

Assessment of Remediation Methods Using Macrophyte and Fish Indicators in Manmade
Canals within the Florida Keys National Marine Sanctuary

Preliminary Report

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Project Summary

Many residential canals in the Florida Keys are showing the typical symptoms of unhealthy, eutrophic water including anoxia, low water clarity, and increasing hydrogen sulfide that have resulted in waters unsuitable for swimming and much sea life. To remediate these canals, Monroe County has approved the installation of multiple types of remediation technologies to determine the most feasible option for larger-scale remediation efforts. This project will assess the effectiveness of these remediation technologies by comparing post-remediation canals with their respective, unaltered controls for a period of at least three years. The effectiveness of remediation technology will be determined by using organismal indicators including seagrass, macroalgae, and fish that are established proxies for water quality. Surveys of indicator species are further supported by changes in sediment and plant tissue nutrient content between experimental and control canals. The local government as well as many individual citizens of Monroe County await cost-effective, viable solutions to improve water quality within their residential waters as well as the adjacent waters within in the Florida Keys National Sanctuary.

The Seagrass Ecosystems Research Laboratory at Florida International University has been sampling the project canals since Spring 2014 in order to 1) establish baseline characteristics (floral, faunal, and sediment composition) within residential canals and adjacent waters, and 2) document changes resulting from restoration technologies. Unfortunately, only three of the 10 technologies have been installed by our last survey in Fall 2015. We are beginning to document the results of the restoration effects, however the delayed installation of remediation technologies require monitoring efforts to be extended if improvements are to be documented. The effects of the largest remediation effort, the backfilling of a deep canal, were clear and immediate. The canal with an installed culvert saw initial, positive changes in ecological and biogeochemical characteristics, though political problems have led to the temporary closure of the culvert. The canal with an installed weed gate showed no improvement compared to baseline data or its experimental control, though this technology is likely to be gradual in effect.

Demonstration canals included in survey

A total of 19 canals are included in the Quality Monitoring Project for Demonstration of Canal Remediation Methods. For 18 of the 19 canals involved in the monitoring project, there is a designated experimental control of an adjacent canal of similar dimensions and orientation. The list of canals along with their location and designated technological remediation method follows:

Table 1. Demonstration Canals monitored for the Water Quality Remediation Project. Canals with experimental remediation techniques are in Gray

Canal	Location		Key	Technology
	Longitude	Latitude		
29	-80.3856793	25.16392268	Largo	Backfilling
28	-80.38565392	25.16462222	Largo	Control for 29
137	-80.57215639	24.95358079	Plantation	Weed Gate
132	-80.56543265	24.9572583	Plantation	Control for 137
148	-80.70313681	24.86822581	Lower Matacumbe	Weed Gate
147	-80.70165738	24.87021255	Lower Matacumbe	Control for 148
266	-81.34821282	24.69879375	Big Pine	Organic Removal + Weed Gate
263	-81.34842801	24.69951073	Big Pine	Control for 266
277	-81.35618775	24.69158936	Big Pine	Culvert
282	-81.35288376	24.68450542	Big Pine	Control for 277
278	-81.37795957	24.68420154	Big Pine	Pumping
287	-81.3449099	24.67704471	Big Pine	Air curtain
288	-81.34374123	24.67627006	Big Pine	Control for 287
290	-81.34186039	24.67503877	Big Pine	Organic Removal
293	-81.34135	24.67440955	Big Pine	Control for 290
459	-81.64902293	24.58431936	Geiger	Culvert
458	-81.64875699	24.58507307	Geiger	Control for 459
472	-81.65469881	24.57785369	Geiger	Culvert
476	-81.65691932	24.57639818	Geiger	Control for 472

Timeline of remediation technology installation

As of December 2015, only three of the 10 planned remediation technologies have been installed in the experimental canals:

Canal 137 (24°57'18.52"N, 80°34'21.43"W), Plantation Key. A weed gate was installed across the mouth of the canal intended to prevent input of wrack. Construction ended on November 2014.

Canal 29 (25° 9'50.08"N, 80°23'5.18"W), Key Largo. This canal was backfilled with inert, carbonate sand to a standard depth of ~5 ft. Construction ended on July 2015

Canal 472 (24°34'43.17"N, 81°39'17.11"W), Geiger Key. A culvert was installed in the rear of the canal, allowing water to flow through the canal to linked bodies

of water. Construction ended on May 2015 though the culvert was closed shortly after due to complaints from local residents.

Timeline of Monitoring

Sampling was planned to occur three times per year Winter (January), Spring (May), and Fall (September-October), however due to permit-related delays in technology installation, the sampling schedule was altered. Initial monitoring and sample collection was completed in May 2014. Subsequent sampling was conducted in January 2015, May 2015 and October 2015.

Baseline Results

Canals involved in this project were chosen for their subpar conditions with initial surveys in 2013 indicating low dissolved oxygen and water clarity. Baseline surveys within canals (Spring 2014) show a lack of benthic flora beyond the mouth in almost all project canals (the exception being canals 458, 459, and 278). Unlike the sandy sediments of Florida Bay, canal sediments are light (Figure 1) and have a high percentage of organic matter with two to five times the organic carbon content of adjacent bay (Figure 2).

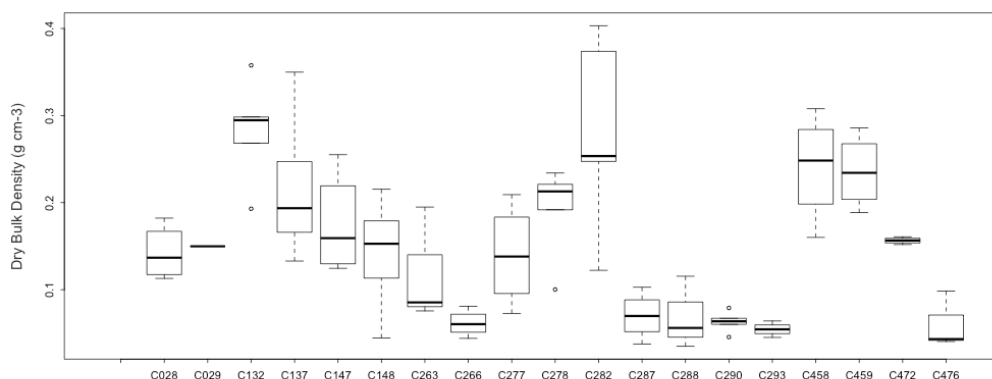


Figure 1. Bulk Densities of canal sediments during baseline surveys (Spring 2014). Seagrasses in South Florida have not been reported in sediment densities less than 0.24 g cm⁻¹.

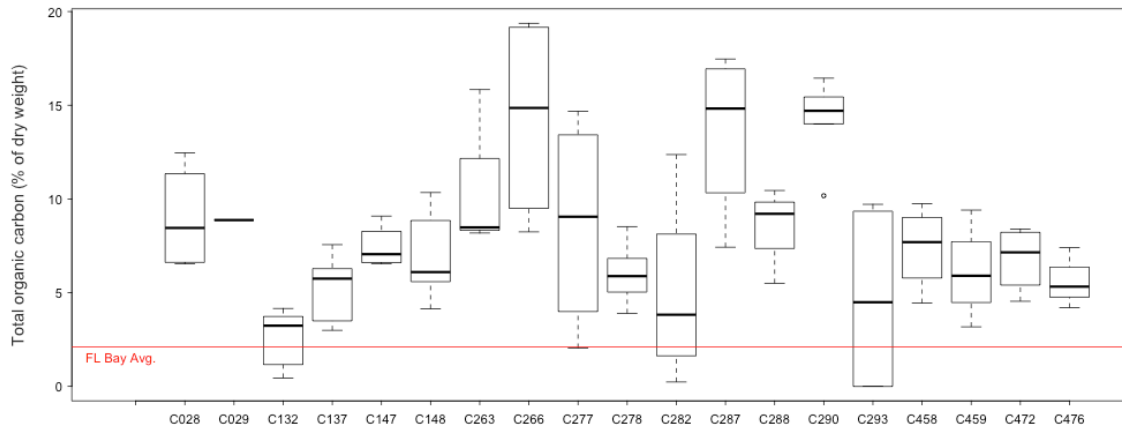


Figure 2. Organic carbon content of canal sediments during baseline surveys (Spring 2014).

Organic carbon content varies greatly between the sampled canals, though is positively correlated with sediment nitrogen content and to a lesser extent, phosphorus (Figure 3). Phosphorus, typically identified as the limiting nutrient for plant growth in Florida Bay, is greater than an order of magnitude in most canals compared to bay-wide averages (Figure 4). The high nutrient content of canal sediments is more similar to plant tissue than typical marine sediments. In fact, the sediments of many of the canals can be identified visually as plant material at various levels of decomposition (Figure 5). The organically rich sediment that has accumulated since the creation of these canals can surpass to 3 m with an average of 0.98 m depth.

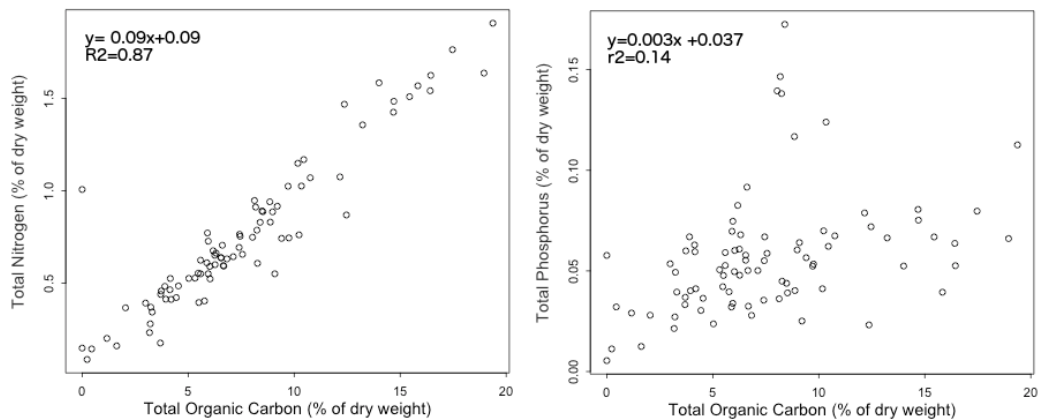


Figure 3. Total nitrogen and phosphorus content of canal sediments as function of organic carbon content during baseline surveys (Spring 2014).

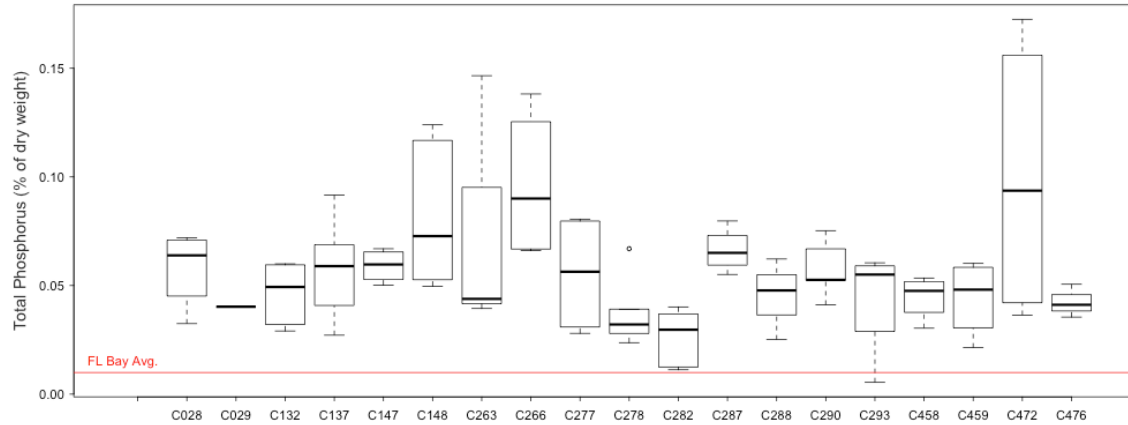


Figure 4. Total phosphorus content of sediments across sampled canals during baseline surveys (Spring 2014).

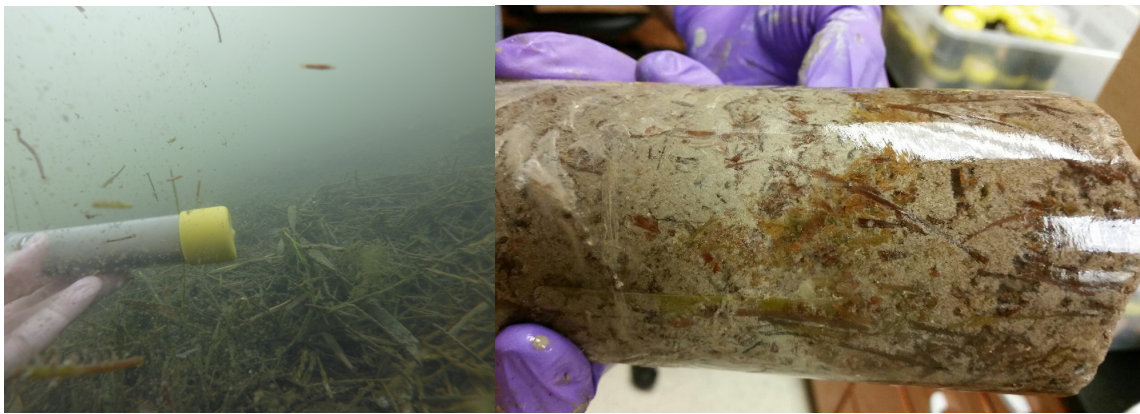


Figure 5. Examples of the high contribution of seagrass leaves to sediments. Left: Benthos of Big Pine canal consists of dead seagrass leaves. Right: Frozen sediment core captures decaying seagrass leaves within fine sediment grains.

While the benthos generally lacked flora and fauna, the majority of the canal walls surveyed supported identifiable autotrophic organisms (typically turf forming green algae, species of *Caulerpa*, or red algae) or animals (barnacles or sponges). The canal walls near the mouth had greater a number of identifiable species than those towards the canals' rear, which often consisted of a single species or decaying biomass (Figure 6).

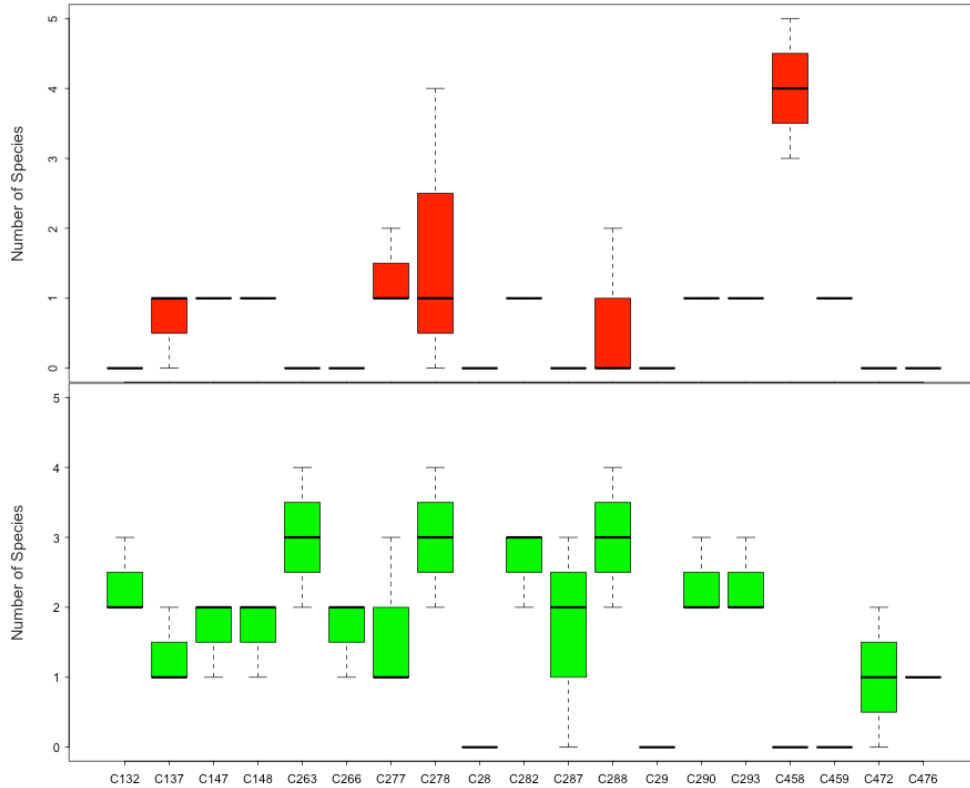


Figure 6. Number of identifiable species living on canal walls in the rear (in red) and at the mouth (in green) during Spring 2014 sampling.

Fish are encountered during surveys within project canals with the most common being Mangrove snapper (*Lutjanus griseus*) with occasional sightings of sergeant major (*Abudefduf saxatilis*) and needle fish (family Belonidae). However, the majority of canals lacked fish completely during our surveys (Figure 7).

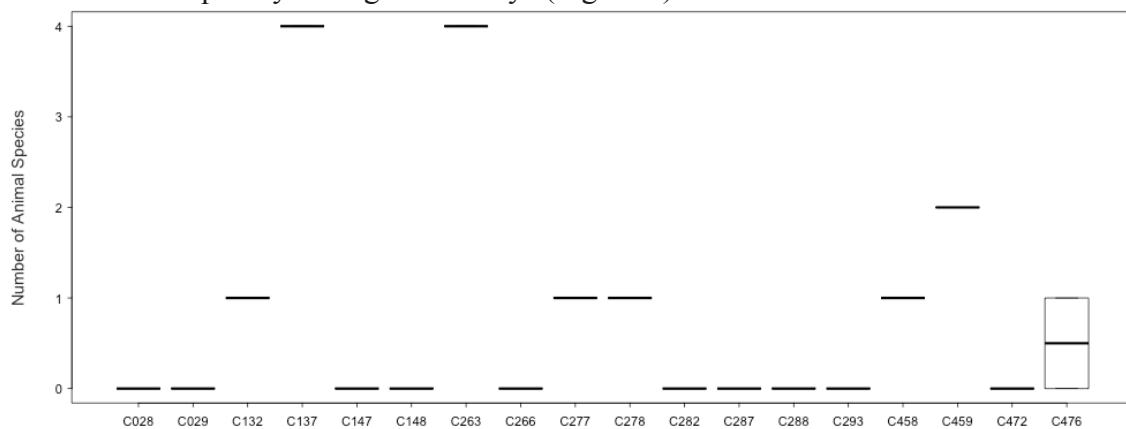


Figure 7. Number of fish species counted within canals during Spring 2014 sampling.

Benthic coverage was assessed at 0m, 10m, 50m, 100m, and 250m from the mouth of the canal. Changes along the transect from the canal mouth follow similar

trends across most sites, with a barren benthos within the canal, followed by an appearance of benthic macroalgae (typically *Halimeda sp* and *Penicillus sp*) or seagrass *Halodule wrightii*, then a shift to *Thalassia testudinum*-dominated seagrass communities 100m to 250m outside the canal.

Table 2. Maximum Braun-Blanquet percent cover score on Transects spanning from canal mouth to 250m outside. Baseline data (Spring 2014) are presented using the following scale: 0 = absent; 0.1 = one individual, less than 5% cover; 0.5 = few individuals, less than 5% cover; 1 = many individuals, less than 5% cover; 2 = 5–25% cover; 3 = 25–50% cover; 4 = 50–75% cover; and 5 = 75–100% cover. Heat map coloration correlates with cover						
Canal	Distance from Canal Mouth (m)					
	0	10	50	100	250	
<i>Thalassia testudinum</i>						
28	0	4	2	4	1	
29	2	4	5	4	0	
132	0	0	1	0	1	
137	0	0	2	0	5	
147	0	0	0	2	2	
148	0	0	0	5	0	
263	0	0	5	5	0	
266	0	3	4	4	0	
277	1	2	2	0	3	
278	1	0	0.5	0	3	
282	0	0	0	5	5	
287	0	0	0	0	4	
288	0	0	0	0	5	
290	0	0	3	4	1	
293	0	0	0	0	4	
472	0	0	2	1	4	
476	0	0	1	5	2	
<i>Syringodium filiforme</i>						
28	0	0	0	0	0	
29	0	0	0	0	0	
132	0	0	0	0	0	
137	0	0	2	0	0	
147	0	0	0	0	0	
148	0	0	0	0	0	
263	0	0	1	2	0	
266	0	0	0	1	0	
277	0	0	4	0	0	
278	0	0	0	1	0	
282	0	0	0	0	0	
287	0	0	0	5	0	
288	0	0	0	5	0	
290	0	0	0	0	0	
293	0	0	0	4	0	
472	0	0	0	0	0	
476	0	0	0	0	0	

Table 2. continued						
Canal	Distance from Canal Mouth (m)					
	0	10	50	100	250	
<i>Halodule wrightii</i>						
28	2	2	2	0	0	
29	0	0	0	0	2	
132	0	0	0	0	0	
137	0	0	0	1	0	
147	1	0	4	3	3	
148	2	0	0	0	0	
263	0	0	0	0	0	
266	0	3	0	0	0	
277	2	3	2	4	0	
278	5	3	5	4	0	
282	0	0	3	2	0	
287	0	0	0	0	0	
288	0	0	0	0	0	
290	0	0	0	0	0	
293	0	0	0	0	0	
472	0	2	2	1	0	
476	0	0	1	0	0	
Calcifying Benthic Macroalgae						
28	0	0	1	0.1	0.5	
29	0	0.5	0	0.1	1	
132	0	2	3	2	2	
137	2	3	2	0	0.1	
147	0	5	0	0	2	
148	5	5	5	2	2	
263	0	0	0.5	0	2	
266	0	0	0	2	2	
277	0	2	0	1	0	
278	1	3	1	1	2	
282	0	0	0	0	0	
287	0	0	0	2	2	
288	0	1	0.5	0.1	2	
290	0	0	0	0	2	
293	0	0	1	0	0	
472	0	1	2	1	2	
476	0	4	0.5	1	2	

Elemental stoichiometry and stable isotope signatures of seagrass can be used to characterize both the nutritional status and environmental conditions of marine plant communities. High nitrogen to phosphorus ratio (typically those above 30) indicate an abundance of available nitrogen for growth or unavailability of sufficient phosphorus (Figure 8). Ratios reported here indicate a possible phosphorus limitation for the marine plant growth directly outside canals. Low carbon:phosphorus and carbon:nitrogen ratios (Table 3) can indicate low light availability for photosynthesis. Low $\delta^{13}\text{C}$ isotopic signature of reported seagrass tissue also indicate low photosynthetic rates or possibly high concentrations of carbon dioxide.

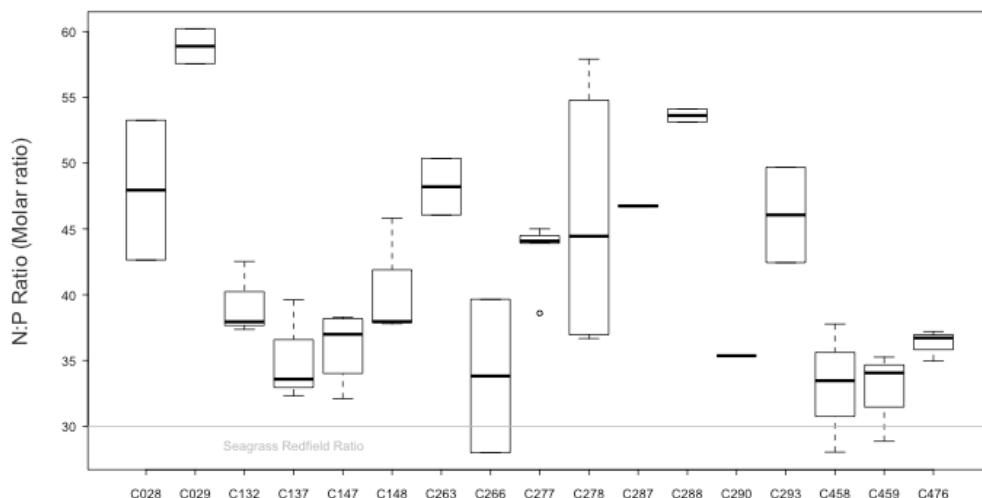


Figure 8. Nitrogen to Phosphorus ratios of seagrass leaf tissue collected outside the mouths of project canals. Values above the “Seagrass Redfield Ratio” of 30:1 indicate possible phosphorus limitation while values below suggest nitrogen limitation.

Table 3. *Thalassia testudinum* leaf elemental and stable isotope composition. “Canals” samples collected outside demonstration canals and respective controls while “South Florida” values taken from the Campbell et al (2009) survey across Florida Bay and the Keys. Seagrasses closest to each canal were harvested for analysis and data consists of all samples taken during 2014 and 2015 sampling campaigns.

	$\delta^{15}\text{N}$		$\delta^{13}\text{C}$		%C		%N		%P		C:N		C:P		N:P	
	South FL	Canals	South FL	Canals	South FL	Canals	South FL	Canals	South FL	Canals	South FL	Canals	South FL	Canals	South FL	Canals
Mean	2.0	2.1	-8.6	-11.1	39.2	37.2	1.9	2.6	0.1	0.1	24.1	17.2	870.8	707.3	36.5	41.3
n	78.0	45.0	78.0	45.0	134.0	46.0	134.0	46.0	134.0	46.0	134.0	46.0	134.0	46.0	134.0	46.0
SE	0.2	0.3	0.2	0.4	0.2	0.3	0.0	0.0	0.0	0.0	0.3	0.3	1.1	22.4	1.1	1.2
Median	1.8	2.4	-8.3	-10.4	39.6	37.2	1.9	2.5	0.1	0.1	24.0	16.9	34.4	662.6	34.4	38.4
Minimum	-2.2	-2.6	-13.0	-19.8	31.1	32.2	1.4	2.0	0.1	0.1	17.1	13.7	17.1	468.4	17.1	28.0
Maximum	5.4	7.2	-5.3	-6.8	43.2	42.2	2.6	3.2	0.2	0.2	33.9	22.3	76.5	1062.8	76.5	60.2

Preliminary Findings – Post-technology changes

Canal 29 – Prior to remediation efforts, the depth of Canal 29 increased from ~5 ft at the canal’s mouth to ~30 ft towards to rear. The surface water had a secchi depth of 100-120cm, though became red at approximately 10ft, then completely lacked natural light starting at 15 ft depth. This canal was backfilled (finished July 2015) with inert, carbonate based sand to a consistent depth of ~5 ft. Three months after the project was complete, visibility was clear to the bottom, with 100’s of juvenile fish (~2cm) and greater than 50 juvenile Mangrove Snapper (15-20cm) throughout the canal. While small, 2cm fish were seen in high numbers before remediation as well as within the adjacent, unaltered control canal, larger fish were found only in the post-installation canal. Macroalgae *Caulerpa sertularioides* was found in high benthic coverage in the rear of the canal, both on the rear canal wall and benthos (up to 75% benthic coverage) decreasing in abundance until is was no longer found at the center of the canal (Figure 9). Algae within the genera *Acetabularia* and *Barophora* species were found in low abundances

approximately $\frac{3}{4}$ into the canal. These species of benthic algae quickly colonized the canal after the change to more suitable sediment, light and chemical conditions.

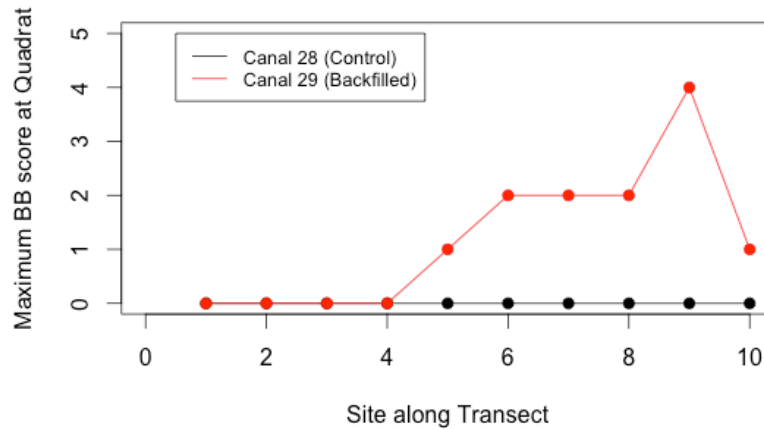


Figure 9. Maximum Braun–Blanquet percent cover score for macroalgae *Caulerpa sertularioides* within the backfilled canal and its control during Fall 2015 sampling. Transect runs from canal mouth to rear (0 → 10). BB scale: 0 = absent; 0.1 = one individual, less than 5% cover; 0.5 = few individuals, less than 5% cover; 1 = many individuals, less than 5% cover; 2 = 5–25% cover; 3 = 25–50% cover; 4 = 50–75% cover; and 5 = 75–100% cover.

Differences in sediment nitrogen and organic carbon content between the canal and its adjacent experimental control are clear and expected (Figure 10), with the backfilled canal containing notably less. The newly backfilled canal has an average organic carbon content of $1.23 \pm 0.56\%$, compared to the control canal of $8.63 \pm 0.76\%$. Both canals contained highest organic carbon content at the mouth, where there was clear accumulation of seagrass wrack and decomposing organic matter. Total nitrogen content of the sediment showed a similar trend with $0.08 \pm 0.07\%$ in the backfilled canal compared to $0.69 \pm 0.13\%$ in the control (Figure 11). However, total phosphorus content of the sediment was not significantly different between the canal 29 and its experimental control (Figure 11; t-test, $p=0.51$).

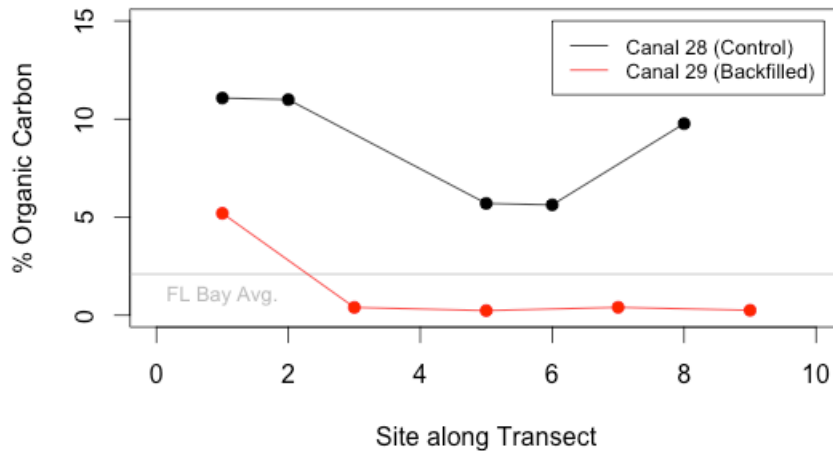


Figure 10. Sediment organic carbon content of backfilled canal and its control during Fall 2015 sampling. Transect runs from canal mouth to rear (0 → 10).

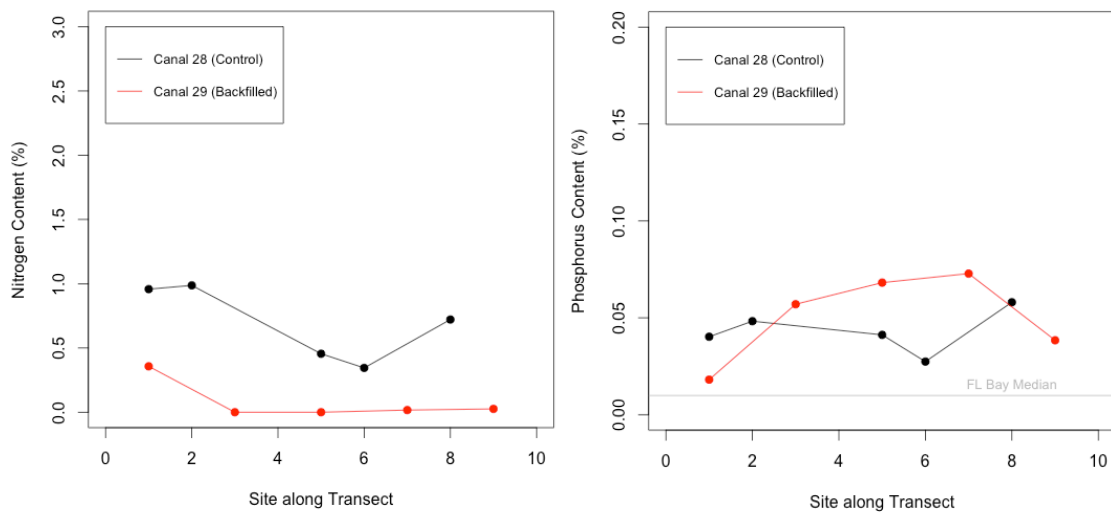


Figure 11. Total sediment nitrogen and phosphorus content of backfilled canal and its control during Fall 2015 sampling. Transect runs from canal mouth to rear (0 → 10).

Canal 137

Canal 137 consists of an 80m narrow canal that opens up into a large basin over 80m in width. The canal opens to the Atlantic Ocean and suffers high seaweed loading. With average depths of 10.5ft and deeper stagnant zones, the canal has struggles with areas of low O₂ and organic sedimentation. In November 2014, a weed gate and additional aerators were installed. As of December 2015, there is not a clear difference in sediment organic carbon content (Figure 12) or sediment density (Figure 13) between canal 137 and its experiment control. There is still a complete lack of benthic plants and algae

within both demonstration and control canals.

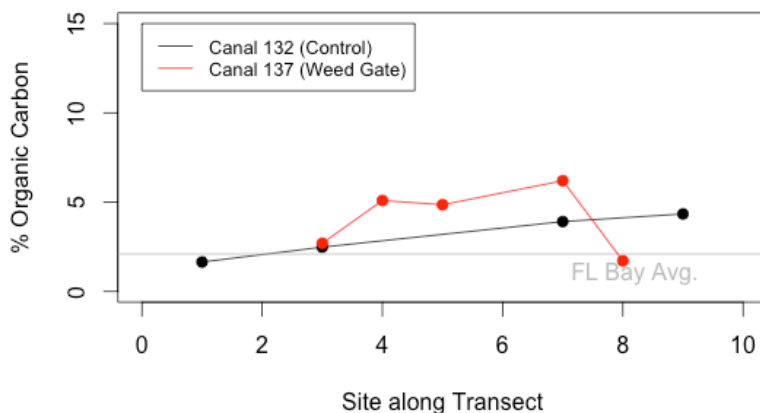


Figure 12. Sediment organic carbon content of canal with weed gate and its control during Spring 2015 sampling. Transect runs from canal mouth to rear (0 → 10).

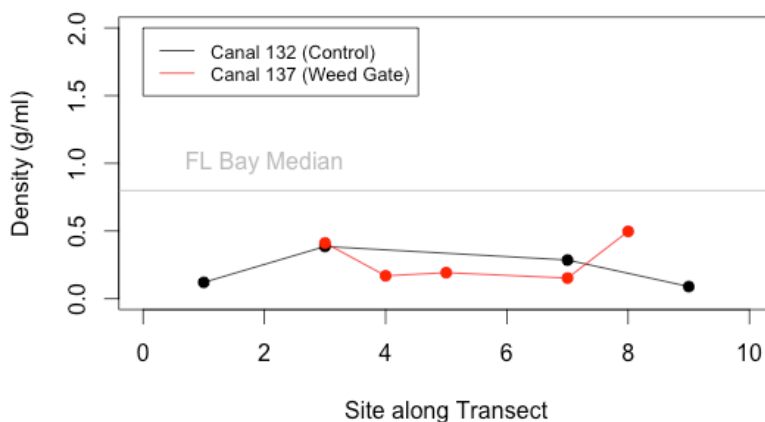


Figure 13. Bulk sediment density of the canal with weed gate and its control during Spring 2015 sampling. Transect runs from canal mouth to rear (0 → 10).

Canal 472

Canal 472 is a narrow canal approximately 190m long opening up southward to the Atlantic Ocean. The canal suffers high organic input from seagrass and seaweed and supports an average water depth of ~10m with, prior to remediation, a notably lower water depth in the rear where wrack has accumulated. The installation of a culvert connecting the rear of the canal to an adjacent canal was finished May 2015. Sampling was conducted within one month of the culvert opening. Comparing post-culvert to pre-culvert canal conditions while controlling for season (comparing only springtime measurements), there was a large decrease in sediment depth (Figure 14) as well as sediment organic carbon content (Figure 15). There was also increase in sediment density (Figure 16), particularly in the rear where the sediment changes were greatest. There were 30 mangrove snapper (~20cm length) counted during the Spring 2015 sampling

after the culvert installation, an increase from the zero that were counted in Spring 2014.

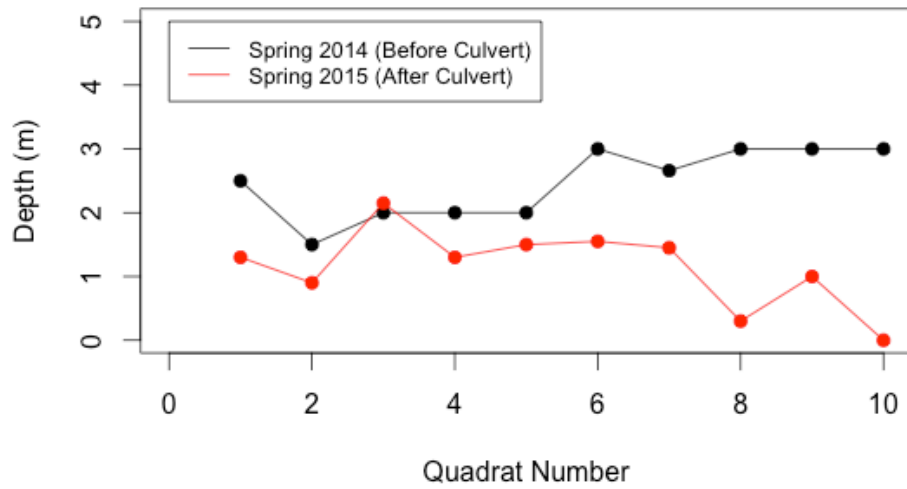


Figure 14. Depth from bedrock to sediment surface in canal before and after installation of culvert during the same season (Spring). Transect runs from canal mouth to rear (0 → 10).

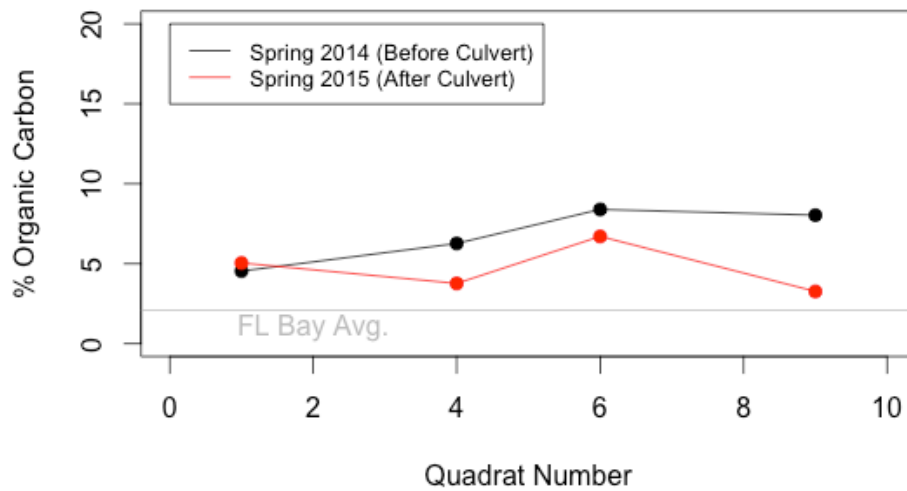


Figure 15. Sediment organic carbon content in canal before and after installation of culvert during the same season (Spring). Transect runs from canal mouth to rear (0 → 10).

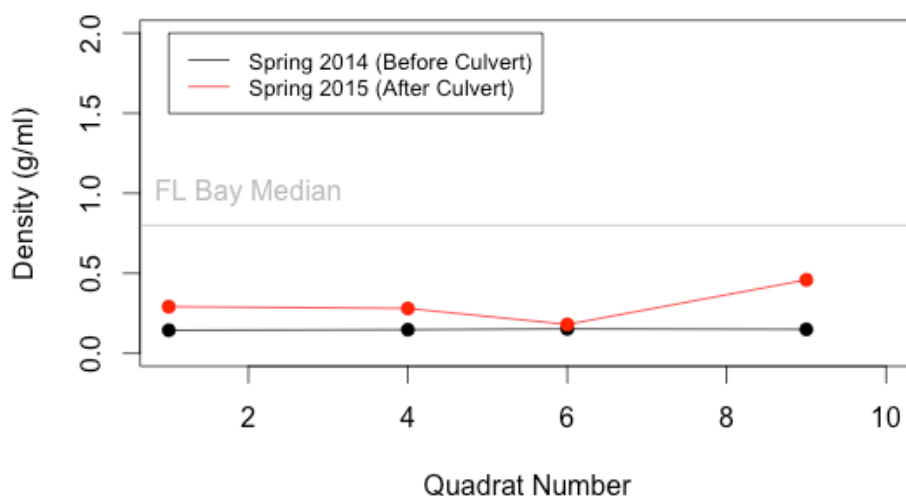


Figure 16. Bulk sediment density in canal before and after installation of culvert, during the same season (Spring). Transect runs from canal mouth to rear (0 → 10).

Conclusions

Canals chosen for the remediation project lack benthic plants and algae that typically inhabit shallow coastal zones of Florida Bay and the Florida Keys. These benthic organisms are regarded as indicators of long term environmental conditions due to specific ranges of survival and chemical composition that have been reported in academic literature and used in previous monitoring efforts in South Florida (Fourqurean and Zieman 1992, Anderson and Fourqurean 2003, Armitage et al. 2005, Fourqurean et al. 2005, Herbert and Fourqurean 2008, Campbell and Fourqurean 2009, Armitage et al. 2011). Sediments within canals have densities and nutrient composition that were initially outside the recorded range for seagrass survival in Florida Bay. Seagrasses and macroalgae communities directly outside canals are controlled by the nutrient availability, light and sediment composition with macroalgae and, to a lesser extent, *Halodule wrightii* more commonly found at canal mouths and *Thalassia testudinum* found at 100m and 250m transects.

While only three of the remediation plans have been completed, there are already clear benthic changes due to backfilling and the culvert installation. The weed gate has not yet proved effective to improve benthic conditions, though its slow remediation of sediment conditions via decrease organic matter loading is expected to take time.

Work Cited

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