Quantitative Methods in Ecology & Evolution Final Project

# EFFECTS OF PROPELLER SCARRING ON ORGANIC MATTER DECOMPOSITION IN *THALASSSIA TESTUDINUM* MEADOWS


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## ABSTRACT

Coastal seagrass meadows have been widely recognized as habitats capable of sequestering large amounts of organic carbon, primarily within the sediments associated with the seagrass. Decomposition within the meadow determines the amount of organic carbon that is available in the environment to become stored for long periods of time. *Thalassia testudinum*, a climax seagrass species, has slow decomposition rates and is known to store large amounts of carbon and dominates seagrass meadows in the Florida Keys. Unfortunately, meadows within the Florida Keys also experience high levels of anthropogenic disturbances due to boating activity that has been on the rise for years. Propeller scars are common in this area, and they are known to damage seagrass meadows, create fragmented landscapes, and often take multiple years to recover from scarring events. Scarring events alter variables that drive decomposition, and the aim of this study was to determine if decomposition rates are different in scars compared to vegetated meadow at various spatial scales over the course of 6 months. The Tea Bag Index method was used to capture decomposition over time with standardized material in the form of green and rooibos tea. Green tea decay rates did not differ between scarred areas and vegetated areas at multiple spatial scales but were more influenced by site-level environmental variables. Rooibos (red) tea was found to be higher in the scar compared to vegetated areas with increased distance from the scar. Red tea was found to be influenced by belowground biomass.

**Keywords:** Decomposition – Thalassia testudinum – Propeller scar – Carbon - Disturbance

## INTRODUCTION

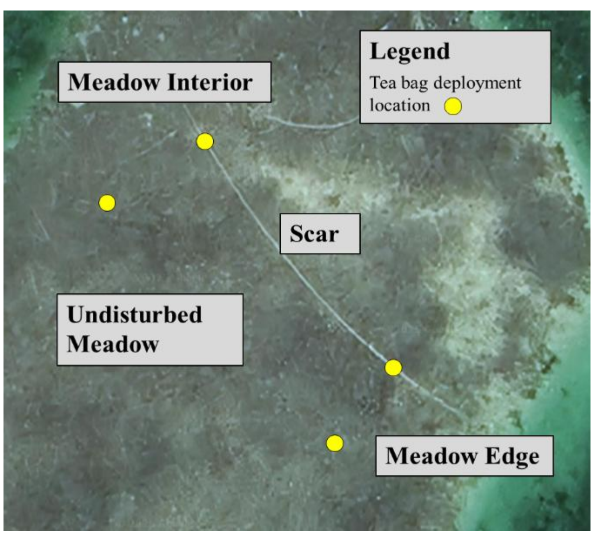
Coastal seagrass meadows sequester large amounts of organic carbon ($C_{org}$) through high burial rates of organic material, coupled with slow decomposition that occurs in the anoxic sediment environment (Trevathan-Tackett et al., 2024). Because these processes within meadows create large carbon stocks, seagrass meadows are recognized as highly efficient carbon sequestration systems that ultimately help to mitigate climate change (Howard et al., 2021). Decomposition, a complex process that drives carbon sequestration, is controlled by a multitude of biotic and abiotic variables, some of which include temperature (Trevathan-Tackett, Brodersen, et al., 2020), sedimentation (Howard et al., 2021), seagrass abundance (Fourqurean et al., 2023) and microbial activity (Trevathan-Tackett, Jeffries, et al., 2020). A combination of these variables influences the rate at which organic material is broken down and stored in the sediments. Slow decomposition is favorable for carbon sequestration, but seagrass meadows are highly susceptible to anthropogenic disturbances that accelerate decomposition and result in carbon loss (Arney et al., 2021).

Propeller scarring is a common type of disturbance that occurs when boaters drive through shallow seagrass flats and propellers damage or remove plant tissue and redistribute sediments within the propeller's path. The Florida Keys experience high levels of boat traffic and propeller scarring within meadows primarily composed of *Thalassia testudinum*, a slow growing climax species associated with large carbon stocks. Propeller scarring within *Thalassia* meadows are of particular concern, as it's been recorded to take nearly 8 to 10 years to see full recovery of the species within the scar after a scarring event has taken place (Kenworthy et al., 2002). Propeller scarring alters multiple variables that are known to influence decomposition rates, yet it is not understood if decomposition within these disturbed areas differs from the surrounding, undisturbed vegetated seagrass meadow.

To better understand if propeller scarring affects decomposition in seagrass meadows, we conducted a decomposition experiment in coastal meadows throughout the Florida Keys National Marine Sanctuary (FKNMS). Standardized organic materials, green and rooibos tea, were used to determine how decomposition of labile and recalcitrant materials differed over time when placed in scars and vegetated areas at multiple spatial scales (Keuskamp et al., 2013). The first spatial scale of interest investigated if green and rooibos tea decay rates differ between the meadow edge and meadow interior. We also wanted to determine if green and rooibos tea decay rates change as you increase distance away from a scar into adjacent, vegetated meadow. Additional data including seagrass biomass and morphometry, sediment grain size and organic matter (OM) content, and scar characteristics were collected to compare with decay rates to determine which environmental variables have the largest effect on decay rates. We then analyzed how predictor variables differed between scarred and vegetated areas within the plots, which could explain any potential differences in decay rates among treatment groups.

## SAMPLING METHODS

This study took place in shallow seagrass meadows located near the middle Florida Keys from July 2025 to January 2026 (the final collection has not occurred yet). A total of 3 propeller scars were selected for the decomposition study; each scar was in a separate meadow. Equal numbers of green and red tea bags (3 ± 0.05 g; $n$ = 288) were buried at a depth of 5 cm in the surface sediments at 6 positions per site to assess decomposition in scarred and vegetated areas (Figure 1). A subset of tea bags (~3-4 depending on collection success) were collected at pre-determined intervals to capture the decay rate of OM over time. Collections from each site position at all sites took place on 12-, 26-, and 48-days post-deployment. Tea bags were rinsed and cleaned of sediments and epiphytic material, dried at 60 C for a minimum of 44 hours, then weighed to determine the dry mass of the tea remaining. Any tea bags that were exposed in the water column, damaged or had indication of tea loss due to anything other than decomposition itself were excluded from analyses.



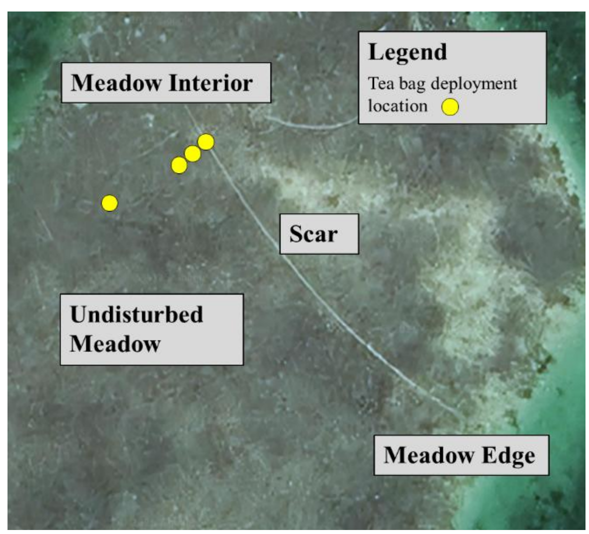




**Figure 1.** Setup of meadow edge vs meadow interior plot design (left), setup of scar vs adjacent distance into meadow plot design (right). Yellow dots represent tea bag deployment locations, both plot designs are present at each scar ($n$ = $3$). Sites located near middle Florida Keys, USA.

## DATA ANALYSES

### *Decomposition*

Decay rates of green tea (*Kg*) and rooibos tea (*Kr*) were calculated separately for each site position at all sites by fitting a nonlinear least squares exponential decay model to tea mass remaining over time, following the Tea Bag Index approach:

$$\mathbf{W(t) = a}\boldsymbol{e^{-kt}} + (\mathbf{1} - \boldsymbol{a})$$

Where *W(t)* is the weight of the tea at time since deployment, *a* represents the labile proportion and *(1-a)* represents the recalcitrant proportion of each respective tea type, and finally *k* is the decay rate (day $^{-1}$) of the incubated tea (Keuskamp et al., 2013). Including *a* and *(1-a)* is necessary to find the best fit of k; each type of organic material, green and rooibos tea, contains a labile proportion that quickly decomposes, leaving only the recalcitrant proportion associated with slower decay rates to be broken down over longer periods. Although both tea types have a labile and recalcitrant proportion, green tea is composed primarily of labile material and is expected to decompose faster than rooibos tea, which is composed mainly of recalcitrant materials that are harder to break down and experience slower decay rates. Values of *a* were calculated using the proportion of mass lost by the 48-day mark but will be recalculated at the conclusion of the experiment to get a more accurate estimate of *a* for both tea types once all labile material has been decomposed.

This method resulted in the estimation of a single *Kg* and *Kr* for each site x site position combination (*n = 18 k values per tea type*), which were subsequently complimented by bootstrap resampling with 1,000 replications per group to better describe the variability and uncertainty of decay rates between treatment groups. Each bootstrap iteration utilized a resampled combination of green and rooibos tea dry mass values across time, refitting the nonlinear decay model each time to produce 1,000 *Kg* and *Kr* values per site x site position. Pairwise differences of bootstrap-derived decay rates were calculated for each tea type and treatment group (e.g., $\Delta k = k_{\text{edge}} - k_{\text{interior}}$) to determine if decay rates change from meadow edge to meadow interior, and if the decay rates changed as distance from a scar into adjacent, vegetated meadow increased. These distributions allowed us to estimate a median difference, 95% confidence intervals, and the probability that bootstrapped decay rates were higher in one group of interest compared to the other without having to rely on overlapping CI's and parametric assumptions.

*Environmental Variables*

Mixed effect linear models were used to determine which environmental variables were most influential on decay rates derived from our initial estimates of *Kg* and *Kr* (non-bootstrapped *k* values). For this analysis, *Kg* and *Kr* were grouped by site position only, pooling data across sites but accounting for site-level variability by appointing site as a random effect in each model. Green and rooibos tea have significantly different decay rates and organic material composition that respond differently to environmental variables, so they were modeled separately.

# RESULTS

*Decomposition – Distance from Meadow Edge to Meadow Interior*

Green tea decay rates were filtered from the full bootstrap dataset to contain only *Kg* values that represent the meadow edge (0m) and meadow interior (10m) positions for both treatment types, scarred and vegetated. Probability values > 0.75 indicate a strong trend that Kg values are higher at the meadow edge compared to the meadow interior, probability values ~ 0.5 indicate no trend, while probability values < 0.25 indicate a higher probability of increased decay rates at the meadow interior (Table 1). It is important to note these are not equivalent to p-values but reflect the proportion of bootstrap-derived decay rates that were greater in one group compared to the other.

Green tea decay rates do not vary much between treatment types, but there is site-level variation in their decay rates between the meadow edge and meadow interior with no clear trend (Figure 2).

Red tea decay rates were analyzed using the same method for green tea. *Kr* appears more similar at the meadow edge and interior within the vegetated meadow with probability values nearer to ~0.5 for each site compared to the probability values of Kr in the scar which are more near the probability values that indicate a strong trend (Table 2). More importantly, mean *Kr* rates in scarred areas are slightly elevated compared to the vegetated areas across all sites (Figure 3).

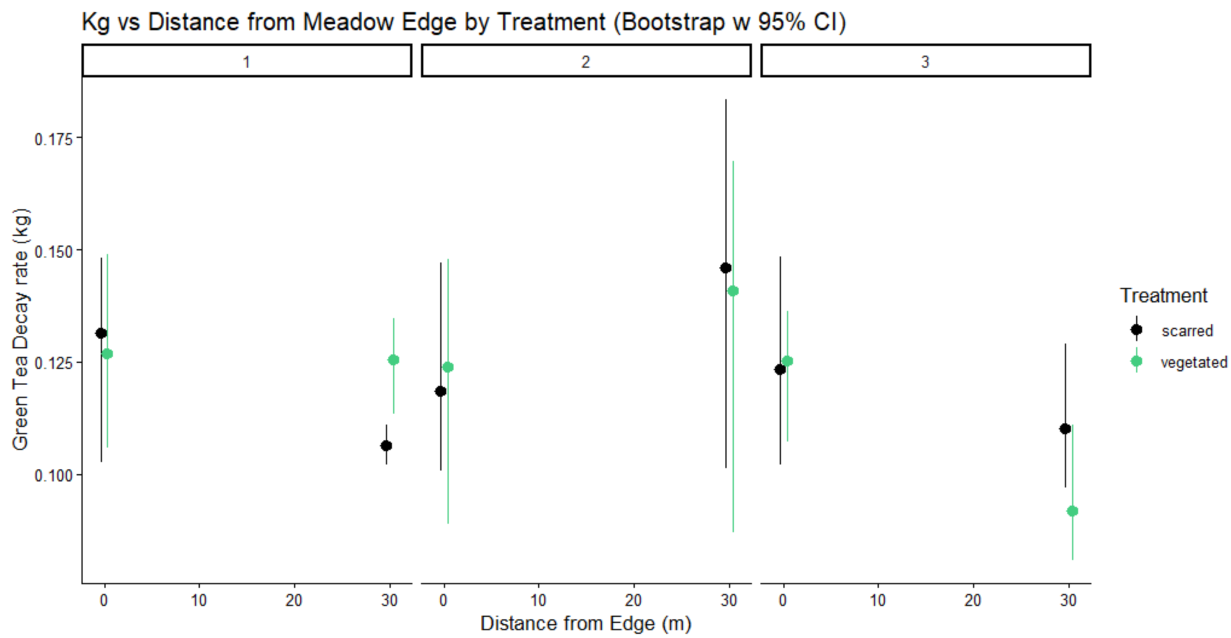



**Figure 2.** Bootstrap Kg means with 95% confidence intervals compared to meadow edge (0m) and meadow interior (30m), grouped by treatment type. Black CI's represent scarred *Kg* distributions; green CI's represent vegetated *Kg* distributions.

| Site | Treatment | Median delta | Lower CI | Upper CI | Probability Edge $k$ > Interior $k$ |
|---|---|---|---|---|---|
| 1 | scarred | 0.272 | -0.00284 | 0.0418 | 0.965 |
| 1 | vegetated | 0.00128 | -0.0215 | 0.0258 | 0.545 |
| 2 | scarred | -0.0288 | -0.0676 | 0.0247 | 0.119 |
| 2 | vegetated | -0.0173 | -0.0617 | 0.0357 | 0.213 |
| 3 | scarred | 0.0131 | -0.0140 | 0.0419 | 0.836 |
| 3 | vegetated | 0.0355 | 0.00735 | 0.0509 | 0.985 |

**Table 1.** Probability distributions for each site x treatment combination, with associated effect size (median delta), as well as lower and upper confidence intervals for each green tea group.

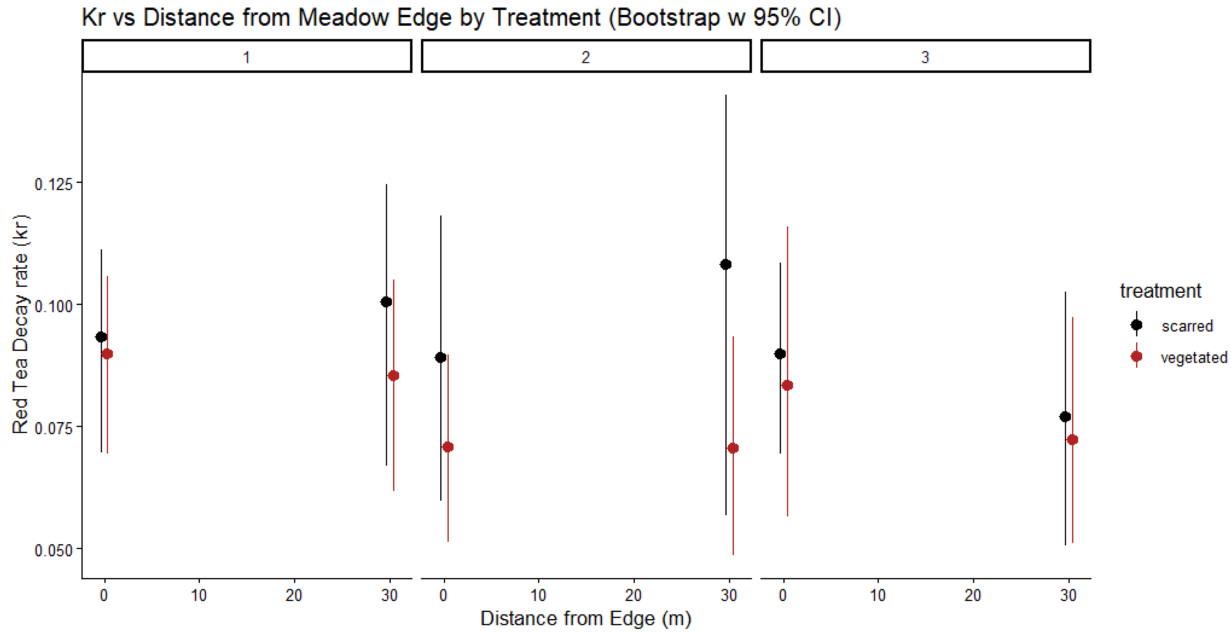



**Figure 3.** Bootstrap Kr means with 95% confidence intervals compared between meadow edge (0m) and meadow interior (30m), grouped by treatment type. Black CI's represent scarred *Kr* distributions; red CI's represent vegetated *Kr* distributions.

| Site | Treatment | Median delta | Lower CI | Upper CI | Probability Edge *k* > Interior *k* |
|---|---|---|---|---|---|
| 1 | scarred | -0.00797 | -0.0405 | 0.0324 | 0.331 |
| 1 | vegetated | 0.00441 | -0.0247 | 0.0343 | 0.616 |
| 2 | scarred | -0.0221 | -0.0681 | 0.0406 | 0.233 |
| 2 | vegetated | -0.000936 | -0.0303 | 0.0298 | 0.477 |
| 3 | scarred | 0.0124 | -0.0213 | 0.0465 | 0.755 |
| 3 | vegetated | 0.0103 | -0.0270 | 0.0511 | 0.690 |

**Table 2.** Probability distributions for each site x treatment combination, with associated effect size (median delta), as well as lower and upper confidence intervals for each green tea group.

## RESULTS

*Decomposition – Distance from Scar into Adjacent Vegetated Meadow*

Green tea decay rates were filtered from the full bootstrap dataset to contain only *Kg* values that represent decomposition within the scar and at various distances away from the scar. These distances include 0m (in the scar), 0.25m (edge of scar), 1m, and 10m (control). There were no strong trends in *Kg* probability distribution values as distance from scar increased (Table 3), and the relationship across sites were variable (Figure 4).

Red tea decay rates were analyzed using the same method for green tea. A large proportion of *Kr* values at every distance within the vegetated positions at both Site 1 and Site 2 were lower compared to the scarred areas. The probability distributions for each of these distances at both sites are greater than 0.75, confirming there is a strong probability distribution for *Kr* values to be higher in the scar compared to the adjacent, vegetated meadow (Table 4). Site 3 does not follow this trend, the probability of Kr to be higher in the scar compared to each vegetated meadow distance is ~50% (Figure 5).

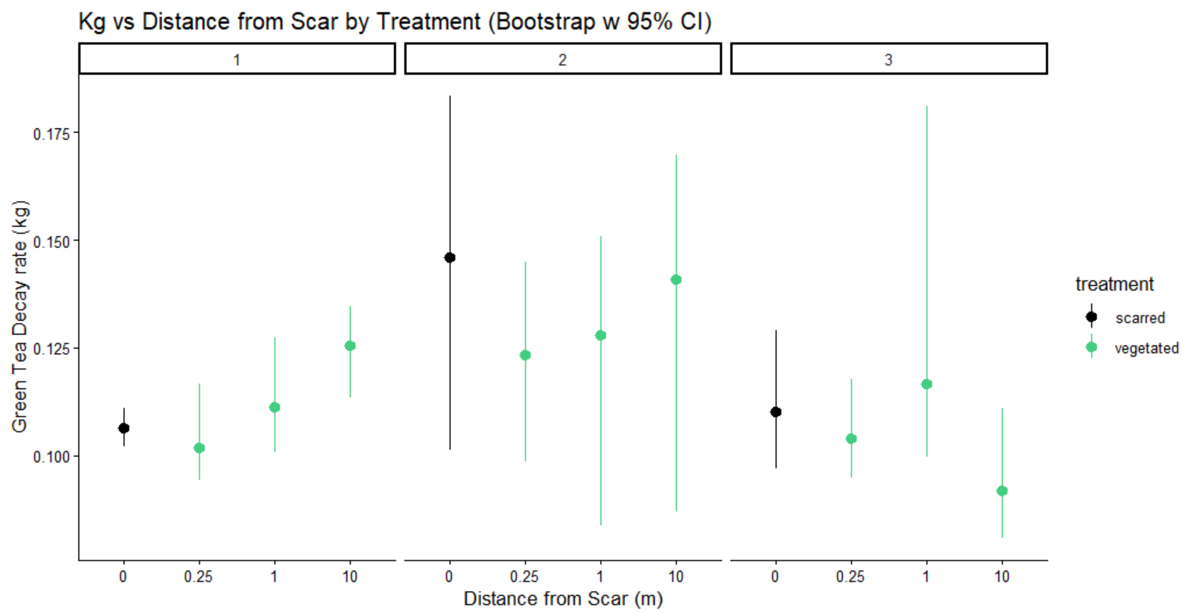



**Figure 4.** Bootstrap *Kg* means with 95% confidence intervals compared between various distances from target propeller scar. Black CI's represent scarred *Kg* distributions; green CI's represent vegetated *Kg* distributions.

| Site | Distance from Scar (m) | Median delta | Lower CI | Upper CI | Probability Scar *k* > Vegetated *k* |
|---|---|---|---|---|---|
| 1 | 0.25 | 0.00556 | -0.0103 | 0.0133 | 0.834 |
| 1 | 1 | -0.00389 | -0.0207 | 0.00751 | 0.274 |
| 1 | 10 | -0.0192 | -0.0299 | -0.00611 | 0.002 |
| 2 | 0.25 | 0.0237 | -0.0260 | 0.0657 | 0.868 |
| 2 | 1 | 0.0170 | -0.0356 | 0.0715 | 0.791 |
| 2 | 10 | 0.00453 | -0.0471 | 0.0610 | 0.582 |
| 3 | 1 | 0.00599 | -0.0113 | 0.0268 | 0.774 |
| 3 | 0.25 | -0.00462 | -0.0723 | 0.0193 | 0.324 |
| 3 | 10 | 0.0186 | -0.00591 | 0.0395 | 0.951 |

**Table 3.** Green tea probability distributions for each site x treatment combination, with associated effect size (median delta), as well as lower and upper confidence intervals for each distance from scar group.

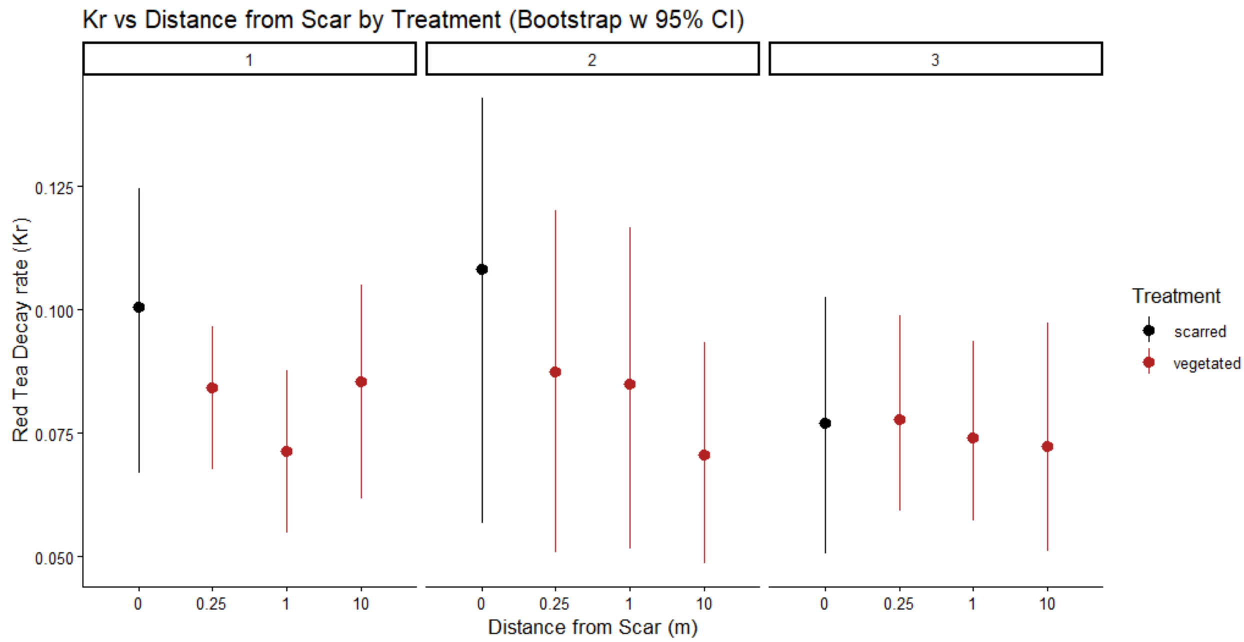



**Figure 5.** Bootstrap *Kr* means with 95% confidence intervals compared between various distances from target propeller scar. Black CI's represent scarred *Kr* distributions; red CI's represent vegetated *Kr* distributions.

| Site | Distance from Scar (m) | Median delta | Lower CI | Upper CI | Probability Scar *k* > Vegetated *k* |
|---|---|---|---|---|---|
| 1 | 0.25 | 0.0177 | -0.0216 | 0.0452 | 0.833 |
| 1 | 1 | 0.0303 | -0.00571 | 0.0579 | 0.943 |
| 1 | 10 | 0.0160 | -0.0272 | 0.0510 | 0.791 |
| 2 | 0.25 | 0.0223 | -0.0426 | 0.0743 | 0.760 |
| 2 | 1 | 0.0264 | -0.0392 | 0.0761 | 0.781 |
| 2 | 10 | 0.0406 | -0.0180 | 0.0798 | 0.902 |
| 3 | 1 | -0.00103 | -0.0320 | 0.0337 | 0.474 |
| 3 | 0.25 | 0.00354 | -0.0302 | 0.0348 | 0.574 |
| 3 | 10 | 0.00505 | -0.0321 | 0.0381 | 0.599 |

**Table 4.** Red tea probability distributions for each site x treatment combination, with associated effect size (median delta), as well as lower and upper confidence intervals for each distance from scar group.

# RESULTS

*Environmental Variables*

Green and rooibos tea decay rates were grouped among sites to compare which environmental variables collected in the field had the strongest influence on either increasing or decreasing decay rates. Linear models with site as a fixed effect to account for site level differences outperformed linear mixed models with site as a random effect with lower AIC scores. Models chosen to best represent the relationship between environmental variables and decay rates were then tested to make sure they met model assumptions. Fine grain sediments (<63 microns) were found to significantly lower decay rates of green tea and the residuals from this model met the appropriate assumptions (Figure 6). Red tea decay rates seem to be most influenced by belowground biomass, known as the roots and rhizomes of the plant. Assumptions of the rooibos tea model were also tested and met (Figure 7).

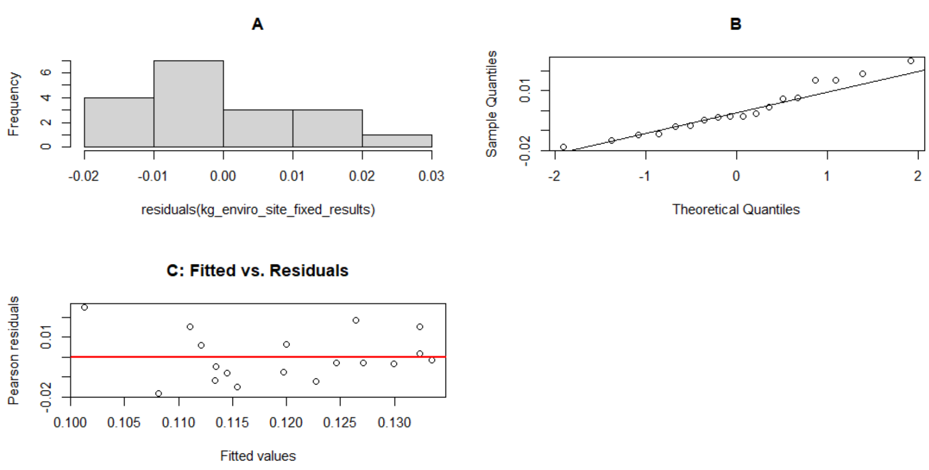



**Figure 6.** Green tea decay rate best fit model; fine sediment grain size has the most influence on lowering Kg, with site as a fixed effect in the model.

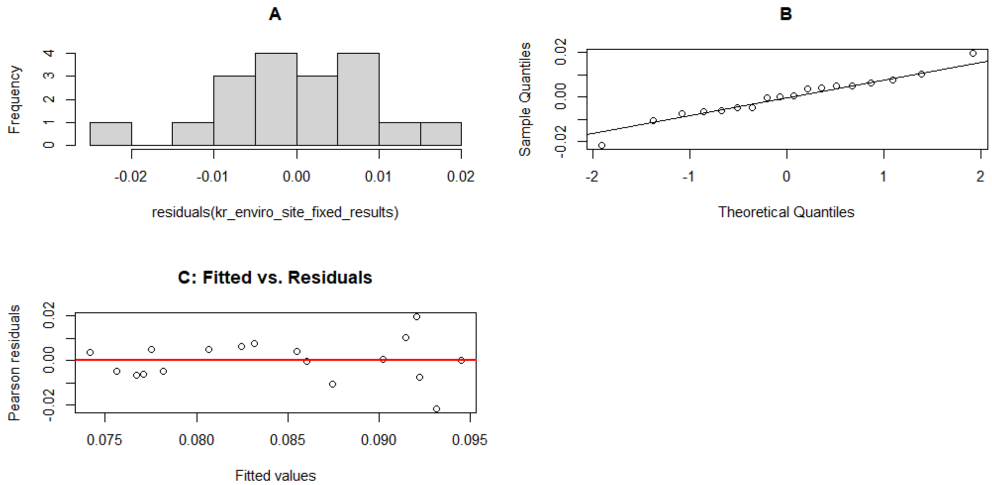



**Figure 7.** Red tea decay rate best fit model assumptions check; belowground biomass has the most influence on lowering Kr, with site as a fixed effect in the model.

# DISCUSSION

Green tea decay rates were extremely variable across sites and various spatial parameters including distance from the meadow edge and distance from the scar out into adjacent vegetation. There was a very strong negative relationship between fine sediment grain size and decay rates. This relationship can be explained by the lack of space in between tightly packed fine sediments, which inhibits the intrusion of porewater into the sediments and limits exposure to oxygen; aerobic decomposition is much faster than anaerobic decomposition (Howard et al., 2021). Rooibos tea was more likely to decay faster in the scarred area compared to adjacent, vegetated positions at 2 of the 3 sites in our study. Rooibos tea was most influenced by belowground biomass, which is known to stabilize sediments and could be associated with different microbial communities – this could explain why rooibos is decaying faster in the scar at majority of our sites, but further data collection would be needed to support this theory. The increased decomposition of recalcitrant material means less organic material, particularly the kind that stays in the environment for longer periods of time, is available to enter the organic matter pool which eventually is stored as carbon. These findings could have important implications for recalcitrant organic matter storage in relation to propeller scars in shallow seagrass meadows.

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