.9	
Inner Harbor	Chromium	7440-47-3	SW 846/6010	mg kg^{-1}	75.8	0.999	5.00	
Inner Harbor	Nickel	7440-02-0	SW 846/6010	mg kg^{-1}	41.1	0.999	5.00	
Inner Harbor	Phosphorus	7723-14-0	SW 846/6010	mg kg^{-1}	1410	20.0	99.9	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	Zinc	7440-66-6	SW 846/6010	mg kg^{-1}	211	0.999	5.00	
Inner Harbor	Arsenic-75 [1]	7440-38-2	SW 846/6020	mg kg^{-1}	18.0	0.0400	0.200	
Inner Harbor	Cadmium-111 [1]	7440-43-9	SW 846/6020	mg kg^{-1}	0.118	0.0400	0.200	J
Inner Harbor	Copper-65 [2]	7440-50-8	SW 846/6020	mg kg^{-1}	75.9	0.0400	0.200	
Inner Harbor	Lead-208 [1]	7439-92-1	SW 846/6020	mg kg^{-1}	60.9	0.0400	0.200	
Inner Harbor	Selenium-77 [1]	7782-49-2	SW 846/6020	mg kg^{-1}	3.11	0.0400	0.200	
Inner Harbor	Nitrogen, Kjeldahl	STL00296	4500 NorgC-2011	mg kg^{-1} dry	1200	170	280	
Inner Harbor	Loss on Ignition	STL00832	ASTM D2974	%	12.0	0.5	0.5	
Inner Harbor	Total Organic Matter	STL00484	ASTM D2974	%	12.0	0.5	0.5	
Inner Harbor	Clay	STL00587	D422	%	21.3			
Inner Harbor	Coarse Sand	STL00583	D422	%	0.0			
Inner Harbor	Fine Sand	STL00585	D422	%	23.0			
Inner Harbor	Gravel	STL00581	D422	%	0.0			
Inner Harbor	Hydrometer Reading 1–Percent Finer	STL01284	D422	% Passing	43.2			
Inner Harbor	Hydrometer Reading 2–Percent Finer	STL01285	D422	% Passing	38.8			
Inner Harbor	Hydrometer Reading 3–Percent Finer	STL01286	D422	% Passing	31.5			
Inner Harbor	Hydrometer Reading 4–Percent Finer	STL01287	D422	% Passing	25.7			
Inner Harbor	Hydrometer Reading 5–Percent Finer	STL01288	D422	% Passing	21.3			
Inner Harbor	Hydrometer Reading 6–Percent Finer	STL01290	D422	% Passing	15.5			
Inner Harbor	Hydrometer Reading 7–Percent Finer	STL01291	D422	% Passing	9.6			
Inner Harbor	Medium Sand	STL00584	D422	%	2.3			
Inner Harbor	Sand	STL00582	D422	%	25.3			
Inner Harbor	Sieve Size #10–Percent Finer	STL01268	D422	% Passing	100.0			
Inner Harbor	Sieve Size #100–Percent Finer	STL01269	D422	% Passing	86.2			

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	Sieve Size #20–Percent Finer	STL01271	D422	% Passing	99.2			
Inner Harbor	Sieve Size #200–Percent Finer	STL01272	D422	% Passing	74.7			
Inner Harbor	Sieve Size #4–Percent Finer	STL01274	D422	% Passing	100.0			
Inner Harbor	Sieve Size #40–Percent Finer	STL01275	D422	% Passing	97.7			
Inner Harbor	Sieve Size #60–Percent Finer	STL01276	D422	% Passing	94.4			
Inner Harbor	Sieve Size #80–Percent Finer	STL01277	D422	% Passing	90.0			
Inner Harbor	Sieve Size 0.375 inch–Percent Finer	STL01278	D422	% Passing	100.0			
Inner Harbor	Sieve Size 0.75 inch–Percent Finer	STL01279	D422	% Passing	100.0			
Inner Harbor	Sieve Size 1 inch–Percent Finer	STL01280	D422	% Passing	100.0			
Inner Harbor	Sieve Size 1.5 inch–Percent Finer	STL01281	D422	% Passing	100.0			
Inner Harbor	Sieve Size 2 inch–Percent Finer	STL01282	D422	% Passing	100.0			
Inner Harbor	Sieve Size 3 inch–Percent Finer	STL01283	D422	% Passing	100.0			
Inner Harbor	Silt	STL00586	D422	%	53.4			
Inner Harbor	Total Organic Carbon	7440-44-0	EPA Lloyd Kahn	mg kg^{-1}	51000	670	1000	
Inner Harbor	1,2,4-Trichlorobenzene	120-82-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	5.9	130	
Inner Harbor	1,2-Diphenylhydrazine(as Azobenzene)	122-66-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	8.7	130	
Inner Harbor	2,2-oxybis[1-chloropropane]	108-60-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	9.4	25	
Inner Harbor	2,4,6-Tribromophenol (Surr)	118-79-6	SW 846 EPA 8270E LL	ug kg^{-1} dry	270			
Inner Harbor	2,4,6-Trichlorophenol	88-06-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.0	130	
Inner Harbor	2,4-Dichlorophenol	120-83-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	9.8	25	
Inner Harbor	2,4-Dimethylphenol	105-67-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.9	130	*+
Inner Harbor	2,4-Dinitrophenol	51-28-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	700	1300	
Inner Harbor	2,4-Dinitrotoluene	121-14-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	19	130	
Inner Harbor	2,6-Dinitrotoluene	606-20-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.8	130	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	2-Chloronaphthalene	91-58-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	5.8	25	
Inner Harbor	2-Chlorophenol	95-57-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	5.9	130	
Inner Harbor	2-Fluorobiphenyl	321-60-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	270			
Inner Harbor	2-Fluorophenol (Surr)	367-12-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	290			
Inner Harbor	2-Nitrophenol	88-75-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	20	130	
Inner Harbor	3,3-Dichlorobenzidine	91-94-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	120	130	
Inner Harbor	4,6-Dinitro-2-methylphenol	534-52-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	220	650	
Inner Harbor	4-Bromophenyl phenyl ether	101-55-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	8.9	130	
Inner Harbor	4-Chloro-3-methylphenol	59-50-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	6.0	130	*+
Inner Harbor	4-Chlorophenyl phenyl ether	7005-72-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.7	130	
Inner Harbor	4-Nitrophenol	100-02-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	89	650	*+
Inner Harbor	Acenaphthene	83-32-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	290	7.3	25	
Inner Harbor	Acenaphthylene	208-96-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	310	5.6	25	
Inner Harbor	Anthracene	120-12-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	240	6.6	25	
Inner Harbor	Benzidine	92-87-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	960	2500	
Inner Harbor	Benzo[a]anthracene	56-55-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	1000	11	25	
Inner Harbor	Benzo[a]pyrene	50-32-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	2300	11	25	
Inner Harbor	Benzo[b]fluoranthene	205-99-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	1700	6.2	25	
Inner Harbor	Benzo[g,h,i]perylene	191-24-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	2400	5.5	25	
Inner Harbor	Benzo[k]fluoranthene	207-08-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	540	7.6	25	
Inner Harbor	Bis(2-chloroethoxy)methane	111-91-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	6.0	130	
Inner Harbor	Bis(2-chloroethyl)ether	111-44-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	4.6	25	
Inner Harbor	Bis(2-ethylhexyl) phthalate	117-81-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	150	140	1300	Ja
Inner Harbor	Butyl benzyl phthalate	85-68-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	87	130	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	Chrysene	218-01-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	1100	14	25	
Inner Harbor	Dibenz(a,h)anthracene	53-70-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	280	16	25	
Inner Harbor	Diethyl phthalate	84-66-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	44	130	
Inner Harbor	Dimethyl phthalate	131-11-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	9.4	130	
Inner Harbor	Di-n-butyl phthalate	84-74-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	56	130	
Inner Harbor	Di-n-octyl phthalate	117-84-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	74	130	
Inner Harbor	Fluoranthene	206-44-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	2000	6.7	25	
Inner Harbor	Fluorene	86-73-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	73	5.0	25	
Inner Harbor	Hexachlorobenzene	118-74-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	9.1	25	
Inner Harbor	Hexachlorobutadiene	87-68-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.4	25	
Inner Harbor	Hexachlorocyclopentadiene	77-47-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	13	130	
Inner Harbor	Hexachloroethane	67-72-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	6.5	130	
Inner Harbor	Indeno[1,2,3-cd]pyrene	193-39-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	1700	13	25	
Inner Harbor	Isophorone	78-59-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	6.5	130	*+
Inner Harbor	Naphthalene	91-20-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	160	4.9	25	
Inner Harbor	Nitrobenzene	98-95-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	46	250	*+
Inner Harbor	Nitrobenzene-d5 (Surr)	4165-60-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	320			
Inner Harbor	N-Nitrosodimethylamine	62-75-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	13	130	
Inner Harbor	N-Nitrosodi-n-propylamine	621-64-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	8.6	25	*+
Inner Harbor	N-Nitrosodiphenylamine	86-30-6	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	42	130	
Inner Harbor	Pentachlorophenol	87-86-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	200	650	
Inner Harbor	Phenanthrene	85-01-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	790	6.8	25	
Inner Harbor	Phenol	108-95-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	38	130	
Inner Harbor	Phenol-d5 (Surr)	4165-62-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	290			

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Inner Harbor	Pyrene	129-00-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	3300	6.0	25	
Inner Harbor	Terphenyl-d14 (Surr)	1718-51-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	260			
Kuli‘ou‘ou	% Solids	NA	ASTM D2216-98	% Solids	73.2	0.500	0.500	
Kuli‘ou‘ou	4,4´-DDD	72-54-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	4,4´-DDE	72-55-9	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	4,4´-DDT	50-29-3	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Aldrin	309-00-2	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	alpha-BHC	319-84-6	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	alpha-Chlordane [2C]	5103-71-9	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	beta-BHC	319-85-7	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	cis-Nonachlor	510-37-31	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Dieldrin	60-57-1	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	EndoSulfan I [2C]	959-98-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Endosulfan II	33213-65-9	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Endosulfan sulfate [2C]	1031-07-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Endrin	72-20-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Endrin aldehyde	7421-93-4	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Endrin ketone	53494-70-5	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	gamma-BHC (Lindane)	58-89-9	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	gamma-Chlordane	5566-34-7	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Heptachlor	76-44-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Heptachlor epoxide	1024-57-3	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Methoxychlor	72-43-5	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Oxychlordane	26880-48-8	EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	trans-Nonachlor [2]		EPA 8081A	ug kg^{-1} dry	ND	0.071	0.221	U
Kuli‘ou‘ou	Toxaphene	8001-35-2	EPA 8081A	ug kg^{-1} dry	ND	2.65	8.84	U
Kuli‘ou‘ou	2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA 8081A	ug kg^{-1} dry	2.98	0.071	0.221	
Kuli‘ou‘ou	PCB 198	68194-17-2	EPA 8081A	ug kg^{-1} dry	4.45	0.071	0.221	
Kuli‘ou‘ou	Nitrate + Nitrite as N		EPA 300.0	mg kg^{-1}	0.235	0.0110	0.0230	H
Kuli‘ou‘ou	Ammonia as N	7664-41-7	EPA 350.1	mg kg^{-1}	2.31	0.0294	0.0979	
Kuli‘ou‘ou	Orthophosphate as P	1426-54-42	EPA 365.1	mg kg^{-1}	0.892	0.300	1.00	H, J
Kuli‘ou‘ou	Mercury	7439-97-6	EPA 7474	mg kg^{-1}	0.0120	0.00245	0.00490	
Kuli‘ou‘ou	pH	NA	EPA 9045C	pH Units	8.89	1.00	1.00	HTR
Kuli‘ou‘ou	PCB-1016	12674-11-2	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1221	11104-28-2	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1232	11141-16-5	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1242	53469-21-9	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1248	12672-29-6	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1254	11097-69-1	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	PCB-1260	11096-82-5	EPA8082	ug kg^{-1} dry	ND	0.74	2.25	U
Kuli‘ou‘ou	2,4,5,6 Tetrachloro-m-xylene	877-09-8	EPA8082	ug kg^{-1} dry	3.31			
Kuli‘ou‘ou	PCB 198 (2C)	68194-17-2	EPA8082	ug kg^{-1} dry	4.93	0.11	0.33	
Kuli‘ou‘ou	Barium	7440-39-3	SW 846/6010	mg kg^{-1}	6.81	0.997	4.98	
Kuli‘ou‘ou	Calcium	7440-70-2	SW 846/6010	mg kg^{-1}	317000	19.9	99.7	
Kuli‘ou‘ou	Chromium	7440-47-3	SW 846/6010	mg kg^{-1}	26.2	0.997	4.98	
Kuli‘ou‘ou	Nickel	7440-02-0	SW 846/6010	mg kg^{-1}	11.6	0.997	4.98	
Kuli‘ou‘ou	Phosphorus	7723-14-0	SW 846/6010	mg kg^{-1}	990	19.9	99.7	
Kuli‘ou‘ou	Zinc	7440-66-6	SW 846/6010	mg kg^{-1}	11.4	0.997	4.98	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	Arsenic-75 [1]	7440-38-2	SW 846/6020	mg kg^{-1}	10.1	0.0399	0.199	
Kuli‘ou‘ou	Cadmium-111 [1]	7440-43-9	SW 846/6020	mg kg^{-1}	ND	0.0399	0.199	U
Kuli‘ou‘ou	Copper-65 [2]	7440-50-8	SW 846/6020	mg kg^{-1}	6.02	0.0399	0.199	
Kuli‘ou‘ou	Lead-208 [1]	7439-92-1	SW 846/6020	mg kg^{-1}	1.78	0.0399	0.199	
Kuli‘ou‘ou	Selenium-77 [1]	7782-49-2	SW 846/6020	mg kg^{-1}	1.92	0.0399	0.199	
Kuli‘ou‘ou	Nitrogen, Kjeldahl	STL00296	4500 NorgC-2011	mg kg^{-1} dry	5200	120	210	
Kuli‘ou‘ou	Loss on Ignition	STL00832	ASTM D2974	%	4.6	0.5	0.5	
Kuli‘ou‘ou	Total Organic Matter	STL00484	ASTM D2974	%	4.6	0.5	0.5	
Kuli‘ou‘ou	Clay	STL00587	D422	%	3.1			
Kuli‘ou‘ou	Coarse Sand	STL00583	D422	%	0.0			
Kuli‘ou‘ou	Fine Sand	STL00585	D422	%	75.0			
Kuli‘ou‘ou	Gravel	STL00581	D422	%	0.0			
Kuli‘ou‘ou	Hydrometer Reading 1–Percent Finer	STL01284	D422	% Passing	4.1			
Kuli‘ou‘ou	Hydrometer Reading 2–Percent Finer	STL01285	D422	% Passing	3.6			
Kuli‘ou‘ou	Hydrometer Reading 3–Percent Finer	STL01286	D422	% Passing	3.6			
Kuli‘ou‘ou	Hydrometer Reading 4–Percent Finer	STL01287	D422	% Passing	3.6			
Kuli‘ou‘ou	Hydrometer Reading 5–Percent Finer	STL01288	D422	% Passing	3.1			
Kuli‘ou‘ou	Hydrometer Reading 6–Percent Finer	STL01290	D422	% Passing	2.6			
Kuli‘ou‘ou	Hydrometer Reading 7–Percent Finer	STL01291	D422	% Passing	2.1			
Kuli‘ou‘ou	Medium Sand	STL00584	D422	%	20.9			
Kuli‘ou‘ou	Sand	STL00582	D422	%	95.9			
Kuli‘ou‘ou	Sieve Size #10–Percent Finer	STL01268	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size #100–Percent Finer	STL01269	D422	% Passing	26.5			
Kuli‘ou‘ou	Sieve Size #20–Percent Finer	STL01271	D422	% Passing	99.5			

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	Sieve Size #200–Percent Finer	STL01272	D422	% Passing	4.1			
Kuli‘ou‘ou	Sieve Size #4–Percent Finer	STL01274	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size #40–Percent Finer	STL01275	D422	% Passing	79.1			
Kuli‘ou‘ou	Sieve Size #60–Percent Finer	STL01276	D422	% Passing	55.0			
Kuli‘ou‘ou	Sieve Size #80–Percent Finer	STL01277	D422	% Passing	41.0			
Kuli‘ou‘ou	Sieve Size 0.375 inch–Percent Finer	STL01278	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size 0.75 inch–Percent Finer	STL01279	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size 1 inch–Percent Finer	STL01280	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size 1.5 inch–Percent Finer	STL01281	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size 2 inch–Percent Finer	STL01282	D422	% Passing	100.0			
Kuli‘ou‘ou	Sieve Size 3 inch–Percent Finer	STL01283	D422	% Passing	100.0			
Kuli‘ou‘ou	Silt	STL00586	D422	%	1			
Kuli‘ou‘ou	Total Organic Carbon	7440-44-0	EPA Lloyd Kahn	mg kg^{-1}	43000	670	1000	
Kuli‘ou‘ou	1,2,4-Trichlorobenzene	120-82-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.2	46	
Kuli‘ou‘ou	1,2-Diphenylhydrazine(as Azobenzene)	122-66-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.2	46	
Kuli‘ou‘ou	2,2-oxybis[1-chloropropane]	108-60-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.4	9.3	
Kuli‘ou‘ou	2,4,6-Tribromophenol (Surr)	118-79-6	SW 846 EPA 8270E LL	ug kg^{-1} dry	330			
Kuli‘ou‘ou	2,4,6-Trichlorophenol	88-06-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.5	46	
Kuli‘ou‘ou	2,4-Dichlorophenol	120-83-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.6	9.3	
Kuli‘ou‘ou	2,4-Dimethylphenol	105-67-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.9	46	*+
Kuli‘ou‘ou	2,4-Dinitrophenol	51-28-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	260	460	F1
Kuli‘ou‘ou	2,4-Dinitrotoluene	121-14-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.0	46	
Kuli‘ou‘ou	2,6-Dinitrotoluene	606-20-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.9	46	
Kuli‘ou‘ou	2-Chloronaphthalene	91-58-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.1	9.3	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	2-Chlorophenol	95-57-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.2	46	
Kuli‘ou‘ou	2-Fluorobiphenyl	321-60-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	330			
Kuli‘ou‘ou	2-Fluorophenol (Surr)	367-12-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	350			
Kuli‘ou‘ou	2-Nitrophenol	88-75-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	7.4	46	
Kuli‘ou‘ou	3,3-Dichlorobenzidine	91-94-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	43	46	
Kuli‘ou‘ou	4,6-Dinitro-2-methylphenol	534-52-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	80	240	
Kuli‘ou‘ou	4-Bromophenyl phenyl ether	101-55-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.3	46	
Kuli‘ou‘ou	4-Chloro-3-methylphenol	59-50-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.2	46	*+
Kuli‘ou‘ou	4-Chlorophenyl phenyl ether	7005-72-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.8	46	
Kuli‘ou‘ou	4-Nitrophenol	100-02-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	33	240	*+
Kuli‘ou‘ou	Acenaphthene	83-32-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	3.0	2.7	9.3	Ja
Kuli‘ou‘ou	Acenaphthylene	208-96-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.0	9.3	
Kuli‘ou‘ou	Anthracene	120-12-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.4	9.3	
Kuli‘ou‘ou	Benzidine	92-87-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	350	930	F1
Kuli‘ou‘ou	Benzo[a]anthracene	56-55-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	4.2	9.3	
Kuli‘ou‘ou	Benzo[a]pyrene	50-32-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	4.4	4.0	9.3	Ja
Kuli‘ou‘ou	Benzo[b]fluoranthene	205-99-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	3.6	2.3	9.3	Ja
Kuli‘ou‘ou	Benzo[g,h,i]perylene	191-24-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.0	9.3	
Kuli‘ou‘ou	Benzo[k]fluoranthene	207-08-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.8	9.3	
Kuli‘ou‘ou	Bis(2-chloroethoxy)methane	111-91-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.2	46	
Kuli‘ou‘ou	Bis(2-chloroethyl)ether	111-44-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	1.7	9.3	
Kuli‘ou‘ou	Bis(2-ethylhexyl) phthalate	117-81-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	49	460	
Kuli‘ou‘ou	Butyl benzyl phthalate	85-68-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	32	46	
Kuli‘ou‘ou	Chrysene	218-01-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	5.1	9.3	

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	Dibenz(a,h)anthracene	53-70-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	5.9	9.3	
Kuli‘ou‘ou	Diethyl phthalate	84-66-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	16	46	
Kuli‘ou‘ou	Dimethyl phthalate	131-11-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.4	46	
Kuli‘ou‘ou	Di-n-butyl phthalate	84-74-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	20	46	
Kuli‘ou‘ou	Di-n-octyl phthalate	117-84-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	27	46	
Kuli‘ou‘ou	Fluoranthene	206-44-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	5.9	2.4	9.3	Ja
Kuli‘ou‘ou	Fluorene	86-73-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	2.0	1.8	9.3	Ja
Kuli‘ou‘ou	Hexachlorobenzene	118-74-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.3	9.3	
Kuli‘ou‘ou	Hexachlorobutadiene	87-68-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.7	9.3	
Kuli‘ou‘ou	Hexachlorocyclopentadiene	77-47-4	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	4.7	46	F1, F2
Kuli‘ou‘ou	Hexachloroethane	67-72-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.4	46	
Kuli‘ou‘ou	Indeno[1,2,3-cd]pyrene	193-39-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	4.6	9.3	
Kuli‘ou‘ou	Isophorone	78-59-1	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	2.4	46	*+
Kuli‘ou‘ou	Naphthalene	91-20-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	74	1.8	9.3	
Kuli‘ou‘ou	Nitrobenzene	98-95-3	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	17	93	*+
Kuli‘ou‘ou	Nitrobenzene-d5 (Surr)	4165-60-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	390			
Kuli‘ou‘ou	N-Nitrosodimethylamine	62-75-9	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	4.6	46	
Kuli‘ou‘ou	N-Nitrosodi-n-propylamine	621-64-7	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	3.1	9.3	*+
Kuli‘ou‘ou	N-Nitrosodiphenylamine	86-30-6	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	15	46	
Kuli‘ou‘ou	Pentachlorophenol	87-86-5	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	74	240	F1
Kuli‘ou‘ou	Phenanthrene	85-01-8	SW 846 EPA 8270E LL	ug kg^{-1} dry	5.3	2.5	9.3	Ja
Kuli‘ou‘ou	Phenol	108-95-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	ND	14	46	
Kuli‘ou‘ou	Phenol-d5 (Surr)	4165-62-2	SW 846 EPA 8270E LL	ug kg^{-1} dry	340			
Kuli‘ou‘ou	Pyrene	129-00-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	6.2	2.2	9.3	Ja

Site	Analyte	CAS	Method	Units	Result	DL	RL	Note
Kuli‘ou‘ou	Terphenyl-d14 (Surr)	1718-51-0	SW 846 EPA 8270E LL	ug kg^{-1} dry	340			

*+ LCS and/or LCSD is outside acceptance limits, high biased.

0.0 0.0

F1, MS and/or MSD recovery exceeds control limits.

F2, MS/MSD RPD exceeds control limits

H, This sample was extracted and/or analyzed outside of the EPA recommended holding time.

HTR, Sample was received outside of EPA recommended holding time.

J, Detected but below the Reporting Limit (Limit of Quantitation); therefore, result is an estimated concentration.

Ja, Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.

Q, Value is outside of acceptance limits.

QM-07, The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS recovery.

QM-11, The spike recovery was outside of QC acceptance limits for the MS and/or MSD due to inherent analyte concentration greater than the spike concentration. The QC batch was accepted based on LCS and/or LCSD recoveries within the acceptance limits.

RPD-04, RPD between primary and confirmation column values >40%, likely due to co-eluting or interfering peaks. The lower result has been reported.

RPD-06, RPD exceeds acceptance limit.

S-GC, Surrogate recovery outside of control limits. The data was accepted based on valid recovery of the remaining surrogate/s.

U, Analyte included in the analysis, but not detected

Z-03, See case narrative.

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14. ABSTRACT

Sedimentation can occur near a dredge operation in pulses over days, and potentially impact coral reefs occurring in close proximity. To improve the ability to predict the effects of dredging on corals, the effects of sedimentation in two 18-day experiments were studied for three common coral species representing different morphologies. In a laboratory setting, coral fragments were exposed to four sedimentation concentrations dosed every four days ranging from 0 to 60 mg cm^{-2}. Separate experiments were performed in series, once with fine grain sediment and repeated with a coarse grain sediment. A 30-day sediment free observation period followed each experiment. Coral responses were measured throughout the experiment and at the end of the 18-day exposure and 30-day sediment free observation period. Photosynthetic yield, lipid ratios, tissue color, tissue loss, growth, and sediment cover varied among the treatment groups. All coral species were minimally affected when sediment concentrations were at or below 6 mg cm^{-2}. *P. meandrina* and *P. lobata* experienced the most sediment coverage and tissue loss when exposed to sediment concentrations >30 mg cm^{-2} for either sediment. *M. capitata* experienced no sediment coverage or tissue loss when exposed to either sediment, but a reduction in photosynthetic yield at 60 mg cm^{-2} fine grain sediment was observed. During the 30-day post-exposure sediment free observation period, *P. meandrina* tissue loss continued, *P. lobata* nearly completely regrew lost tissue, while *M. capitata* showed no lingering effects. This study improves the US Army Corps of Engineers (USACE) ability to estimate the impacts of dredging on coral reefs.

15. SUBJECT TERMS

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