Supplementary Material
Data Analysis Update

In addition to the General Linear Models (GLM), we conducted a statistical analyses update for sportfish abundance strictly using Generalized Linear Mixed Effect Models (GLMMs) to incorporate time since restoration as a random effect and oyster reef location (i.e., north or south "reef block") as a fixed effect. The previous package used (MASS in R) lacked the capability of incorporating predictor variables that had "na" in the dataset, which was present due to disproportionate sampling frequency between benthic habitat and fisheries data collections. The glmmTMB package was capable of handling these data and was thus a more robust approach to proceed with the more appropriate GLMM for all models.

Methods

Data Analysis

Generalized Linear Mixed Effect Models (GLMM) included time as a random effect - season was used for oyster reefs as it better captured variance than restoration timeline, while restoration timeline better explained the variance for living shorelines than season. GLMMs would not converge using season nested with restoration timeline. Models were run using the glmmTMB package in R. Oyster models included reef location as a fixed effect ("reef block") to account for the distance (~4km) between reefs located closer to Ponce de Leon inlet in the north, and reefs further south (Fig. 1). Previously, "inlet distance" was a continuous variable to account for the distance from the inlet to each individual site. Using "reef block" as a fixed effect better accounted for any spatial autocorrelation. Living shoreline sites were separated by a maximum of 2.25 km but were not spatially autocorrelated (Moran's I p=0.74).

The same original variables were used (Table S1) to test *a priori* hypotheses and thus construct the models. Quantitative variables were scaled in the model to allow for direct coefficient comparison (ex., scale(variable 1) + scale (variable 2) + … + reef block + (1|temporal variable)). These models maintained the negative binomial distribution, as the response variable was zero-inflated (e.g., 53.4% of the samples in this study caught zero sportfish). Models were compared using the Akaike Information Criterion (AIC) in the bbmle package in R.

Results

Using GLMM, the leading models for 2017 oyster reefs were similar to the original GLM, with oyster density, reef height, macroinvertebrate abundance, and reef block constituting the best predictors of sportfish abundance (AICw=0.52), followed by this same model with the addition of prey fish abundance (AICw=0.36). Sportfish abundance at 2018 reefs was similarly best predicted by oyster density, reef height,

macroinvertebrate abundance, prey fish abundance, reef block, and dissolved oxygen (DO) (AIC*w*=0.47, Table 3, Appendix A), followed by a model including only oyster density, reef height, macroinvertebrate abundance, and reef block (AIC*w*=0.31).

There was a weak positive correlation between sportfish and oyster density (2017 reefs), DO (2018 reefs), and proximity to the inlet (i.e., northern reef block). Sportfish abundance had a weak negative correlation with reef height (2017 reefs), with peak abundances at intermediate reef heights (Fig. 2). Although these are relatively weak correlations, they still ranked higher than abiotic variables and were likely weak due to disproportionate sampling frequency between fisheries and benthic data collections. In addition to the summary statistics of these top variables in Appendix A, prey fish abundances mirrored that of sportfish in having highest catch per unit effort (CPUE) at restored 2018 reefs (513.7 ± 156.5), followed by live (515.6 ± 142.3), 2017 restored (210.8 ± 46.8), and dead reefs (249.6 ± 78.7) [44, 52]. Seasonal CPUE was variable as described, and highest in the summer (Mean ± SE, 1.2 ± 0.17), followed by fall (0.9 ± 0.2), spring (0.5 ± 0.2), and winter (0.2 ± 0.1).

For living shorelines, the leading model contained the same predictor variables as the GLM (benthic cover, prey fish abundance, invertebrate abundance), with the addition of dissolved oxygen (AIC*w*=1.0, Table 3, Appendix A). Seasonal oscillations in CPUE were evident, and highest in summer (Mean ± SE; 18 ± 5.1), fall (6.7 ± 1.8), winter (2.5 ± 0.7) and spring (0.3 ± 0.2).

Discussion

Based on these updated GLMM results and the sportfish abundance trends relative to the predictor variables, our management recommendations for utilizing oyster reefs and living shorelines as a tool to support juvenile sportfish populations remain the same. In addition to previous recommendations, optimal prey fish abundance was also observed at ~45-80 mm reef height and 50-175 oysters/m^2 [52], within the range primarily occupied by both macroinvertebrates and sportfish. The prevalence of biotic variables such as substrate cover and prey abundances in both the top performing GLMs and GLMMs ranking above abiotic variables (e.g., temperature, salinity), encourages the importance of adequate benthic habitat to support juvenile sportfish, which can be improved through restoration. The only abiotic variable to appear in the top models is dissolved oxygen, which is critical for fishes, and can be improved via aquatic vegetation and the water filtration service provided by live oysters.

Table 3. List of top weighted Generalized Linear Mixed Effect Models (with negative binomial distribution and log link) of sportfish abundance, listed by habitat restoration category, with Akaike Information Criterion (AIC). Models, AICc scores, delta AIC, degrees of freedom and AIC model weight are in order of model rank. Top predictor variables include oyster density (number of oysters/m^2), reef height (mm), prey macroinvertabrate abundance, prey fish abundance (i.e., all fishes, except sportfish), reef block (north vs. south; oyster reefs) and percent vegetation cover (shorelines). Significant predictors from the top model were included along with their coefficient estimates and significance values

Model (GLMM)	AICc	delta AIC	df	weight	Top Model Significant Predictor	Coefficient Estimates	Pr (z)
2017 Oyster Reefs							
Abundance~ Oyster Density + Reef Height + Invert Abund + ReefBlock + (1|Season) *Random Effect (Season) Variance = 0.36, Std. Dev. = 1.9*	227.9	0	8	0.51	Oyster Density	1.12	0.009
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + ReefBlock + (1|Season)	228.6	0.7	9	0.36	Reef Height	-0.86	0.02
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + DO + ReefBlock + (1|Season)	230.7	2.8	10	0.13	South Reef Block	-0.97	0.003
2018 Oyster Reefs							
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + DO + ReefBlock + (1|Season) *Random Effect (Season) Variance = 0.13, Std. Dev. = 0.36*	210.2	0	10	0.47	DO	-0.58	0.056
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + ReefBlock + (1|Season)	211.8	1.6	9	0.21	South Reef Block	-1.25	0.003
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + ReefBlock + (1|Season)	211.8	1.6	9	0.21			
Living Shorelines							
Abundance ~ Vegetation/Bare Cover + Fish Abund + Invert Abund + DO +(1|Time) *Random Effect (Restore Timeline) Variance = 2.16, Std. Dev. = 1.47*	227.1	0	8	1	Fish Abundance	0.77	0.001
					Veg/Bare Cover	0.48	0.02

Appendix B

List of all Generalized Linear Mixed Effect Models (with negative binomial distribution and log link), with Akaike Information Criterion (AIC). Models, AICc scores, delta AIC, degrees of freedom and AIC model weight are in order of model rank.

2017 Oyster Reefs				
Model (GLMM)	**AICc**	**deltaAIC**	**df**	**weight**
Abundance~ Oyster Density + Reef Height + Invert Abund + ReefBlock + (1|Season)	227.9	0	8	0.51
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + ReefBlock + (1|Season)	228.6	0.7	9	0.36
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + DO + ReefBlock + (1|Season)	230.7	2.8	10	0.13
Abundance~ Reef Height + ReefBlock + (1|Season)	280.4	52.5	6	<0.001
Abundance~ Oyster Density + Reef Height + ReefBlock + (1|Season)	280.5	52.6	7	<0.001
Abundance~ Oyster Density + Reef Height + DO + ReefBlock + (1|Season)	282.5	54.6	8	<0.001
Abundance~ Oyster Density + Reef Height + Tide + ReefBlock + (1|Season)	283.8	55.9	10	<0.001
Abundance~ Oyster Density + ReefBlock + (1|Season)	302	74.1	6	<0.001
Abundance~ Invert Abund + Fish Abund + Tide + ReefBlock + (1|Season)	367.3	139.5	10	<0.001
Abundance ~ Invert Abund + Fish Abund + ReefBlock + (1|Season)	368.8	140.9	7	<0.001
Abundance~ Invert Abund + Fish Abund + Invert Richess + Fish Richness + (1|Season)	369.1	141.3	9	<0.001
Abundance~ Invert Abund + Fish Abund + DO + ReefBlock + (1|Season)	371	143.1	8	<0.001
Abundance~ Invert Abund + Fish Abund + Lunar + ReefBlock + (1|Season)	373.9	146	10	<0.001
Abundance~ Air Temp + DO + Salinity + Secchi + Wind + Baro Pressure + ReefBlock + (1|Season)	442.1	214.2	11	<0.001
Abundance~ Water Temp + DO + Salinity + ReefBlock + (1|Season)	478	250.1	8	<0.001
Abundance~ Site Type + DO + ReefBlock + (1|Season)	513.7	285.8	8	<0.001
Abundance~ 1 + (1|Season) (Null Model)	529.1	301.2	4	<0.001
2018 Oyster Reefs				
Model (GLMM)	**AICc**	**delta AIC**	**df**	**weight**
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + DO + ReefBlock + (1|Season)	210.2	0	10	0.47
Abundance~ Oyster Density + Reef Height + Invert Abund + ReefBlock + (1|Season)	211.1	0.8	8	0.31
Abundance~ Oyster Density + Reef Height + Invert Abund + Fish Abund + ReefBlock + (1|Season)	211.8	1.6	9	0.21
Abundance~ Oyster Density + ReefBlock + (1|Season)	236.6	26.4	6	<0.001
Abundance~ Oyster Density + Reef Height + DO + ReefBlock + (1|Season)	236.8	26.6	8	<0.001
Abundance~ Oyster Density + Reef Height + ReefBlock + (1|Season)	238.3	28.1	7	<0.001
Abundance~ Reef Height + ReefBlock + (1|Season)	240.5	30.3	6	<0.001
Abundance ~ Oyster Density + Reef Height + Tide + ReefBlock + (1|Season)	242.2	31.9	10	<0.001
Abundance~ Invert Abund + Fish Abund + Fish Richness + ReefBlock + (1|Season)	323	112.7	8	<0.001
Abundance~ Invert Abund + Fish Abund + Invert Richnes + ReefBlock + (1|Season)	325.9	115.6	8	<0.001
Abundance~ Invert Abund + Fish Abund + DO + ReefBlock + (1|Season)	326.9	116.7	8	<0.001
Abundance ~ Invert Abund + Fish Abund + ReefBlock + (1|Season)	326.9	116.7	8	<0.001
Abundance ~ Invert Abund + Lunar + ReefBlock + (1|Season)	327.2	117	7	<0.001
Abundance~ Water Temp + DO + Secchi + ReefBlock + (1|Season)	331.8	121.5	9	<0.001
Abundance~ Air Temp + DO + Salinity + Secchi + Wind + Baro Pressure + ReefBlock + (1|Season)	345	134.7	8	<0.001
Abundance ~ Site Type + DO + ReefBlock + (1|Season)	352.7	145	12	<0.001
Abundance~ Fish Abund + Lunar + ReefBlock + (1|Season)	389.7	181.9	11	<0.001
Abundance ~ 1 + (1|Time) (Null Model)	416.6	208.8	4	<0.001

Living Shorelines				
Model (GLMM)	**AICc**	**delta AIC**	**df**	**weight**
Abundance ~ Vegetation/Bare Cover + Fish Abund + Invert Abund + DO +(1|Time)	227.1	0	8	1
Abundance ~ Vegetation/Bare Cover + Fish Abund + Invert Abund + (1|Time)	257.8	30.8	7	<0.001
Abundance ~ Vegetation/Bare Cover + DO + (1|Time)	271.8	44.8	6	<0.001
Abundance ~ Vegetation Cover + (1|Time)	309.6	82.5	5	<0.001
Abundance ~ Bare Cover + (1|Time)	309.6	82.5	5	<0.001
Abundance ~ Invert Abund + Fish Abund + DO + (1|Time)	377.1	150.1	7	<0.001
Abundance~ Invert Abund + Fish Abund + Lunar + DO + (1|Time)	383.1	156.1	10	<0.001
Abundance ~ Invert Abund + Fish Abund + Invert Richness + Fish Richness + (1|Time)	404.7	177.6	8	<0.001
Abundance ~ Fish Abund + Invert Abund + (1|Time)	408.7	181.7	6	<0.001
Abundance ~ Fish Abund + Invert Abund + Lunar + (1|Time)	414.5	187.5	9	<0.001
Abundance ~ Wind + Air Temp + Baro Pressure + Secchi + Salinity + Water Temp + DO + Tide + (1|Time)	418.5	191.5	14	<0.001
Abundance ~ Wind + Air Temp + DO + Salinity + Secchi + Baro Pressure + (1|Time)	424.3	197.3	10	<0.001
Abundance ~ 1 (Null Model)	462.6	235.5	4	<0.001
Abundance~ Time (months)	399.9	195.3	3	<0.001
Abundance~Site Type	407.3	202.7	3	<0.001
Abundance~1 (Null Model)	412	207.4	2	<0.001

Table S1. Complete list of predictor variables measured.

	Measured Predictor Variables
Site Type	Restored/Stabilized vs. Control
Abiotic Variables	Dissolved Oxygen (mg/L)
	Salinity (ppt)
	Water Temperature (^{o}C)
	Secchi depth
	Air Temperature (^{o}C)
	Barometric Pressure (mm Hg)
	Wind Speed (kph)
	Tide (high/low/rising/falling)
	Lunar Phase
	Distance to nearest ocean inlet (km)
Biotic Variables	% Vegetation Cover (Shorelines)
	% Seagrass Cover (Shorelines)
	% Bare Cover (Shorelines)
	Oyster Density (#/m^2)
	Reef Height (mm)
	Prey Fish Abundance
	Invertebrate Abundance

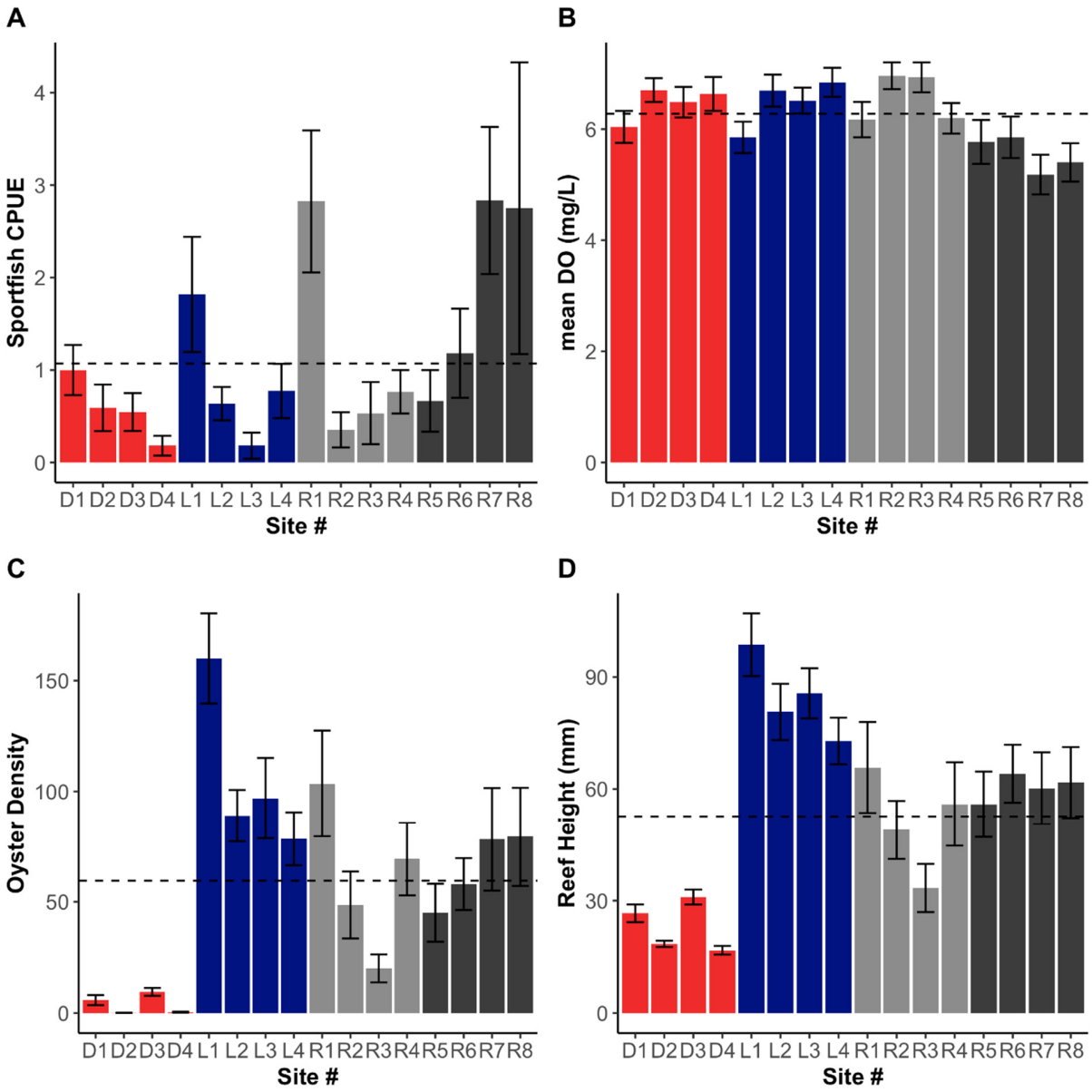

Figure S1. Oyster reef site numbers with (**A**) sportfish abundance and influential predictor variables (**B**) dissolved oxygen (mg/L), (**C**) oyster density (live oysters/m^2, and (**D**) reef height (mm). Red = dead reefs, blue = live reefs, light gray = restored 2017 reefs, dark gray = restored 2018 reefs.