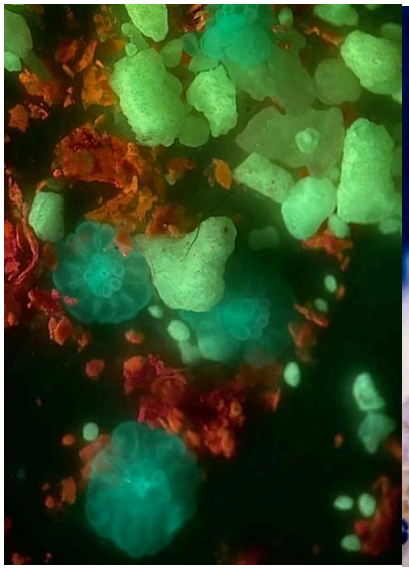
Assessing the effects of sediment sources on coral settlement and recruit survival across multiple Caribbean species



Assessing the effects of sediment sources on coral settlement and recruit survival across multiple Caribbean species

Final Report

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Management Summary (300 words or less)

We conducted experimental studies to assess the impact of port- and reef-derived sediments on the settlement success of coral larvae for multiple reef-building species (*Acropora palmata*, *Diplora labyrinthiformis*, *Orbicella faveolata*, and *Pseudodiploria strigosa*). Sediment from both sources affected larval settlement similarly with no statistical difference between them. Burial under 2 mm of sediment decreased settlement probability to 25% or less, and 4 mm suppressed settlement entirely. Species listed under the Endangered Species Act (*A. palmata*, and *O. faveolata*) were the most susceptible to sediment burial regardless of sediment source. Furthermore, we assessed the lethal and sublethal effects of sediment burial on the survivorship of *O. faveolata* fragments over ten days. Regardless of sediment source and depth, photosynthetic yield across all coral size classes declined by 55% after two days of burial and by 74% after four days. The smallest *O. faveolata* fragments (1 cm^2) began to die after 4 days of burial, and larger fragments that began to die later on: 2.3 cm^2 4 cm^2 fragments began to die after 6 and 8 days of burial, respectively. The dredging of port channels and beach renourishment projects can produce sediment layers 0.5–10 cm thick, yet 0.2 cm was enough to cause drastic decreases in larval settlement and recruit survival. Our results underscore the importance of burial duration and recruit size on determining coral survivorship. Sedimentation has a strong potential for reducing or completely inhibiting coral recruitment and post-settlement growth, reflecting the urgent need to identify the main sedimentary sources on reefs to limit future declines in reef-habitat quality. Our data provide an essential tool for managers to assess the impacts of future sedimentation events on the juvenile assemblages of reef-building species, mitigate their future loss, and maximize future coral recovery.

Executive Summary (max 1 page)

This project aimed to identify the impacts of live sediment originating from ports and reefs on larval settlement and recruit survival across multiple coral species (*A. palmata*, *D. labyrinthiformis*, *O. faveolata*, and *P. strigosa*). Overall, there were no significant differences in the response of larval settlement and recruit survivorship between port and reef sediments. Species listed under the Endangered Species Act (*A. cervicornis*, *A. palmata*, and *O. faveolata*) were the most susceptible to the burial of substrate regardless of sediment source. *O. faveolata* fragments exhibited similar responses to burial under 2 and 4 mm of sediment. There were variations in the timing of mortality, with smaller recruits dying earlier than older recruits. The smallest fragments (1 cm^2) began to die

after four days of burial and the largest fragments began to die after eight days of burial. Sediment depth profiles indicate that dissolved oxygen concentration decreases to hypoxic levels at 2–3 mm deep and to anoxic levels at 4 mm for port and reef sediments. The impacts of long sediment-laden algal turf (LSAT) on coral outplants remain unclear, at least within the first 3 months of exposure. Future studies should focus on addressing these interactions along a larger time scale (6–12 months), while addressing other important factors that influence sediment accumulation and LSAT development such as rugosity, slope, water flow, and seasonality.

These trends provide tangible evidence of the extreme susceptibility corals have to sediment stress for at least the first 1.5 years of their lifespan. These findings highlight the need to address sedimentary stressors across the Florida Reef Tract to promote future coral recovery via sexual reproduction. These data could be of further use for predicting how future sedimentation events could impact the stock of juvenile corals, allowing managers to address the impact of multiple proposed scenarios.

Main Findings

Burial of settlement substrate severely reduced settlement rates for all coral species tested and fine sediment was more impactful than coarse sediment. **Burial of settlement substrate by 2 mm of fine sediment decreased the predicted probability of settlement by 50–90%. Burial of settlement substrate by 4 mm of fine sediments resulted in complete settlement inhibition of most species except *P. strigosa.***

Recruit burial assays revealed that **coral recruits were equally susceptible to 2 and 4 mm of live sediment, regardless of source**. The sublethal effects of sediment burial were detected just after two days; **their photosynthetic yield decreased by 55% after 2 days and 74% after 4 days.** Furthermore, the **time that a coral recruit spends buried under sediment and its size are critical factors that influence the lethal and sublethal effects of sediment**. The **smallest fragments (1 cm^2) began to die after four days of burial,** and **the largest fragments**, which represent the upper size limit that defines a coral recruit/juvenile (4 cm^2), **began to die after eight days of burial**.

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1. BACKGROUND/INTRODUCTION

Coral recruitment and juvenile survival are crucial to the resilience of coral reefs. Coral recruitment is a complex process that encompasses gamete release, fertilization, larval development and settlement, recruit survival, and coral growth. Settlement success often depends on numerous factors, with a major driver being the availability of suitable substrate for settlement. Coral settlement survival also depends on other factors such as larval supply, water flow, and microhabitat conditions, including sediment abundance, substrate position, roughness, color, and benthic composition. Sediments can negatively impact corals through various mechanisms, resulting in partial or complete coral mortality (Tuttle and Donahue 2022).

In Fiscal Year (FY) 2023–24 (PO#: C1F0F3), we conducted a series of aquaria-based experiments to assess the impact of coarse sediment on the settlement of larvae and survivorship of coral recruits of six scleractinian coral species. We found that 2 mm of

coarse sediment (>250 µm) dramatically reduced the probability of settlement of coral larvae across the four species (65–100%). Our results also found that burial of coral recruits under 4 mm of coarse sediment reduced survival by 70–100% (Rodriguez-Ruano et al. In Prep). These findings suggest that even a relatively small amount of coarse sediment (≤4 mm) can have significant consequences for the early life history stages of corals. We built upon these findings during our FY 2024–25 DEP-funded projects (PO#s: C3FC5D and C4075A) to assess the physiological effects of sediment burial on corals across different sediment grain sizes. We found that fine-grained sediment (<62 µm) was more detrimental to larval settlement than coarse-grained sediment, with burial under 2 mm of sediment decreasing the settlement probability to 10% or less, and 4 mm suppressing settlement entirely. By contrast, recruits were more susceptible to coarse sediment; burial under coarse sediment decreased the photosynthetic yield of coral symbionts by up to 94%, and dissolved oxygen (DO) levels dropped by 38% within the first millimeter of burial.

To date, we have evaluated the impact of sediment burial on the survival of juvenile corals across various sediment grain sizes, species, and sediment loads. These assays were conducted with sterilized (oven-dried) sediment; however, our DO vertical profiles indicate that the photosynthesis and respiration dynamics of microbes within sedimentary matrices can significantly modify the biogeochemistry of the porewater. Therefore, we conducted settlement and recruit burial assays with live sediments collected from different sources to test the influence of varying microbial communities on the survival of juvenile corals.

Our lab work has focused on testing the influence of loose sediments on the survival and health of juvenile corals, addressing the impacts of sedimentation in the context of dredging. Loose sediments are easily disturbed and re-suspended; by contrast, long sediment-laden algal turf (LSAT) is a stable matrix of algae and sediment that is widespread on Florida reefs (Guzman et al. 2026). Our FY23 DEP-funded fieldwork revealed that LSAT comprised approximately 40% of the benthos at reef sites across southeast Florida and the upper Keys, and high LSAT cover was associated with a decline in the presence of juvenile corals (Rodriguez-Ruano et al. In Prep). Therefore, LSAT is a serious problem on Florida reefs that requires further understanding to improve habitat quality, promote larval settlement and recruit survival, and ultimately promote the recovery of Florida's reefs. Here, we also propose building upon our FY23 and FY24 work by integrating new field experiments to address the impacts of LSAT on coral growth, photosynthetic yield, and survival.

1.1. Goal 1: Test the effect of live sediments from different sources on larval settlement

Objective 1 – Assess variations in larval settlement rates of multiple coral species when exposed to substrate surrounded by, or buried under port derived and reef-derived sediments.

Rationale: Sedimentation reduces suitable habitat space for larval settlement, yet using sterile sediments may underestimate the impacts of sedimentation to coral larvae compared to live sediments, which contain diverse microbiotas that influence biogeochemical processes of sediment porewater, such as the concentrations of DO. To understand the mechanisms through which sedimentation inhibits future coral recovery, it is essential to understand the response of larvae from multiple coral species to live sediment representative of benthic habitats that they are exposed to in South Florida.

1.2. Goal 2: Test the effect of live sediments from different sources on recruit survivorship

Objective 2 – Assess whether the burial of recruits under port-derived sediment is more detrimental to recruit survivorship than reef-derived sediment.

Rationale: Sediment burial also impacts the survivorship of established coral recruits. It is important to understand the interactions of coral recruits with live sediment from different sources, and how these interactions may influence the biogeochemistry of the sediment porewater and the eventual survivorship of coral recruits. Furthermore, by testing different sediment sources, sediment depths, and coral size classes, we can determine how variations in covariates can affect the coral–sediment relationship. Such information is essential for the management of vulnerable coral populations threatened by sediment stress.

1.3. Goal 3: Test changes in the survivorship and growth of outplants that are exposed to different sedimentary and algal benthic assemblages

Objective 3 – Assess the impacts of Florida's LSAT assemblages on coral growth rates, photosynthetic activity and outplant survivorship

Rationale: LSAT is a pervasive threat to coral recovery across Florida reefs. Yet little is known about how LSAT interacts with coral recruits in the wild, and what the major drivers of outplant mortality are. By addressing how LSAT and other sedimentary and turf algal assemblages interact with outplants, we can identify habitat quality parameters that might be unaccounted for in restoration efforts.

1.4. Goal 4: Investigate the seasonality and range of invasive Caulerpa microphysa blooms in South Florida

Objective 4 – Assess how the densities and locations of *C. microphysa* proliferations change over the seasons in nearshore waters outside of Biscayne Bay.

Rationale: *C. microphysa* is an invasive, unicellular green algae capable of forming dense carpets on the benthos. Conditions created from these carpets can lead to physical smothering and potentially result in anoxic conditions which alter the biochemistry of the area in which they grow. Due to their chemical defenses, this species is not highly targeted by herbivory, furthering the potential damage they can impose. It is important to

monitor how widespread this invasive species blooms in order to get a measure of the health of coastal benthic systems, as well as potential environmental responses leading to and resulting from its growth.

2. METHODS

2.1. Settlement assays

We conducted larval settlement assays to assess the effect of sediments from different sources that possess different biogeochemical properties (e.g., port-derived vs. reef-derived sediments) on larval settlement rates. Settlement assays were conducted using larvae collected by NOAA's Southeast Fisheries Science Center (SEFSC) and Florida International University (FIU) during the summer of 2025 and spring of 2026 spawning windows at sites off Key Largo, Florida (**Figure 1**). The species that we collected were *Acropora palmata* (APAL; summer 2025), *Orbicella faveolata* (OFAV; summer 2025), *Pseudodiploria strigosa* (PSTR; summer 2025), and *Diploria labyrinthiformis* (DLAB; spring 2026). APAL gametes were collected from Elbow Reef, Key Largo, OFAV larvae were collected from North Dry Rocks, Key Largo, and DLAB gametes were collected from an unnamed inshore patch reef in Key Largo. PSTR larvae were obtained from the ex-situ nurseries of the University of Miami.

Our larval settlement assays tested up three different sediment burial treatments:

1) A small amount of sediment on the tile but not completely covering the settlement substrate (burial – sprinkle),
2) 2 mm of sediment on tile (burial – 2 mm),
3) 4 mm of sediment on tile (burial – 4 mm).

These burial treatments were paired with the following sediment presence treatments:

4) A small amount of sediment present in chamber but not on the tile (present – sprinkle),
5) 2 mm worth of sediment present in chamber but not on the tile (present – 2 mm),
6) 4 mm worth of sediment present in chamber but not on the tile (present – 4 mm),
7) control chambers that have no sediment introduced into the chamber.

Since live sediment is wet, we ensured that a consistent sediment-layer thickness was added across all sediment burial trials by estimating the volume required to achieve each layer (2 mm and 4 mm). We measured the dimensions for the sides of the tiles (3.8 x 3.8 cm) and multiplied them by the desired sediment layer height (0.2 and 0.4 cm) to calculate the volume required to achieve each sediment layer (in cm^3). We then 3D-printed scoops with the necessary dimensions to add the necessary volume of sediment to each treatment.

The previously-mentioned treatments (excluding controls) were crossed with sediment source (port-derived vs. reef-derived) for a total of 12 different treatments (plus a control)

for a single replicate. Each run consisted of five replicates per treatment (35 chambers), and we conducted four runs per species (140 chambers in total per species). This task was divided between our group at the Cooperative Institute for Marine and Atmospheric Studies (CIMAS) and our colleagues at FIU to achieve an ideal sample size.

Sediment collections were done the same day that each settlement assay was set up. We collected sediment from two ports in southeast Florida (Port Everglades and Port Miami) and sediment from a reef habitat adjacent to each port (Fort Lauderdale for Port Everglades and Emerald Reef for Port Miami; **Figure 1**) using a petite-Ponar sediment grab. Once sediments were collected, they were placed in mesh bags within individual coolers and taken back to shore.

Larval settlement assays were conducted in 6.35 cm diameter glass chambers (118 ml capacity). A single ceramic tile 3.8 x 3.8 x 0.5 cm (L x W x H) was placed in each chamber, which was filled with filtered and UV-sterilized seawater. Each chamber was assigned an experimental treatment in a random block design, allowing for up to five replicates of each treatment per species within a single experimental run. Thus, a single experimental run included up to 65 individual chambers per target species. Settlement chambers were placed in water baths with powerheads, heaters, and temperature probes to ensure constant temperatures were maintained. Additionally, a HOBO data logger was placed in each water bath to record water temperatures during each experimental run.

Sediment treatments were established prior to adding larvae to the settlement chambers. After establishing sediment treatments, each chamber received a set number of larvae based on larval sizes for each species: ACER = 10 larvae per chamber; OFAV = 20 larvae per chamber, DLAB = 15 larvae per chamber, PSTR = 15 larvae per chamber.

Larval settlement in each treatment was assessed using dissecting microscopes and royal-blue light after 72 hours to quantify settlement rates under each treatment. During the spring of 2026, along with the DLAB settlement assays, we measured daytime and nighttime DO concentration using a Unisense fx-5 UniAmp amplifier with amperometric oxygen sensors (100 µm in diameter). During the first 0–12 hours of the experiment for a subset of samples representative of each treatment to assess the baseline microbial activity of the sediment. During the last 12 hours of the settlement assays (hours 60–72), we re-measured the daytime and nighttime DO concentration for another subset of samples representative of each treatment to assess whether there were any changes in microbial activity during the experiment. DO was measured at 250 µm intervals across vertical profiles that spanned the last 2 mm of the bottom of the water column, 0–2 mm of the sediment matrix for the 2 mm treatments, and 0–4 mm of the sediment matrix for the 4 mm treatments.

2.2. Recruit burial assays

To evaluate the effect of sediment source and depth on the survivorship of young corals, we conducted sediment burial experiments using fragments of OFAV cut to sizes that approximate those of corals aged six months to 18 months of age (approximately 1 cm², 2.3 cm², and 4 cm² live tissue area, respectively). These fragments were cut from

established OFAV colonies from the 2019 spawning period (approx. 6 years old) that have been reared at NOAA's Southeast Fisheries Science Center. These colonies have been reared independently from the larvae used for the settlement assays specified in Goal 1. We constructed acrylic experimental chambers containing equal sized compartments, each sized to fit a single 3.8 x 3.8 x 0.5 cm (L x W x H) ceramic tile, with each tile containing a single coral fragment. A single tile was placed in each compartment, and one of the following sedimentation treatments:

(1) 2 mm of port-derived sediment covering the coral,
(2) 4 mm of port-derived sediment covering the coral,
(3) 2 mm of reef-derived sediment covering the coral
(4) 4 mm of reef-derived sediment covering the coral,
(5) controls that have no sediment present.

Before placing each fragment in its respective chamber, we photographed them beside a ruler to obtain the initial measure of live coral surface area (total live tissue area, mm^2). We also measured photosynthetic yield (Fv/Fm) using a pulse-amplitude modulated fluorometer (Diving PAM II). After collecting initial data, a single tile with a coral fragment was in each chamber compartment, and sedimentation treatments were established. At day 0 of the experiment, using oxygen sensors (100 μm in diameter), we measured daytime and nighttime DO concentration for a subset of samples representative of each treatment to assess the baseline microbial activity of the sediment. Twenty-five corals were placed in each experimental tank, with five sets of each treatment of the five previously-mentioned treatments. Six experimental tanks were set up to have 3 replicates per size class, sediment depth, and sediment source.

Individual experimental tanks were temperature-controlled, and an individual light source was used per tank to ensure consistent temperature and light availability across replicates. From each tank, a single experimental chamber for each treatment was removed at the following five time points: two days, four days, six days, eight days, and ten days after sediment burial. Before removing the corals at each time point, we measured daytime and nighttime DO concentration from a subset of samples representative of each treatment to assess changes in oxygen dynamics, as a proxy for microbial activity, at each time point of the experiment. After removing the sediment from each cell, corals were re-photographed to qualify overall survivorship (alive/dead) and to calculate live tissue area (cm^2) after sediment burial. We also re-measured Fv/Fm to quantify changes in photosynthetic yield due to sediment burial.

2.3. Coral outplant–LSAT interactions

At Paradise Reef, a site offshore of Key Biscayne (7 m deep; **Figure 2**), we identified LSAT-dominated habitats to outplant coral fragments of two different species (DLAB and OFAV), and two different size classes of each species (small: 1–4 cm^2 and large: 5–10 cm^2). All fragments for this experiment were housed and reared at our land-based nursery within the University of Miami's experimental hatchery in Virginia Key. At each LSAT-dominated habitat, we manipulated 40 x 40 cm plots to induce one of four different benthic assemblages:

1) bare substrate: any LSAT and benthic spaceholders will be scraped off to leave that area bare;
2) turf algae devoid of sediment: any sediment present within the algal turf matrix will be suctioned off with 60 mL syringes and the turf length (mm) at the time of outplanting will be measured;
3) loose sediment: sediment suctioned off from LSAT matrices will be placed over the cleared halo of bare substrate until a sediment layer 4 mm deep is achieved;
4) LSAT: established LSAT assemblages will be identified through measurements (minimum sediment depth: 3 mm; minimum turf length: 4 mm) and left untouched.

Ten replicates were established for each treatment, totaling 40 plots per site with four corals each (n = 160 corals). We tracked their growth rate (cm^2 day^{-1}), survivorship (dead/alive), and photosynthetic yield (Fv/Fm) across a timespan of four months. Each outplant and its surrounding 10-cm halo were photographed with an adjacent scale bar to conduct surface area measurements in the lab. Photosynthetic yield was measured for each one of them with the Diving PAM II.

2.4. *Caulerpa* surveys and DNA analysis

Ten sites along the southeastern coast of Florida where previous reports of *Caulerpa* spp., potentially *C. microphysa*, were chosen based off previous abundance reports for the species (**Figure 3**). These sites were visited twice, once in January and once in April. At each site, ten photographs are taken using Olympus Tough TG-7 cameras, with a 25cm x 25cm quadrant in frame for scale. If what is believed to be *Caulerpa microphysa* is present, close up images are taken of each sample with the 25cm x 25cm quadrant and an L-shaped ruler to give scale to the sample. The samples are then collected into Ziplock bags and labeled with whichever site the sample was collected from. All samples are then kept in a cooler until returning to dock at Florida International University's Biscayne Bay Campus, where they are then immediately processed.

Sample processing consists of carefully separating out each individual body of *Caulerpa* under a dissecting microscope. Once separated, any epiphytic growths are also carefully removed to ensure that the sample is as clean as possible for future molecular analysis. Each sample is closely inspected underneath the microscope to verify that the algae possess morphological features indicative of *Caulerpa microphysa* (i.e. small branchlets with constrictions where they attach to the stalk). Once morphological analysis was completed, samples were photographed with labels indicating site origin and L-shaped rulers for scale. Samples were then patted dry with paper towels and weighed, and 0.2g of samples from each site were gently wrapped and placed in small bags filled with silica gel to be sent off for molecular analysis.

Molecular analysis was conducted at the DNA Core Facility at Florida International University's Modesto A. Maidique Campus. The samples in the silica gel bags were dropped off then analyzed using PCR utilizing the tufA and rbcL primers for species identification. The sequences returned were further analyzed using BioEdit to clean the

sequences, and MEGA to create neighbor-joining trees using our sequences alongside other *Caulerpa* species found using AlgaeBase and the NCBI GenBank database.

3. RESULTS

3.1. Settlement assays

When sediment was present around the settlement substrate without covering it, *A. palmata* was the only species to exhibit a significant decrease in settlement probability as the adjacent sediment load increased ($p < 0.001$). Settlement probability for *A. palmata* decreased by 30% when 4 mm of either port or reef sediment were present. Indeed, there was no significant difference in settlement probability between port- and reef-derived sediment (**Figure 4**).

Burial of the settlement substrate had a much stronger effect on settlement probability, yet there still were no significant differences in settlement success between reef- and port-derived sediments (**Figure 4**). The species that were the most sensitive to sediment burial were *A. palmata* and *O. faveolata*. The predicted settlement probabilities for *A. palmata* and *O. faveolata* when no sediment was present were 72–86% and 54–71%, respectively, yet 2 mm of sediment, regardless of sediment source, decreased the probability to 3–6% for *A. palmata* and to 0–2% for *O. faveolata.* Four mm of sediment inhibited larval settlement entirely for both species (**Figure 4**). By contrast, *P. strigosa* was the species that best tolerated the burial of settlement substrate. Although its predicted settlement probability when no sediment was present was lower than the other species tested (baseline settlement probability = 42–52%), its predicted settlement probability remained at 19–26% under 2 mm of sediment and at 7–10% under 4 mm of sediment.

There was a general tendency for higher [DO] in reef-derived sediment than in port derived sediment, yet this trend was not consistent across all treatments and time intervals (**Figures 5 and 6**). However, there was a consistent trend of higher [DO] within reef sediment through time. After 72 hours, at 4 mm, daytime [DO] within reef sediment increased by 129% (22.6 ±9.9–51.8 ±10.9 μmol L^{-1}). By contrast, [DO] decreased through time within port sediment. After 72 hours, at 4 mm, daytime [DO] within port sediment decreased by 96% (120.0 ±0.0–4.73 ±0.7 μmol L^{-1}). Overall, reef sediment tended to have higher [DO] than port sediment.

Reef sediment also had higher [DO] than port sediment during the nighttime (**Figure 6**), and the range of recorded [DO] values were within the range of what we recorded during the daytime (lowest average nighttime [DO] at 4 mm = 9.0 ±3.7 μmol L^{-1}, highest nighttime [DO] at 4 mm = 51.6 ±10.2 μmol L^{-1}). At a depth of 2 mm, no treatment for any sediment source had [DO] below hypoxic conditions (≤62 μmol L^{-1}; as described in Breitburg et al. 2018; lowest recorded [DO] at 2 mm = 65.0 ±18.8, highest recorded [DO] at 2 mm = 177.0 ±9.45). By contrast, hypoxic conditions were prevalent at 4 mm, except

for the port sediments at day 0 during the daytime (lowest recorded [DO] at 4 mm = 4.73 0.708, highest recorded [DO] at 4 mm = 51.8 10.9).

3.2. Recruit burial assays

Although all of the *O. faveolata* fragments buried under sediment exhibited significantly lower survivorship than the controls (no sediment burial), there were no discernible differences between sediment depth nor sediment source treatments (**Figure 7**). One noticeable trend, however, was that smaller fragments started to die earlier in the 10-day timespan than larger fragments. For instance, we began to record mortality for 1 cm^2 fragments after four days of burial (**Figure 7a**), versus six and eight days of burial for 2.3 and 4 cm^2 fragments, respectively (**Figures 7b** and **7c**). Although survivorship was generally higher in reef sediment (25 ±18%) than port sediment (11 ±9%), exact hazard ratio magnitudes are uncertain because of high mortality across all treatments.

Overall, relative tissue loss was significantly higher for corals buried under sediment than the controls ($F_{2,257} = 11.303$, $p < 0.001$; **Figure 8**), but it was not significantly different between 2 and 4 mm (contrast 2 mm – 4 mm = 0.018, p = 0.248). Although tissue loss was generally higher for fragments buried under reef sediment during the first 2–4 days, the magnitude of tissue loss for fragments buried under port sediment "caught up to", or surpassed, the tissue loss experienced by corals under reef sediment in days 6–10. There was a significant increase in tissue loss for buried corals as burial duration increased ($F_{1,257} = 79.274$, $p < 0.0001$), and the most severe tissue losses occurred within 6–10 days, which is when most coral fragments lost 75–100% of their live tissue.

Photosynthetic yield exhibited trends similar to overall survivorship and tissue loss. Corals subjected to all treatments experienced a significant decline in photosynthetic yield 2–6 days after burial (**Figure 9**). Smaller fragments, however, were clearly more vulnerable than larger fragments. The photosynthetic yield of 1 cm^2 fragments decreased by 55% after just two days of burial under any treatment (2 or 4 mm, port or reef) and by 74% after four days. By contrast, 4 cm^2 fragments exhibited differential responses to different sediment depths. They were more vulnerable to all 4 mm treatments than the 2 mm ones, regardless of sediment source (reef 2mm – reef 4 mm = 1.0074, $p < 0.001$; contrast reef 2 mm – port 4 mm = 1.3489, $p < 0.0001$; reef 4 mm – port 2 mm = -0.9468, p = 0.001; port 2 mm – port 4 mm = 1.2883, $p < 0.0001$).

The sediment burying the corals exhibited variations in [DO] through time (**Figures 10** and **11**). The daytime profiles for both reef and port sediments reflect the development of a photosynthetic microbial community, which saturated the sediment porewater with oxygen ([DO porewater] > [DO water column]) within the first 2–3 mm (**Figure 10**). This signal is evident in sediment starting at day 2, and within port sediment at day 4. Unlike the reef sediment, however, the photosynthetic microbial community did not persist within port sediment, as sediment porewater for these treatments was no longer O_2-saturated by day 6. Overall, reef sediment tended to have higher [DO] than port sediment, and the difference in [DO] between sediment sources increased through time.

By day 10, at a depth of 4 mm, [DO] was at 170.0 ±13.4 and 49.6 ±25.4 μmol L^{-1} for reef and port sediment, respectively.

Reef sediment also had higher [DO] than port sediment during the nighttime (**Figure 11**). Unlike the daytime readings, however, the difference between sediment sources was higher at earlier time points and the magnitude of this difference decreased at later time points. Both experienced hypoxic conditions (≤62 μmol L^{-1}; as described in Breitburg et al. 2018) below the first 2–3 mm across all time intervals. Anoxic conditions at 4 mm were more prevalent in days 6–10 for both sediment sources.

3.3. Coral outplant–LSAT interactions

There were no significant differences in changes of relative surface area among treatments ($F_{3,144} = 0.521$, $p = 0.668$), yet there were significant differences among species ($F_{1,144} = 9.126$, $p < 0.01$) and size classes ($F_{1,144} = 39.478$, $p < 0.0001$; **Figure 12**). Small (1–4 cm^2) *O. faveolata* outplants had the highest mortality and rates of partial tissue loss across all treatments. In the sediment treatment, all small *O. faveolata* died from burial. Among the other treatments, most fragments suffered tissue loss from predation. On average across all treatments, small *O. faveolata* experienced relative tissue losses of 87 ±5%. By contrast, small *D. labyrinthiformis* outplants experienced relative tissue losses of 25 ±8% on average across all treatments. There was high variation within the relative surface area trends of large (5–10 cm) outplants for both species. Overall, they exhibited limited gains in live tissue area by 8 ±20% (*O. faveolata*) and 9 ±5% (*D. labyrinthiformis*). There were no discernible differences in photosynthetic yield among treatments or species (**Figures 13 and 14**). Dark Fv/Fm values increased by 68% (average Fv/Fm month 0 = 0.315 ±0.008, average Fv/Fm month 2 = 0.547 ±0.009) two months after they were initially outplanted. Similarly, light Fv/Fm values increased by 36% (average Fv/Fm month 0 = 0.277 ±0.025, average Fv/Fm month 3 = 0.378 ±0.009) two months after they were initially outplanted.

3.4. Caulerpa surveys and DNA analysis

Of the ten sites visited, five of them had *C. microphysa*. The visit in January had *C. microphysa* in Site 5 and Site 7, and the visit in April found the algae in Site 4, Site 9, and Site 10. The samples were confirmed to fall within the *C. lentillifera* clade based on the molecular analysis completed at the DNA Core Facility at Florida International University's Modesto A. Maidique Campus (**Figure 15**). Current taxonomic treatment of *C. microphysa* and *C. lentillifera* classifies the two as synonymous to one another, therefore their sequences are intermixed. The neighbor-joining tree made using all samples as well as other *Caulerpa* species places all Floridian samples together, forming a single, highly supported monophyletic clade with most of the collected samples being genetically identical to one another.

4. DISCUSSION

This study solidifies our findings from previous years: sediment burial is an effective suppressor of larval settlement, and it can quickly kill coral recruits. The critical sediment depths for larval settlement are similar to what we have seen with sterilized sediments: 2 mm of sediment can decrease settlement probability by 50–90%, and 4 mm can suppress it entirely. The lack of variation between port and reef-derived sediment, and the consistency of the trends exhibited by live and sterilized sediment, suggest that biogeochemical sedimentary processes may not impact larval settlement as much as the physical sedimentary processes. This inference is especially evident when we examine the settlement assays that test the response of larval settlement to the presence of sediment around the tiles: only one species had a significant response to sediment presence, and settlement probability decreased by 30% when 4 mm were present, which is in stark contrast to the response of settlement when 4 mm of sediment bury the substrate: settlement probability plummets to zero. Another trend that was consistent with previous trials was the high susceptibility of *A. palmata* and *O. faveolata*. Both species have historically been the major reef-building taxa along Florida's coral reefs, and many restoration efforts are prioritizing their recovery, since they are also listed as "threatened" under the Endangered Species Act (National Marine Fisheries Service 2006 and 2014). Therefore, the successful recovery of these reef-building species relies on the proper management and mitigation of sedimentary stressors to maximize habitat quality and the success of future restoration efforts along with the natural recovery of wild populations.

Incorporating live sediment into the recruit burial assays revealed that coral recruits were equally susceptible to 2 and 4 mm of sediment, which differs to previous trials done with sterilized sediment, where there were clear differences in susceptibility among sediment loads (Rodriguez-Ruano et al. *In Prep*). The increased susceptibility of coral recruits to 2 mm of live sediment, compared to 2 mm of sterilized sediment from previous trials, suggests that live sediment, regardless of the source, is more detrimental to coral survival than sterilized sediment. Therefore, biogeochemical processes, driven by microbes living within the sedimentary porewater, might further decrease the critical sediment depth required to kill juvenile corals from 4 to 2 mm. Trends in DO further corroborate this inference. At sediment depths between 2 and 3 mm [DO] concentrations within the sediment porewater were hypoxic during the nighttime throughout the entire duration of the study. Indeed, hypoxia has been previously reported as a major stressor for adult coral colonies that can cause widespread mortality (Altieri et al. 2017).

The recruit sediment burial assays with live sediment also revealed that the time that a coral recruit spends buried under sediment and its size are critical factors that influence the lethal and sublethal effects of sediment. Mortality of the smallest fragments (1 cm^2) began to occur after four days of burial, and mortality of the largest fragments, which represent the upper size limit that defines a coral recruit/juvenile (4 cm^2), began to occur 8 days after sediment burial. Yet the sublethal effects of sediment burial were detected just after two days of burial in the form of drastic decreases in their photosynthetic yield. These trends provide essential information for managing future coastal development projects that may impact adjacent coral populations. By assessing the abundance of

juvenile corals within areas projected for coastal development (port dredging, beach renourishment, etc.) along with the projected sediment load, managers can estimate the ideal timing and duration of operations and predict the impacts of such operations in those areas.

LSAT influence on established recruits is still unclear. Our study suggests that other factors, such as predation, seem to overwhelm the effects of LSAT on the growth and survivorship of outplants. With the data collected up to date, it seems as if larger outplants (5–10 cm^2) are able to withstand predation, yet the time scale is probably still too short to completely unveil the contribution of LSAT and other turf–sedimentary assemblages on their future growth and survivorship. Therefore, future studies should focus on addressing these interactions along a larger time scale (6–12 months), while addressing other important factors that influence sediment accumulation and LSAT development such as rugosity, slope, water flow, and seasonality.

Regarding *Caulerpa*, more visits over the seasons will be needed to evaluate the changes at the ten survey locations in order to validate seasonality as a driver of varying densities and range. As for the samples that were analyzed, the tree indicates that the samples have extremely low intraspecific divergence, which is consistent with intraspecific variation within *C. lentillifera*. These results are important to consider due to *C. lentillifera* traditionally being considered as an Indo-Pacific species, of which is an invasive species now seen in the Caribbean Sea potentially altering current ecosystem function. Future studies should investigate other potential drivers of *C. microphysa* or *C. lentillifera* blooms in South Floridian waters, such as nutrient analyses.

Management recommendations

Our results indicate that the physical burial of suitable substrate and of established corals under 2 mm of sediment, regardless of the sediment source, can inhibit larval settlement and kill juvenile corals. More importantly, the main bottleneck to recruit survivorship is the time that corals remain buried along with their size. Burial under 2–4 mm of sediment for four days or more significantly increases the likelihood of coral mortality for the smallest individuals, and the risk increases for larger individuals as the burial duration increases. Therefore, future coastal development projects that produce sediment plumes as a byproduct should minimize the duration of sediment-producing activities as much as possible to ensure the survival and recovery of coral populations adjacent to the affected area. Additionally, the timing at which coastal development projects are conducted is crucial to mitigate coral mortality and maximize the settlement of new recruits. Most corals in Florida spawn in the spring and summer months (April–October), and larvae are actively settling within this period. To ensure that those larvae are able to settle and grow into established coral recruits, it is important to avoid any activities that may increase the sediment loads on reefs during this time period.

Our previous research also highlights that the sediment loads we have tested in our laboratory experiments (2–4 mm of sediment) are already prevalent across Florida's coral reefs in the form of LSAT (Guzman et al. 2026). Thus to ensure the region-wide recovery of coral populations, action should also be taken to improve reef-habitat quality

throughout the region. This includes managing larger scale disturbances such as reducing sedimentary inputs from coastal runoff, and mitigating coral mortality from other disturbances such as disease and thermal stress events to preserve live coral cover and avoid the subsequent erosion of our reef framework.

5. LIST OF FIGURES

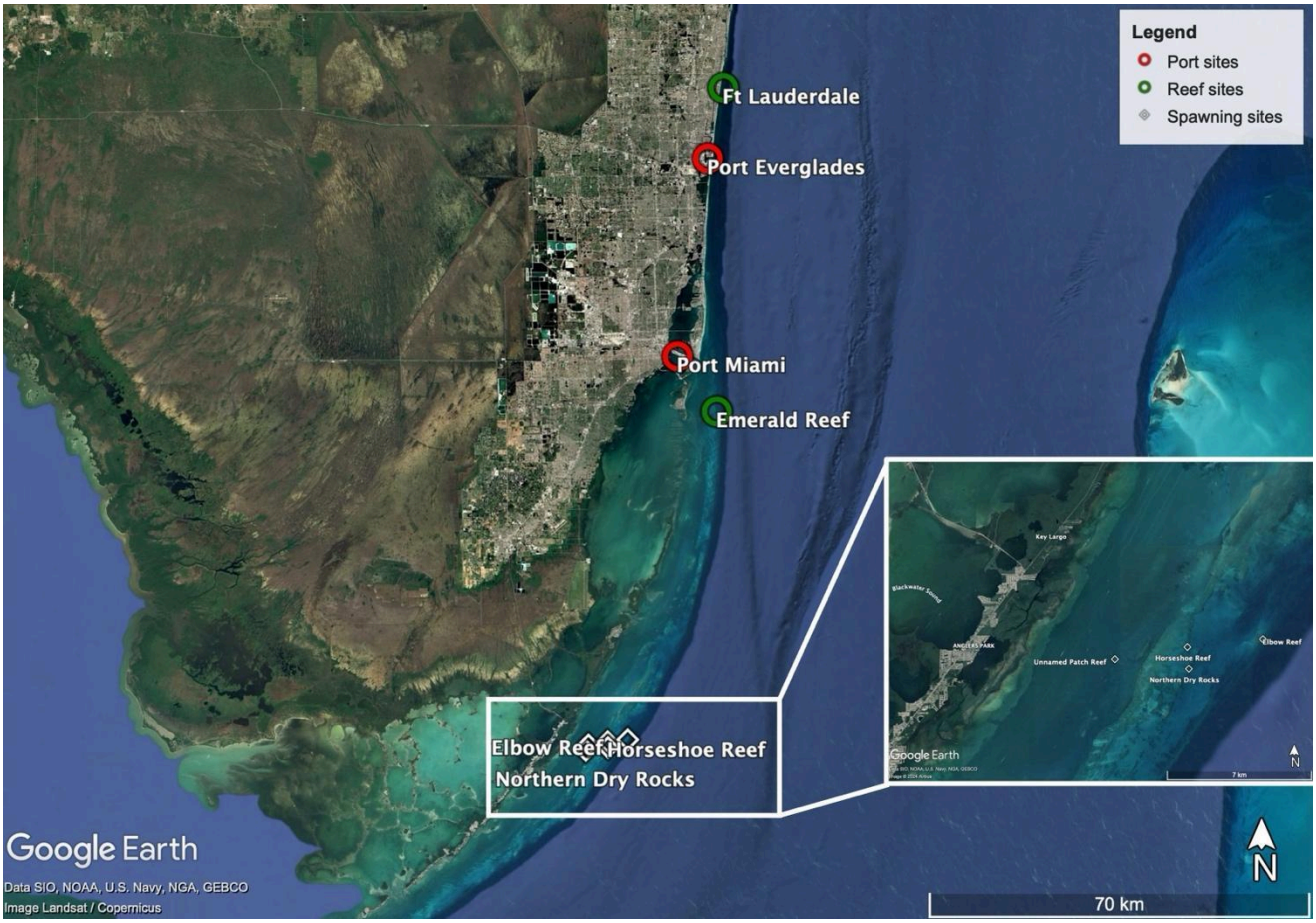

Figure 1: Map of South Florida with an inset along Key Largo depicting the location of sites that were monitored for coral spawning activity (four white diamonds), and sites from which port-derived (red circles) and reef-derived (green circles) sediments were collected for settlement and recruit burial assays.

Figure 2: Map of Miami and the northern end of Biscayne Bay depicting Paradise Reef, the site where we conducted in situ survivorship and growth experiments on outplanted coral colonies exposed to different sedimentary and algal turf assemblages. The green circle represent Paradise Reef proper, and the blue diamond represents the location of NOAA's Southeast Fisheries Science Center, the facility from which our CIMAS team operates.

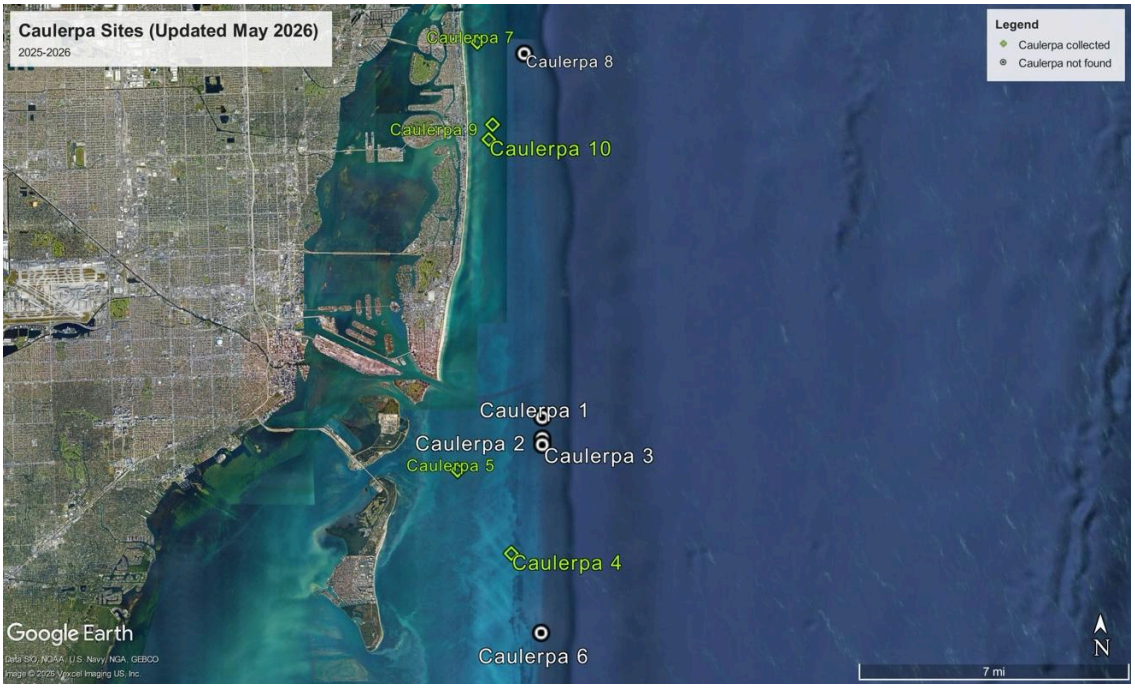

Figure 3: Map of Miami and the northern end of Biscayne Bay depicting the sites that were surveyed for *Caulerpa* spp. presence. The sites with green diamonds and labels represent sites were *Caulerpa* spp. was found and collected. Sites with white diamonds and labels represent sites were *Caulerpa* spp. was not found.

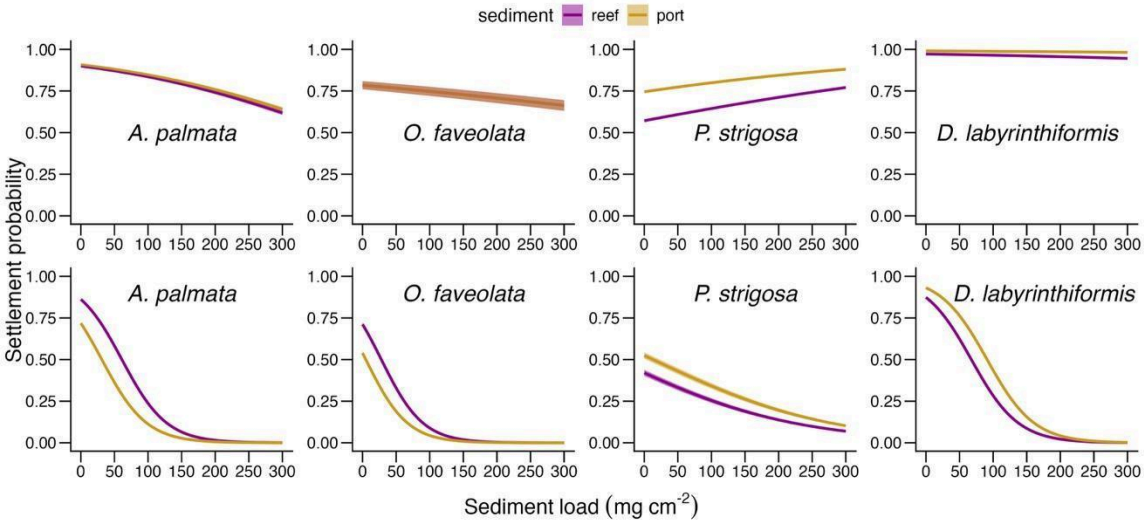

Figure 4: The color-coded curves depict the best-fit curves of logistic generalized mixed-effects models that predict the probability of settlement for each species tested across the sedimentary gradient for each sediment source. The shaded areas represent the 95% confidence intervals of the models. Plots on the top row depict the results for treatments with sediment around the tiles without burying them, and plots on the bottom row depict the results for treatments with sediment on top of the tiles (burying them).

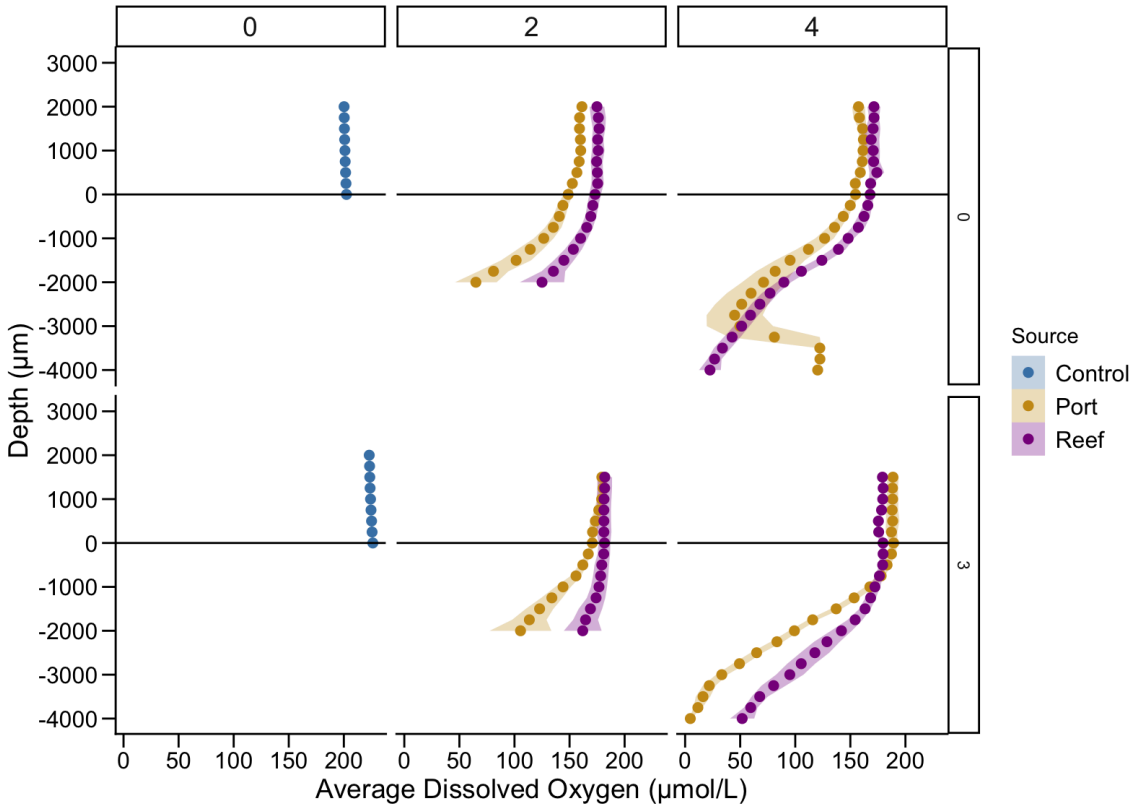

Figure 5: Daytime vertical profiles of [DO] (µmol L^{-1}) within the first 6 mm of the sediment-water interface for port- and reef-sediment matrices that were covering ceramic tiles for larval settlement for 3 days. Numbers labeling the columns represent the sediment depth treatments in mm, while numbers labeling the rows represent the sampling time in days. Each dot represents the mean [DO] at the respective depth (µm) and the shaded area represents the ±standard error. The horizontal line at depth = 0 represents the sediment surface, and negative depth values represent measurements done within the sediment porewater, while positive depth values represent measurements done within the water column.

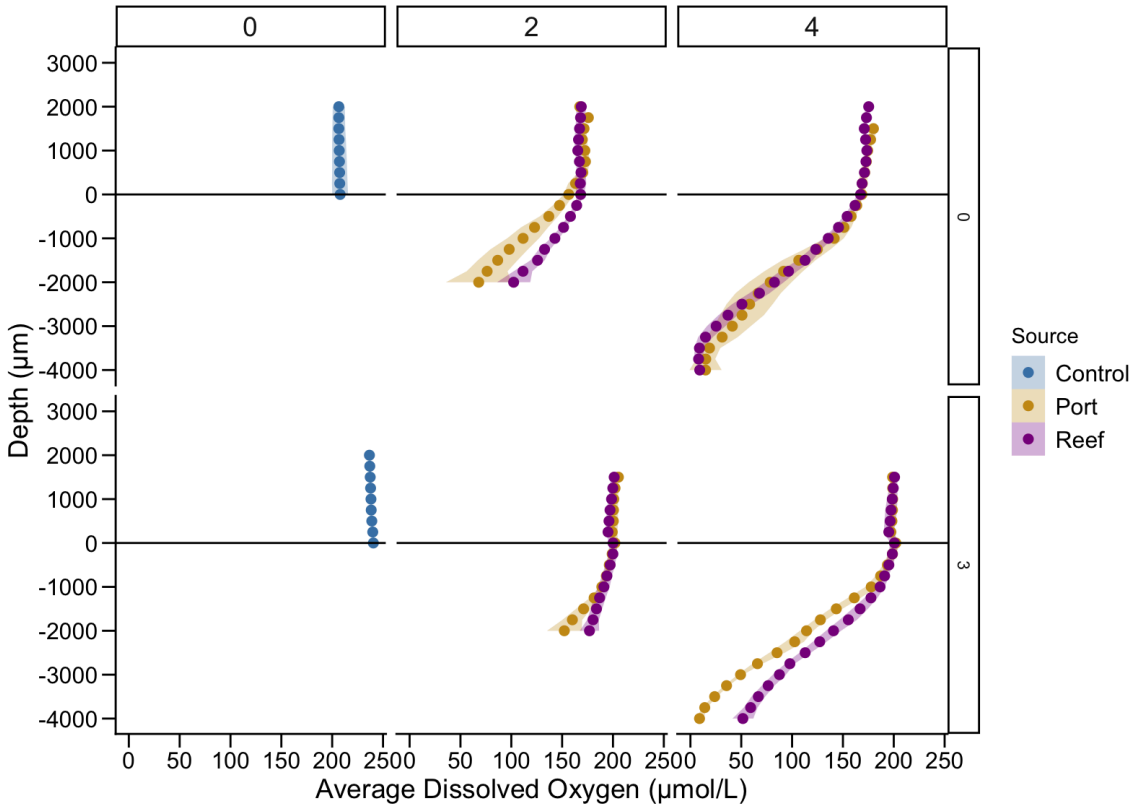

Figure 6: Nighttime vertical profiles of [DO] (µmol L^{-1}) within the first 6 mm of the sediment-water interface for port- and reef-sediment matrices that were covering ceramic tiles for larval settlement for 3 days. Numbers labeling the columns represent the sediment depth treatments in mm, while numbers labeling the rows represent the sampling time in days. Each dot represents the mean [DO] at the respective depth (µm) and the shaded area represents the ±standard error. The horizontal line at depth = 0 represents the sediment surface, and negative depth values represent measurements done within the sediment porewater, while positive depth values represent measurements done within the water column.

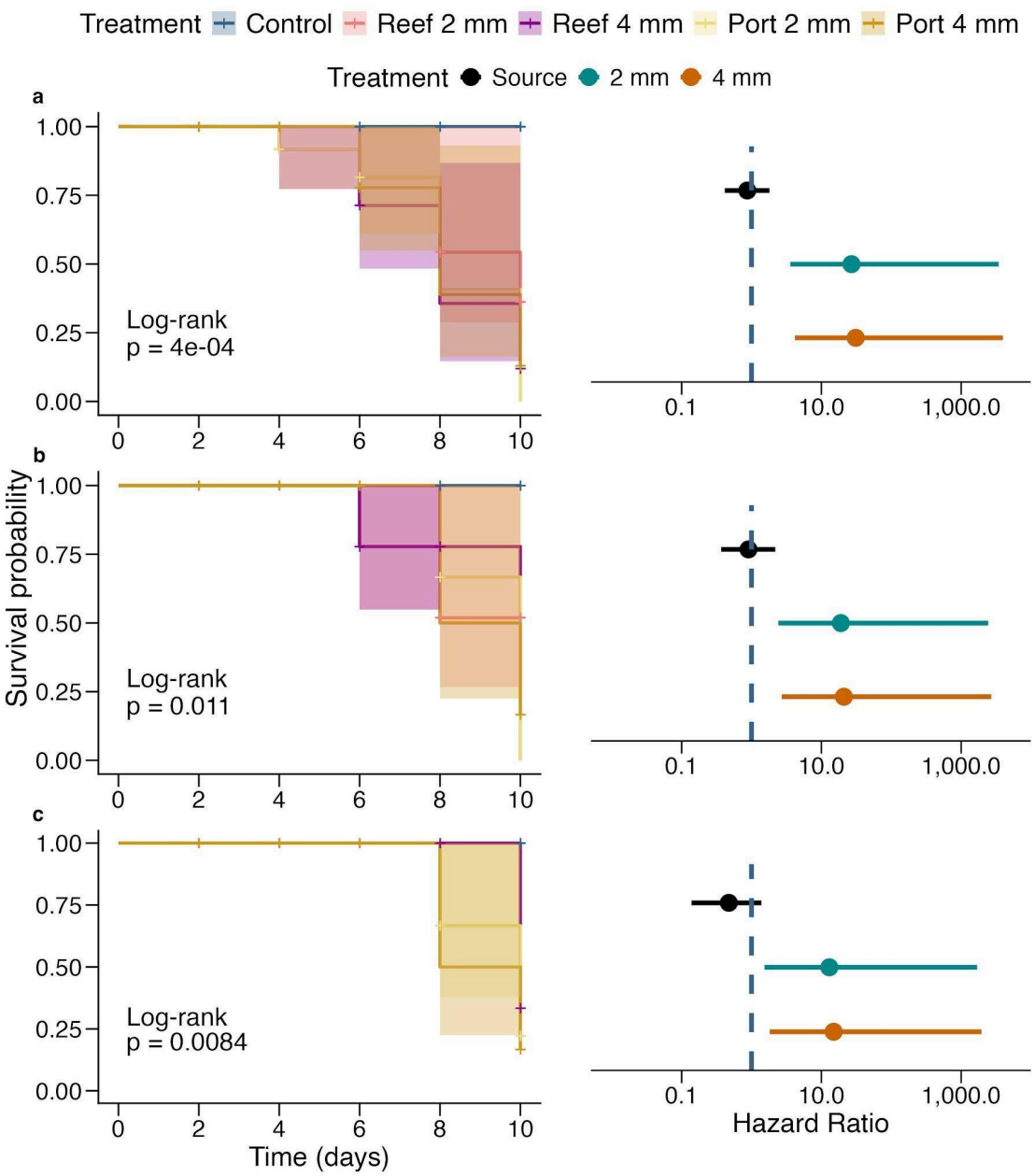

Figure 7: Survival trends of *O. faveolata* fragments **a** 1, **b** 2.3, and **c** 4 cm^2 in size under sediment burial treatments across a timespan of 10 days. Kaplan-Meier curves (left) and forest plots (right) depict survival trends. Kaplan-Meier curves (left) depict recorded mortality events through time and forest plots depict the time-independent hazard ratios calculated by the Firth-penalized Cox regressions for sediment source and each sediment depth treatment (2 and 4 mm). The dotted vertical lines represent a hazard ratio of 1. Any hazard ratio greater than 1 indicates increased mortality risk under the respective treatment. The error bars depict the 95% CIs of the hazard ratios, which, if greater than 1, indicate a significant ($p < 0.05$) hazard of that experimental treatment relative to the control treatment (no sediment burial).

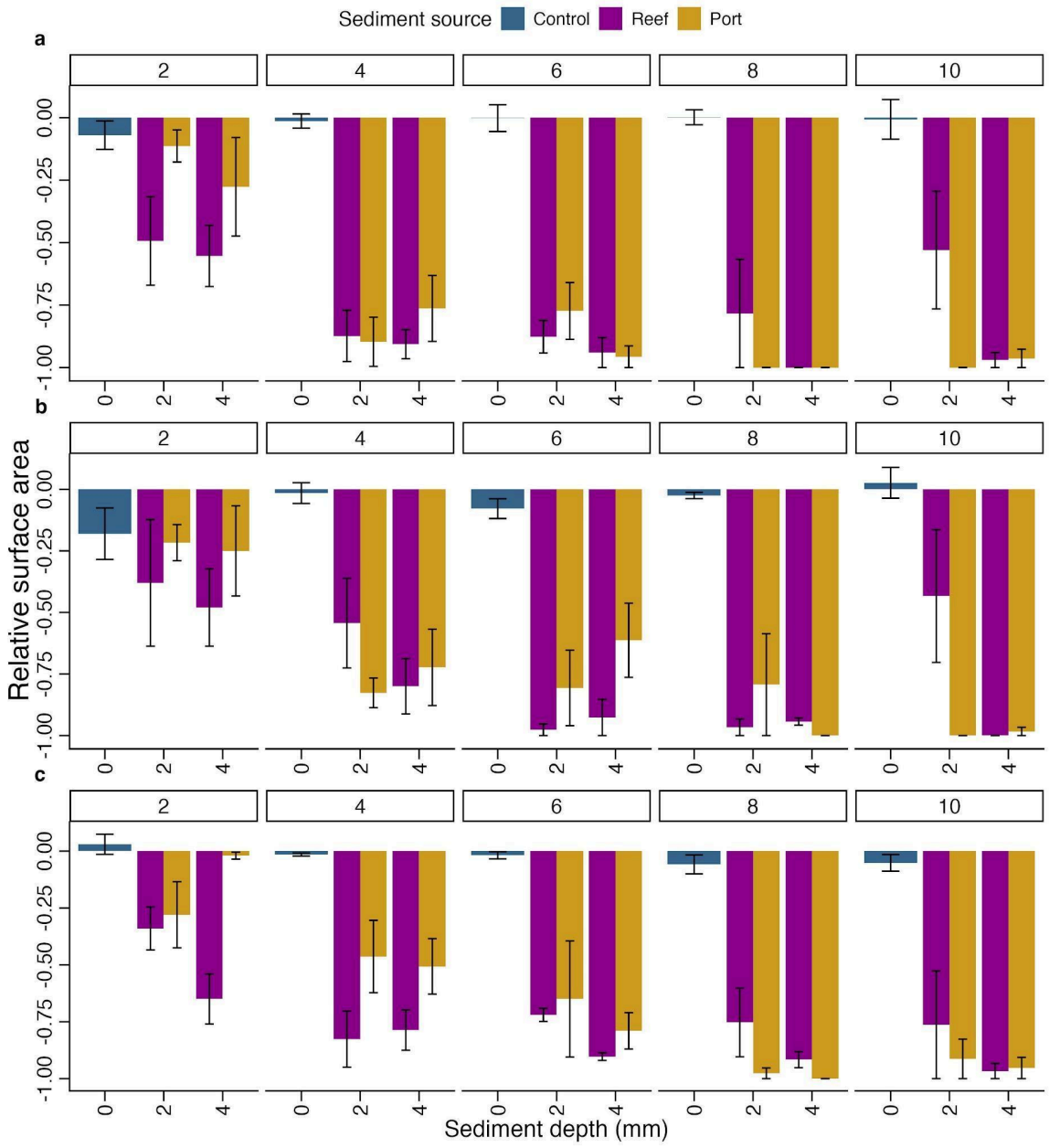

Figure 8: Bar plots depicting mean (±standard error) relative surface area of tissue lost for **a** 1, **b** 2.3, and **c** 4 cm^2 *O. faveolata* fragments that were buried under port or reef sediment under different time spans (columns; 2–10 days). Relative surface area is standardized by dividing the final surface area by the initial surface area of each fragment. Negative values reflect net tissue loss and positive values indicate net tissue gain at the end of the experiment.

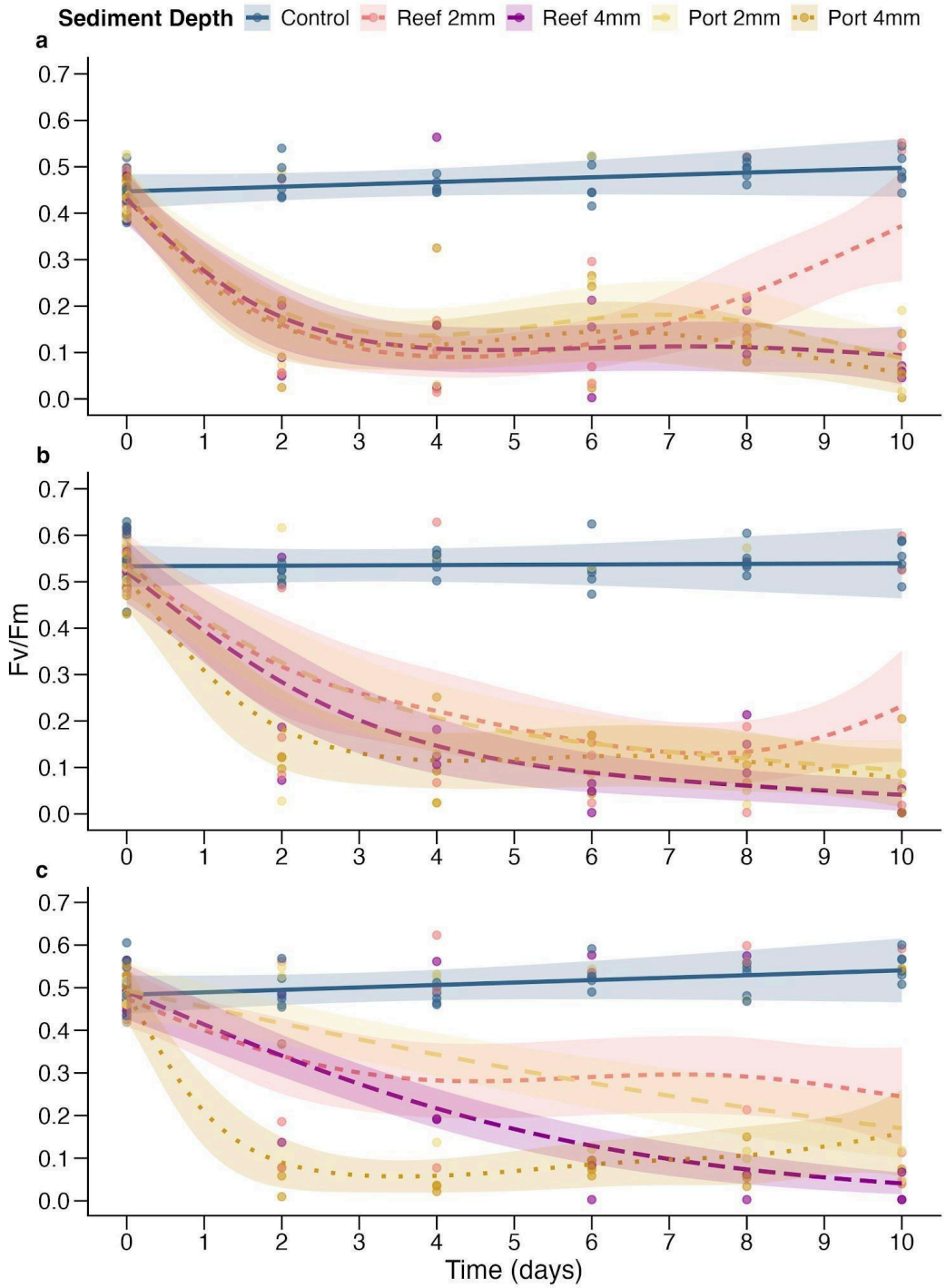

Figure 9: Scatter plots depicting trends in the photosynthetic yield (Fv/Fm) of **a** 1, **b** 2.3, and **c** 4 cm^2 *O. faveolata* fragments buried under 2 and 4 mm of port and reef sediment for up to 10 days. Trend lines were fitted using generalized additive models (GAMs) with a beta error distribution and logit link function.

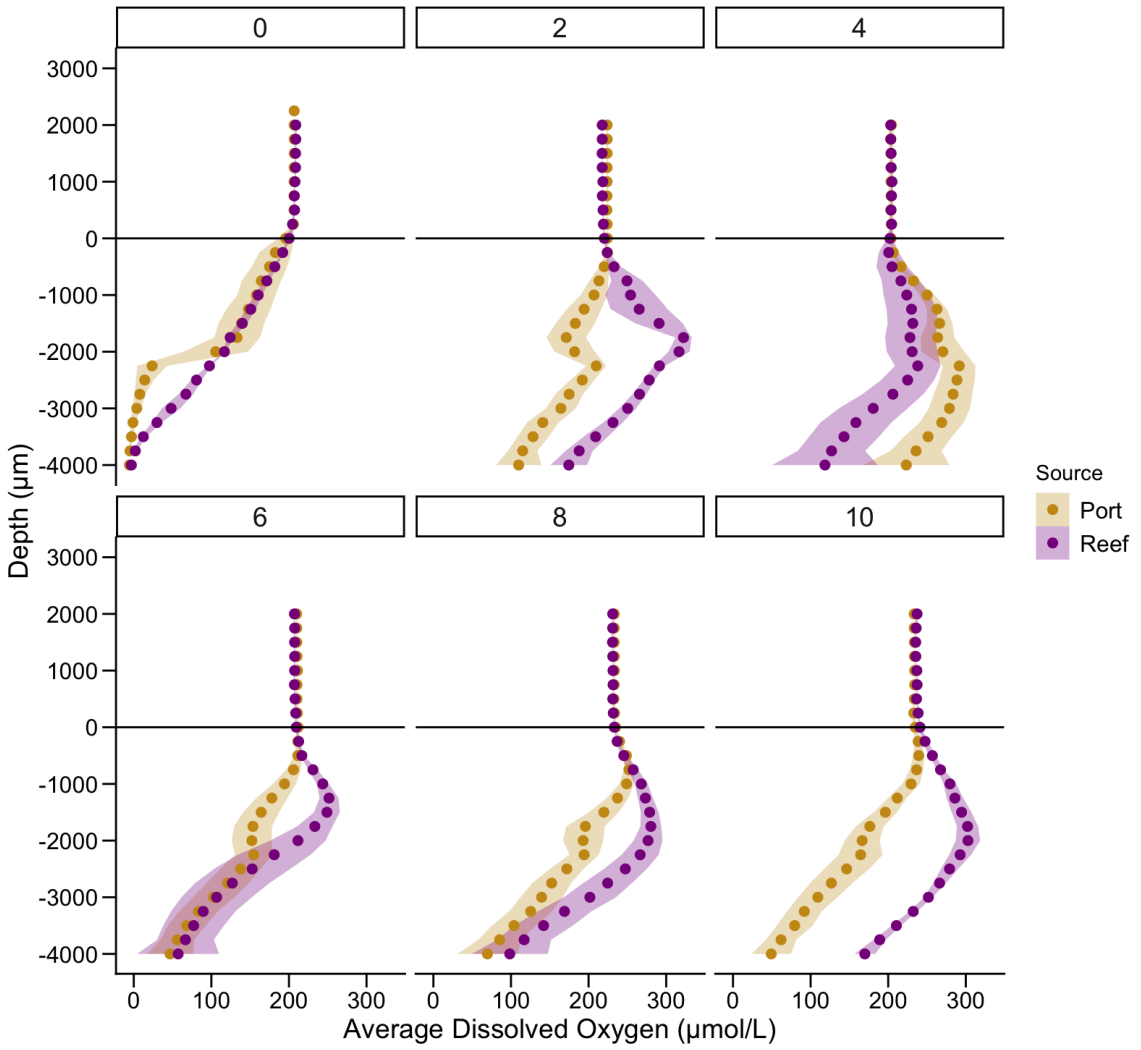

Figure 10: Daytime vertical profiles of [DO] (µmol L^{-1}) within the first 6 mm of the sediment-water interface for port- and reef-sediment matrices that were covering *O. faveolata* fragments for 2–10 days. Each dot represents the mean [DO] at the respective depth (µm) and the shaded area represents the ±standard error. The horizontal line at depth = 0 represents the sediment surface, and negative depth values represent measurements done within the sediment porewater, while positive depth values represent measurements done within the water column.

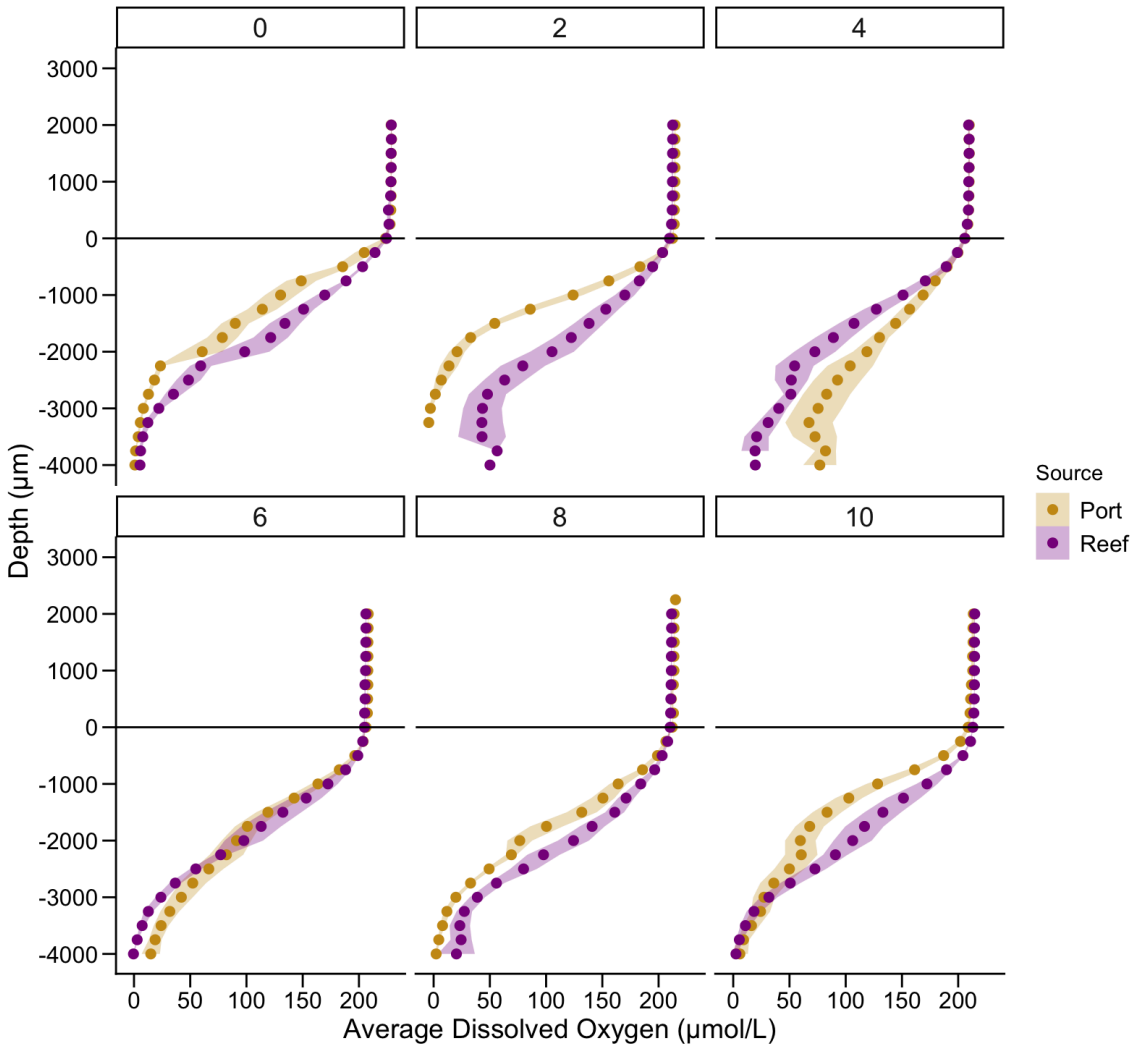

Figure 11: Nighttime vertical profiles of [DO] (µmol L^{-1}) within the first 6 mm of the sediment-water interface for port- and reef-sediment matrices that were covering *O. faveolata* fragments for 2–10 days. Each dot represents the mean [DO] at the respective depth (µm) and the shaded area represents the ±standard error. The horizontal line at depth = 0 represents the sediment surface, and negative depth values represent measurements done within the sediment porewater, while positive depth values represent measurements done within the water column.

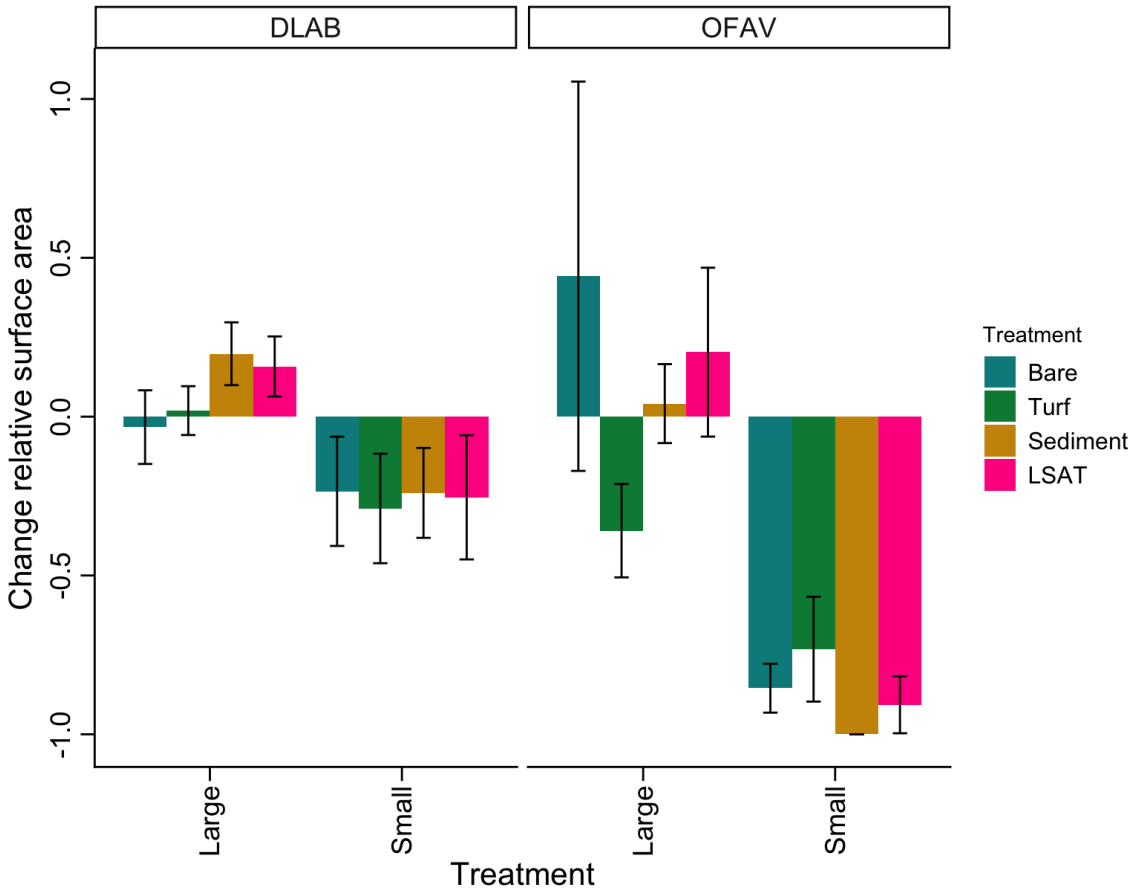

Figure 12: Bar plots depicting mean (±standard error) relative surface area of live tissue for *D. labyrinthiformis* (DLAB) and *O. faveolata* (OFAV) fragments of different sizes (small: 1–4 cm^2, large: 5–10 cm^2) that were outplanted onto plots with different benthic assemblages (Treatment). Relative surface area is standardized by dividing the final surface area by the initial surface area of each fragment. Negative values reflect net tissue loss and positive values indicate net tissue gain at the end of the experiment.

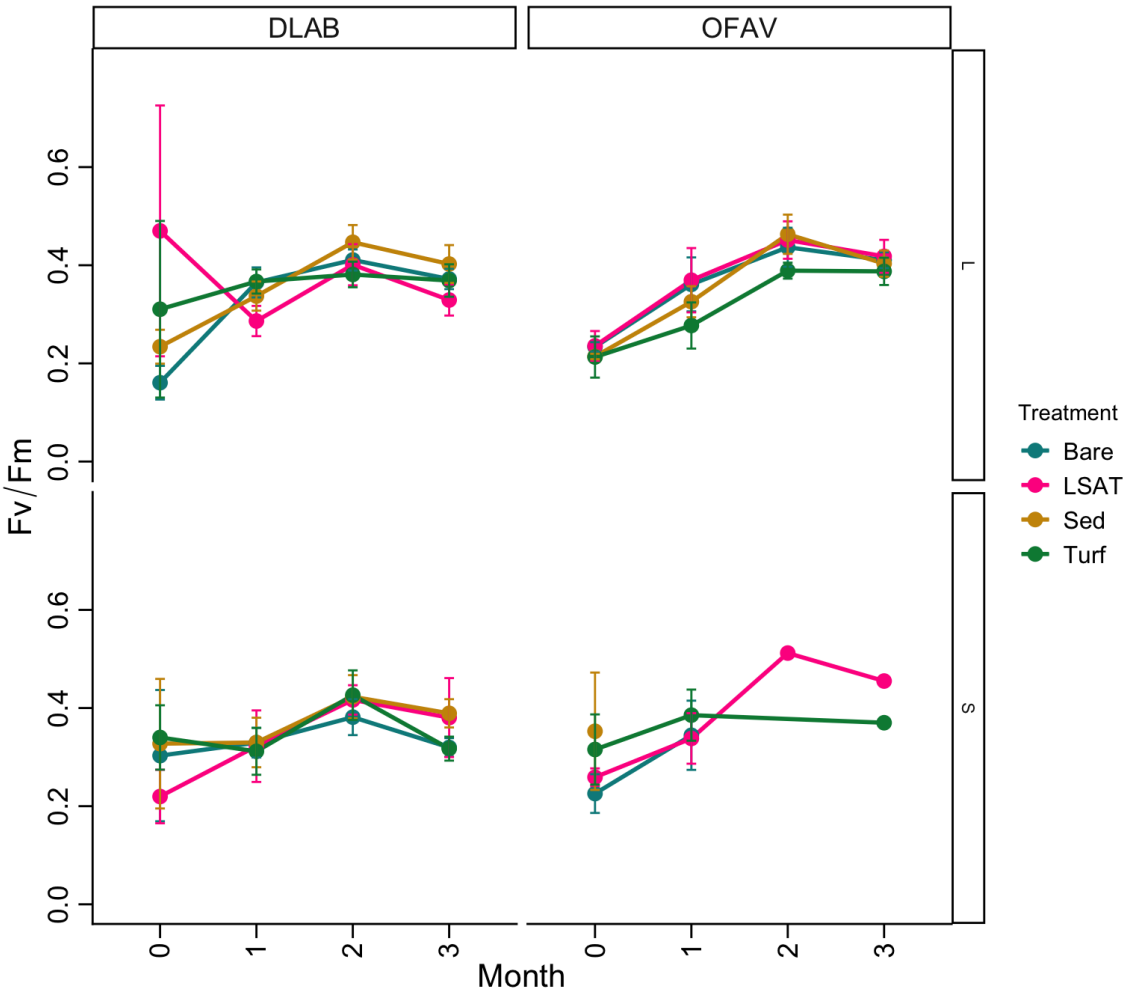

Figure 13: Line plots depicting variations in light measurements of photosynthetic yield (Fv/Fm) for corals outplanted onto different benthic assemblages (Treatment) in Paradise Reef. DLAB = *D. labyrinthiformis*, OFAV = *O. faveolata*. S = small (1–4 cm^2), L = large (5–10 cm^2).

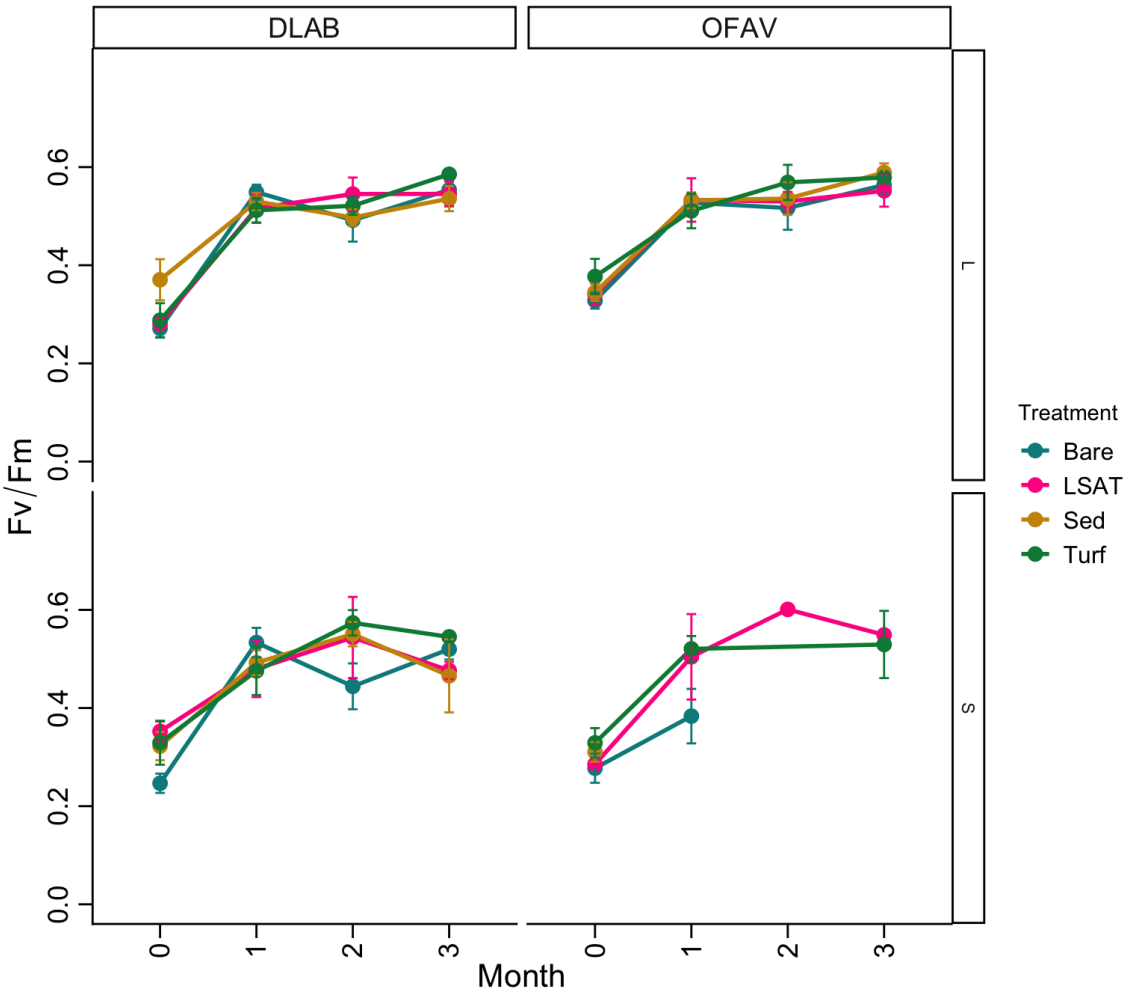

Figure 14: Line plots depicting variations in dark-adapted measurements of photosynthetic yield (Fv/Fm) for corals outplanted onto different benthic assemblages (Treatment) in Paradise Reef. DLAB = *D. labyrinthiformis*, OFAV = *O. faveolata*. S = small (1–4 cm^2), L = large (5–10 cm^2).

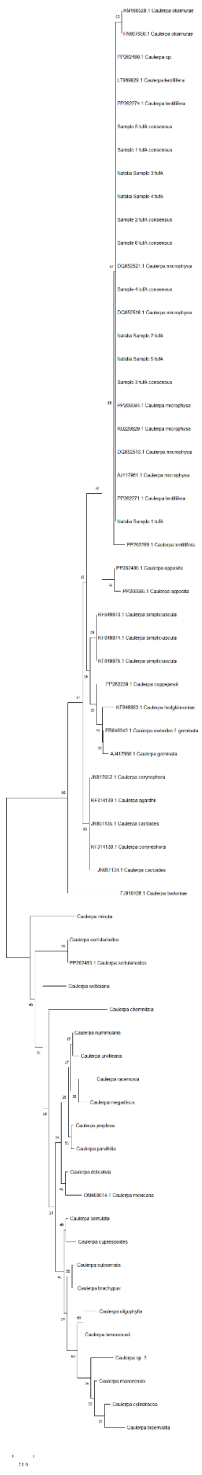

Figure 15: Neighbor-joining phylogenetic tree of *Caulerpa* spp. based on **tufA** sequences. Reference sequences from GenBank are identified by their accession numbers, and sequences generated in this study are labeled as consensus sequences.

6. REFERENCES

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