Drakes Estero Restoration Project Eelgrass Monitoring Report: Year 3[1]

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1. Summary

Between August 2016 and May 2017 the National Park Service (NPS) removed 95 wooden oyster racks and associated mariculture debris from Drakes Estero, a shallow estuary within Point Reyes National Seashore, Marin County, California. A total of 3.8 million lbs. of debris was removed from the estero, with the majority including shell, pressure treated wood, and plastic debris (2.8 million lbs.) from the estero floor where it precluded the growth of eelgrass (*Zostera marina*). In order to (1) detect any impacts on eelgrass, (2) document recovery of eelgrass post-restoration, and (3) track changes to benthic communities including non-native species, we implemented a subtidal monitoring program with control sites and analyzed before and after restoration images for percent cover of benthic communities. We did not detect any quantitative impacts of the restoration activities on eelgrass cover. However, based on our field observations immediately following rack and debris removal, we did estimate minimal impacts from restoration activities (setting anchor spuds, accidental digging) that summed to 3,803 ft^2 of eelgrass impacts. This is an order of magnitude less than our permitted (allowed) pre-implementation estimates of 25,730 ft^2. Aerial imagery confirmed that the restoration project remained chiefly within the designated restoration area footprints and minimized incidental damage to eelgrass.

The follow up (Year 1) surveys in September-October 2017 showed similar lack of impacts due to the restoration, but also did not show any indication of eelgrass regrowth in restored areas. However, these surveys were only conducted 4-6 months after completion of the restoration. Surveys in Year 2 (2018) showed modest eelgrass regrowth that did not meet mitigation requirements. However, the most recent (Year 3) surveys in August-September 2019 convincingly show increases in eelgrass cover in each of the three restoration categories. From 2017 to 2019, mean eelgrass cover increased from ~23% to ~53% in *low debris*[4] transects. This recovery is likely due to elimination of shading and disturbance from oyster culture infrastructure. Similarly, the *woody* debris areas showed a significant increase in eelgrass cover from 2017 to 2019 from 46% to 72% cover. The most impacted areas that required clean-up of *major debris* on the estero floor showed less dramatic, but encouraging, patchy increases in eelgrass cover. All of the *major debris* area recovery was on 3 of the 7 treatment areas with the overall mean increasing from 1% to 7% cover. **As of 2019, the increase in eelgrass cover on all three treatment areas was estimated to be 11,376 sf, which is 249% of the required eelgrass mitigation area of 4,564 sf.** Forthcoming analysis of aerial imagery collected during the summers of 2017, 2018, and 2019 will likely greatly refine this estimate.

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[1] Report to satisfy permitting requirement for California Coastal Commission, National Marine Fisheries Service, US Army Corp of Engineers, and the San Francisco Regional Water Quality Control Board.

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[4] For clarity, here we update the Year 1 Report's transect nomenclature *rack* and *stringer* with *low-debris*, and *wood*, respectively. *Major-debris* and *control* transect names remain the same.

2. Introduction

Between August 2016 and May 2017 the National Park Service (NPS) removed 95 wooden oyster racks and associated mariculture debris from Drakes Estero, a shallow estuary within Point Reyes National Seashore, Marin County, California. Prior to project implementation, State and Federal compliance was coordinated with the US Army Corp of Engineers (USACE), the California Coastal Commission (CCC), the National Marine Fisheries Service (NMFS), the San Francisco Regional Water Quality Control Board (SFRWQCB) and NPS. Each of these agencies granted the NPS the required authorization, permitting, and consistency determinations. A chief concern in environmental compliance was that most of the project area occurred within or adjacent to eelgrass beds, a California state species of concern (NOAA Fisheries 2014). To demonstrate that the project adhered to the State of California and NMFS policies of no net loss of eelgrass habitat and function in California, NPS implemented a comprehensive pre and post-restoration eelgrass survey program (plan approved March 9, 2016 – Becker et al. 2018) that targeted four specific restoration responses with paired reference (control) plots.

While eelgrass is widespread in Drakes Estero, the specific project area primarily occurred within the footprint of ninety-five 12' wide by ~150' to 450' long oyster racks (Fig. 1). During the project, contractors under the supervision of NPS removed all aquaculture infrastructure and marine debris to assist a return to conditions supporting natural ecological and hydrologic process within Drakes Estero. Debris was removed from the estero in a three step process that (1) used a mini excavator floating on a barge to remove all wooden rack infrastructure, (2) cleaned bottom debris from non-eelgrass areas using a custom designed excavator bucket to gently scrape the estero floor to remove debris, and (3) used scuba divers to hand pick all debris in eelgrass areas and to collect any remaining debris in from identified non-eelgrass areas. The divers covered the entire rack area footprint (~7 acres) of the project. The project removed all 95 wooden oyster racks that totaled ~5 miles in length by 12' wide and ~10' feet tall and had a mass of approximately 1,000,000 lbs. Extensive bottom debris consisting of discarded PVC oyster tubes, wire, plastic mats, oyster shell, fallen wooden racks, plastic and cement anchors, and live non-native oysters (~2,700,000 lbs.) was also removed from the estuary.

This monitoring project is a targeted plan to document actual project impacts to eelgrass and assess the amount of new eelgrass growth in the areas where eelgrass is most likely to grow within the footprint of the former racks (areas adjacent to existing eelgrass beds that have minimal oyster shell debris) and whether the restoration activities have achieved the 1.2:1 eelgrass mitigation requirement. This monitoring was not an attempt to document the total areal response of eelgrass to the restoration in Drakes Estero, but rather only within the project area. Failure to document that recovery of eelgrass exceeds actual impacts by at least 20% (a 1.2:1 restoration to impact ratio) shall result in further consultation with NMFS and CCC to discuss whether supplemental restoration activities are warranted to achieve this minimum eelgrass mitigation ratio (NOAA Fisheries 2014). Eelgrass monitoring carried out independently by the California Department of Fish and Wildlife immediately pre and post restoration (approx. 18 months) will also provide additional insight into project and estero-wide eelgrass responses to restoration, but was not designed to provide the level of detail needed to determine if minimum eelgrass mitigation requirements have been met. Additionally, researchers at the University of California, Santa

Barbara and the University of Virginia are currently constructing a high resolution map of eelgrass cover in Drakes Estero via unmanned aerial systems (drone) flown during July – September 2017 which will provide additional information on eelgrass status and provide a baseline for change over time. Some of this preliminary imagery appears later in this report and the team is remapping the area in summer 2019.

Table 1. Eelgrass monitoring schedule.

Survey	Time
Pre-project	< 60 days pre-rack area treatment (Fall 2016)
Immediate post-project	< 60 days post- rack area treatment (Spring 2017)
One-year post-project (*baseline*)	September – October 2017
Two years post-project (*Year 2*)	August – October 2018
Three years post-project (*Year 3*)	August – September 2019

Eelgrass cover and growth is seasonal, with higher coverage in the late spring, summer, and early fall (NOAA Fisheries 2014). Therefore to make valid comparisons between treatment and control sites, we used a before-after control impact study design to account for the seasonality of eelgrass (Smokorowski and Randall 2017). This design allowed us to compare control sites to treatment sites throughout the study, with differing trends between sites indicating differing trajectories (and an impact on eelgrass during the restoration).

This report summarizes and compares (1) initial pre-restoration conditions, (2) post-restoration conditions, (3) one-year post-restoration (which was 4-6 months, but during the peak growing season), and (4) two- and three-years post restoration. Assessments (1) and (2) were to primarily assess the impacts of the restoration activities on eelgrass in Drakes Estero and (3) established a baseline eelgrass cover during summer 2017 that serves as a benchmark for mitigation requirements (Table 1). Assessment periods (Years 2 and 3) during August-October 2018 and 2019 are reported here to track recovery of eelgrass required to meet the mitigation ratio.

3. Methods

3.1 Field Methods

Fifty meter transects were established in five different bottom types. The first four were 50 m long with a 0.5 x 0.5 m quadrat image captured every 5 m (11 plots per transect).

- **Control transects** with high eelgrass cover. These were generally parallel to other transect types.
- **Low debris transects** that were under oyster racks within eelgrass beds but were generally devoid of eelgrass directly beneath the racks. Since these racks did not have extensive bottom debris, these were good candidates for eelgrass regrowth.

- **Wood transects** where the rack generally had eelgrass beneath the rack, but large amounts of wooden racks had fallen into the eelgrass. These plots could have suffered damage during the wood and debris removal process.
- **Major debris transects** that were generally devoid of eelgrass and the estero floor beneath the rack was primarily (generally > 50%) covered with a layer of oyster culture debris (plastic tubes, shell, live oysters, wire, and epiphytes on the debris).
- **Bent transects** were designed to run perpendicular to the rack over areas where subsurface wood was to be pulled up through the sediment and through eelgrass. These were approximately 5 m long.

All plots were selected using field reconnaissance to determine areas that met the transect type criteria. If on-site conditions were different when establishing the rack (i.e., no debris in a debris plot), then the oyster rack area was searched until a suitable location for the plot was found. All plots were established with PVC poles and GPS to ~1 m accuracy with a Trimble GPS to revisit at follow up sampling periods. However, the PVC plot markers (except control plots) were removed during the restoration (after pre-restoration monitoring), so plots were reestablished using Trimble GPS and underwater sighting conditions. Marker posts remained in place after the post-restoration sampling event. This re-establishment process was satisfactory for all transects except the bent transects. One-meter relocation precision was acceptable for other transect types since the racks were 4 m wide and generally the edge of the rack footprint was obvious. However, to track changes to bent transects which scars could have been as small as 2” in eelgrass beds, we were not able to relocate transects with sub-meter accuracy. Therefore, we relocated 7 of the pre-restoration surveys bent plots (within a meter) and qualitatively searched the area for approximately 15 m (3-4 bents) on each side of the prior plot along the former rack line for any observable eelgrass scarring due to removal of subsurface timbers. This allowed us to survey 7 bents on each of 7 racks, resulting in observations of 49 locations where bents were removed from beneath the estero floor.

We collected underwater imagery (stills) during snorkel surveys to quantify the percent cover of eelgrass and other community components (including debris and invasive species) underneath oyster racks (Fig. 3). However, videos were only collected during the pre-restoration surveys. Prior to image collection, a floating 50m line with markers every 5 m was placed between transect marker poles. The snorkeler then traveled along the transect line taking a quadrat image every 5m. Transect surveys were conducted during mid to low tides (generally < 3 ft) to allow snorkelers to access the estero floor with the camera quadrat. In eelgrass beds, the quadrat was placed just at the top of the eelgrass canopy and over non-eelgrass areas, the quadrat was held ~10-20 cm above the estero floor.

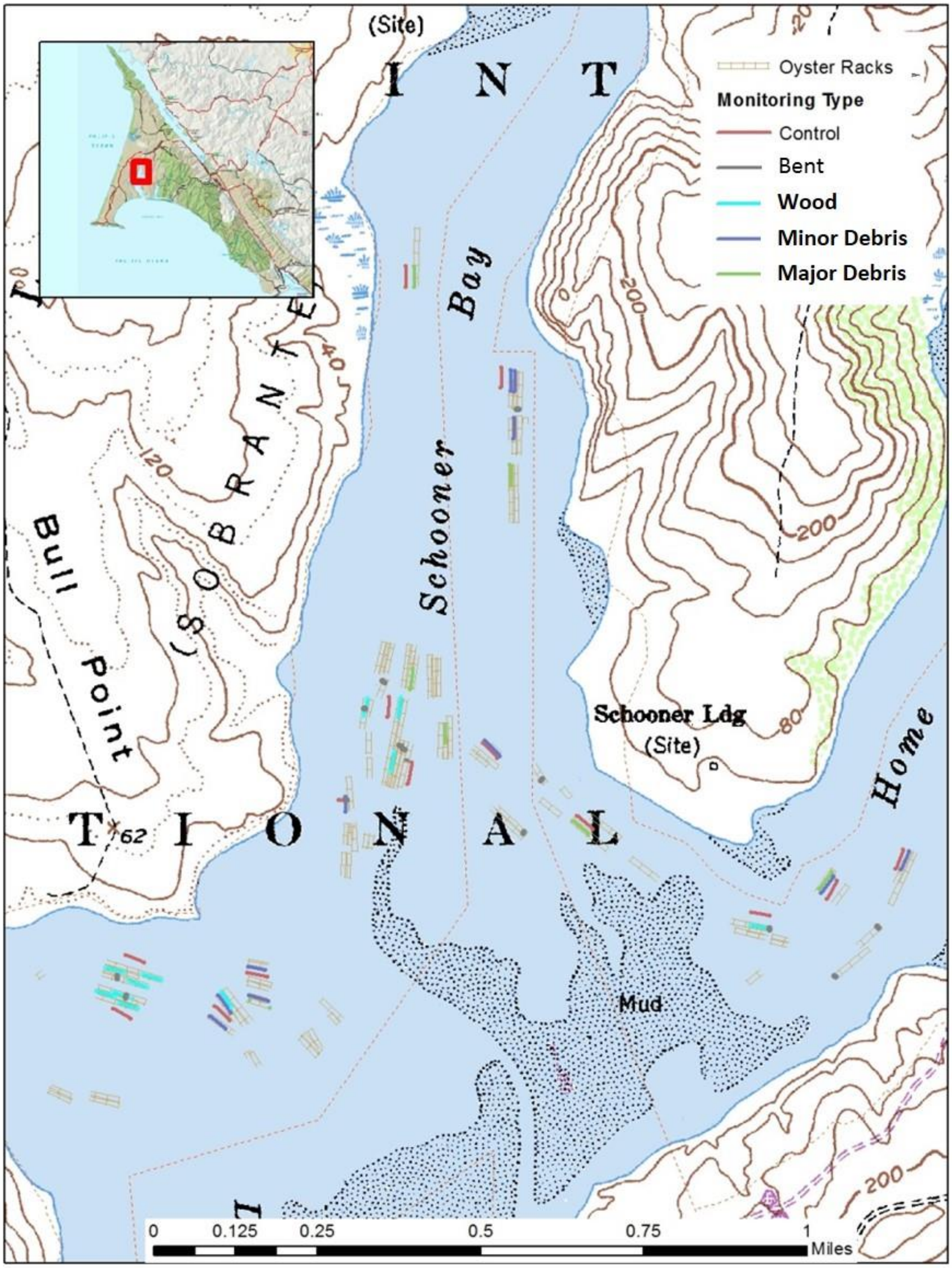

Figure 1. Distribution of oyster racks in Drakes Estero prior to the restoration. Color coding indicates racks and control sites selected for monitoring and monitoring treatment type. See Table 2 for counts of each transect type.

Table 2. Transects used for analyses, grouped by bed. There were 1 or 2 controls per bed. See Becker et al. 2018 for detailed map of racks with bed and letter identifications.

Bed	Controls	Major Debris	Low Debris	Wood	Total
4	1	G	A, B, E		5
6	1,2	B	K		4
8	1,2	F, S		M, N	6
9			A		1
11	1,2	F	B, E, J, K	I	8
22	1,2			A, B, D, E, F, G	8
34	1	A			2
38	1,2	A	B, C		5
41	1			E	2
Total	13	7	11	10	41

The effects of restoration and the status of eelgrass were assessed using areal percent cover of the estero floor using 0.25m^2 quadrat at 5 m intervals along a 50 m transect (11 plots per transect). Equipment included a GoPro Hero 3+ camera in waterproof housing mounted at 44 cm above the quadrat. Percent cover of each species or substrate in each photo was estimated with the assistance of CoralNet (coralnet.ucsd.edu; Beijbom et al. 2015), an online benthic imagery analysis program that utilizes color, texture, and dynamic patch sizing to classify species, and was then proofed visually. Detailed methods and cover classes are reported in Becker et al. 2018.

Our eelgrass monitoring plan indicated we would quantify eelgrass cover under and adjacent the proposed floating dock before installation and after removal. However, the floating dock was relocated to a location with no eelgrass. Therefore, this monitoring was neither needed nor conducted.

This suite of surveys allowed us to quantify:

- Actual impacts to eelgrass from post and cross member removal, which may be different from the approved estimates.
- Recovery of eelgrass from areas shaded/smothered by stringers on the estero floor.
- Recovery of eelgrass impacted around post and cross member removal areas.
- Eelgrass recruitment and growth in restored habitat under racks.

3.2 Analysis

3.2.1 Photoplot Analyses

Percent cover analyses using CoralNet used 50 random points placed on each image and a neural net image analysis learning (after training from us) the spectral signature. A larger number of points has better ability to accurately detect and quantify rarer species, and 50 points generally performs well for species/objects with at least 5% cover and nearly as well as plots with 100 points (Pante and Dustan 2012). Classifications from each image were analyzed for percent cover of 9 cover types collapsed from the original 20+ classes recorded in the field (Becker et al. 2018:

Appendix 8.7). We compared percent cover of eelgrass and other cover types before, after, and at 4-6 months from the end of restoration work, and this latter survey was termed "*Year 1*". The first two surveys (immediate *pre* and *post* restoration) were used to assess baseline eelgrass cover and an immediate post-restoration cover. The difference in these values (once corrected for natural variation in the control (untreated eelgrass) plots) would quantify any impacts from equipment, shading, or direct damage to eelgrass. The 4-6 month follow up ("Year 1") was intended to be a late summer (peak eelgrass growth season) baseline for quantifying any regrowth required under the 1.2:1 mitigation requirement. We then used late summer resurveys in 2018 and 2019 to quantify eelgrass growth from the baseline of Year 1.

Any plots that had 10 or more unclassifiable points (out of 50) were excluded from analyses. The three main reasons for this were (1) data points fell on the quadrat frame, (2) long eelgrass blades near the camera lens obscured large areas below, and (3) limited visibility on some days due to plankton and naturally occurring suspended sediment (Day et al. 1989). If any transect had three or more of the 11 plots of poor quality (generally difficult to discern objects and substrate, even before CoralNet analysis), we resurveyed that transect and used only the updated data.

3.2.2 Univariate Analyses

Temporal and treatment change in eelgrass cover was analyzed in a BACI framework (Smokorowski and Randall 2017, Becker et al. 2018). We used a binomial generalized linear mixed model where points out of 50 (less any "no data" points) were nested by transect within rack group area. Independent variables were survey time and survey type. We also conducted the same analysis using the Bayesian software Stan (Stan Development Team 2017). Stan was run in R using the rstanarm package (Goodrich et al. 2018) with 3 chains, 500 iterations (150 warmup) and a thinning rate of 2. Priors were set with mean 0 and scale = 2.5. Within year temporal variation in eelgrass cover on control transects was also assessed.

3.2.3 Estero Floor Community Analyses

We performed non-metric multidimensional scaling (NMDS) on the nine classes of bottom cover with time and treatment as the grouping variables. Group differences were assessed visually (displaying standard deviations) on the first 2 NMDS axes and using the adonis function in the R-package vegan (Oksanen et al. 2018), which is essentially a multivariate permutation ANOVA. Adonis analyses were blocked by transect type. This method allows a full community assemblage to be described and is useful for visualizing both composition and temporal change in community composition.

3.2.4 Assessment of Eelgrass Impacts and Recovery

We calculated the estero floor area represented by each transect as length (generally 50 m) by rack width (4 m), thus the area represented by most transects was ~200 m^2. This area was multiplied by percent cover for each treatment by time sampling event. Differences in percent cover within treatments before and after restoration represented changes in eelgrass cover and were interpreted as the change in eelgrass area. Any detected loss would be demonstrated in similar fashion to calculate area (percent cover as proxy) needed to meet mitigation ratios.

Because our sampling did not cover all areas where racks were removed and debris cleared, we also used information gleaned from observing the restoration crews to estimate any additional eelgrass impacts. We assumed that the excavator bucket would make up to 1 "mistake" on each transect where eelgrass was adjacent to the eelgrass free area under the rack. A bucket scrape of 3 ft wide scraped for 10 ft would impact 30 ft^2 of eelgrass multiplied by the percent cover of eelgrass in control plots. We also estimated eelgrass damage from any propeller scarring noted by observation teams. These square footage eelgrass impacts on a per event basis (e.g., removal of a post, submerged wood, etc.) were estimated prior to restoration and revised after more information (video and imagery during and after removal) was available.

We added both measured (from transects) and estimated (from observations and field experience) eelgrass impacts to calculate area of eelgrass lost due to the restoration activities. We then calculated the area of eelgrass that would need to be restored to meet the 1.2:1 mitigation ratio (correcting for percent cover of control plot eelgrass).

During the summers of 2017, 2018, and 2019, we collaborated with researchers from the University of California, Santa Barbara and the University of Virginia to obtain high resolution imagery of the restoration area. These images are used to qualitatively contrast the areas of restoration with aerial imagery from March 2015, restoration design plans that show debris and rack conditions, and any potential impacts to eelgrass outside of the intended work areas. That team is currently quantifying changes in eelgrass pre and post restoration. We anticipate quantitative measures of eelgrass recovery from that team during the Summer of 2020.

4. Results

4.1 Surveys and Dataset

Data cleaning and QA/QC reduced the original percent cover dataset to 2,040 quadrat images from the 41 transects (control, major debris, low debris, and wood) collected under racks and adjacent control transects in nine of the twelve oyster rack areas ("beds") where the original 95 oyster racks were located (Table 2). Sixty-two quadrats (3%) were omitted because they had > 9 "no data" points (out of 50) and 3 quadrats (0.1%) were removed due to an error giving them greater than 100% eelgrass cover. Omitted quadrats came almost entirely from pre-restoration control plots (Fig. B2). Representative images from each plot type during pre, post, and Years 1, 2, and 3 are shown in Figure 3.

4.2 Univariate Analyses

Seasonality of eelgrass cover on control plots varied throughout the year, peaking during June – August, and increasing in plot variation in September and October (Figs. 2 & 4). A linear increase in eelgrass cover with month was significant for all plot types (Becker et al. 2018).

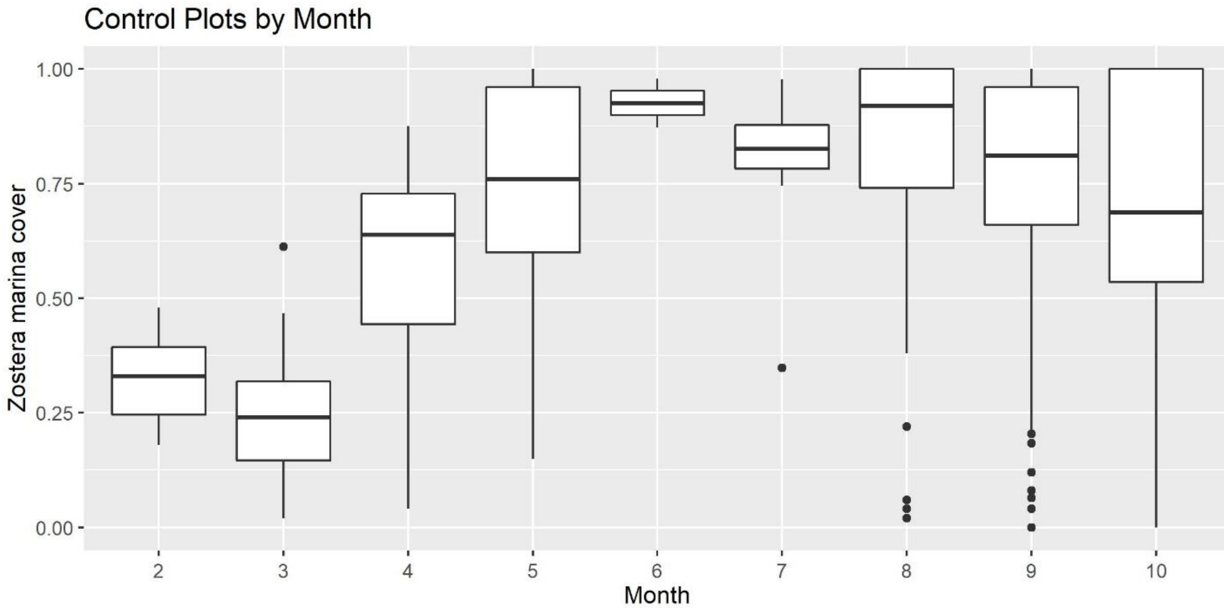

Figure 2. Eelgrass cover on control plots pooled for all survey periods was lowest in February and March, increased on some plots during April and May, was high on all plots during June and July, and then began to increase in variation in August.

Eelgrass cover on control plots had a mean of approximately 81% prior to restoration, dropped to about 56% in the winter just after restoration, and then increased to about 85% during the summer 2017 follow up surveys (Table 4: Year 1). A similar pattern was also evident for the wood transect surveys which also continued to increase in Years 2 and 3. Essentially no eelgrass was present on major debris transects until Years 2 and 3.

Debris cover (Fig. 4) was negligible on control surveys and showed a marked decline post-restoration in the major debris, low debris, and wood transects. However, there was a curious increase in variation (but not the median) of debris on the major debris transects at the Year 1 and 2 sampling events. We attribute this to sampling error since plot locations were not placed in the exact same place along each transect since the transect marker line could drift slightly with the current (but still inside the rack footprint). Similarly, there also were likely some sub-meter variations in sample locations along the transect line at each 5m plot interval. We also opportunistically collected remaining estero floor debris seen on transects (after collecting photo data). Over three seasons, this could have measurably decreased cover of debris, but certainly not to the extent of the differences between years 2 and 3. Additionally, during some of the "*post*" surveys closely following restoration (days to weeks) there was a haze of fine sediment floating a few cm above the estero floor which made it difficult to detect sediment and debris. This may have temporarily decreased the debris detected immediately post restoration, but it should have then been detected again on the Year 1, 2 and 3 surveys.

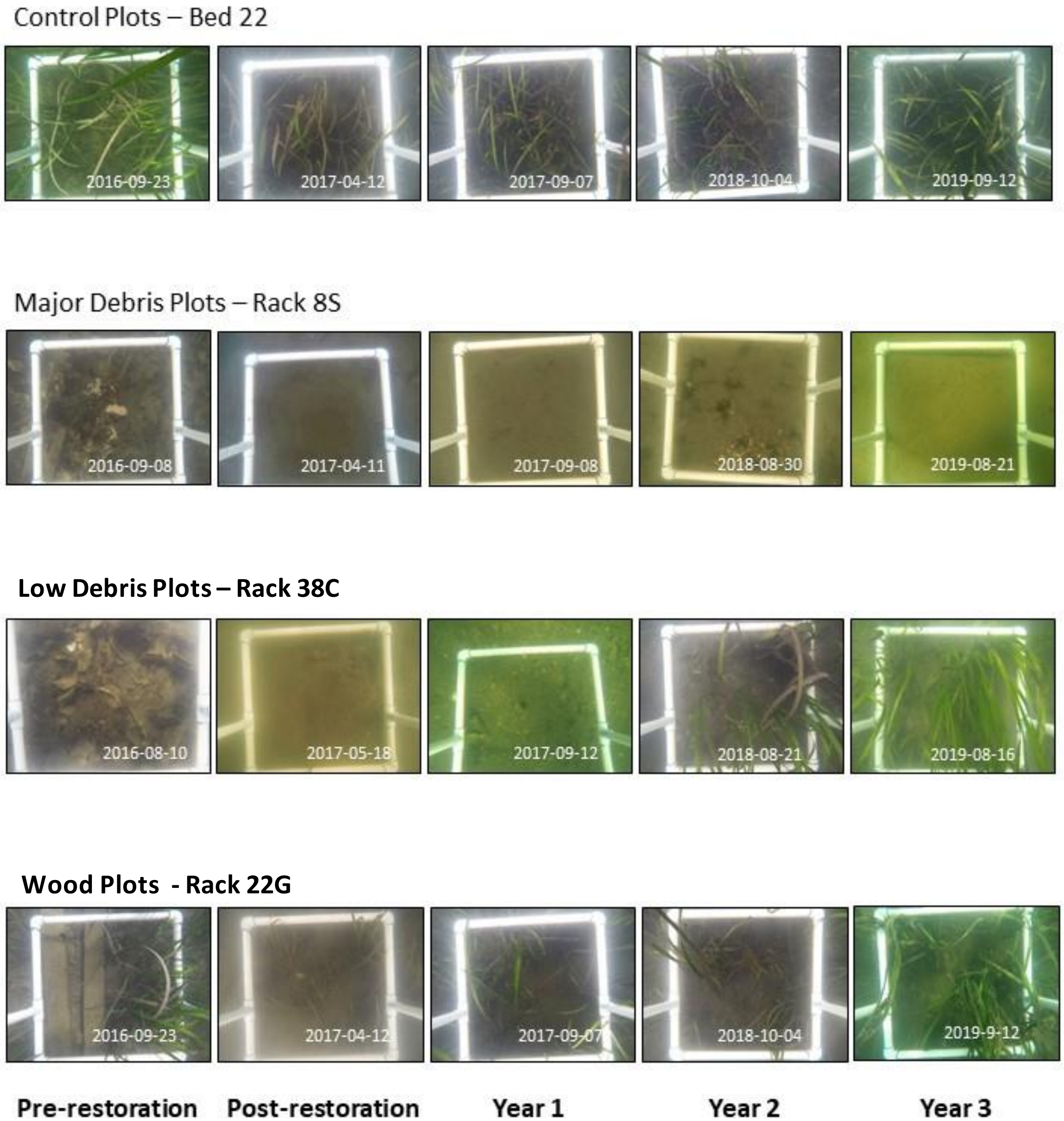

Figure 3. Representative images of photoplots pre, post, 1 year, 2 years, and 3 years after restoration from each of the four plot types. Images are generally from the same area of the transect except for 38C due to water clarity where Year 2 is from another section of the transect

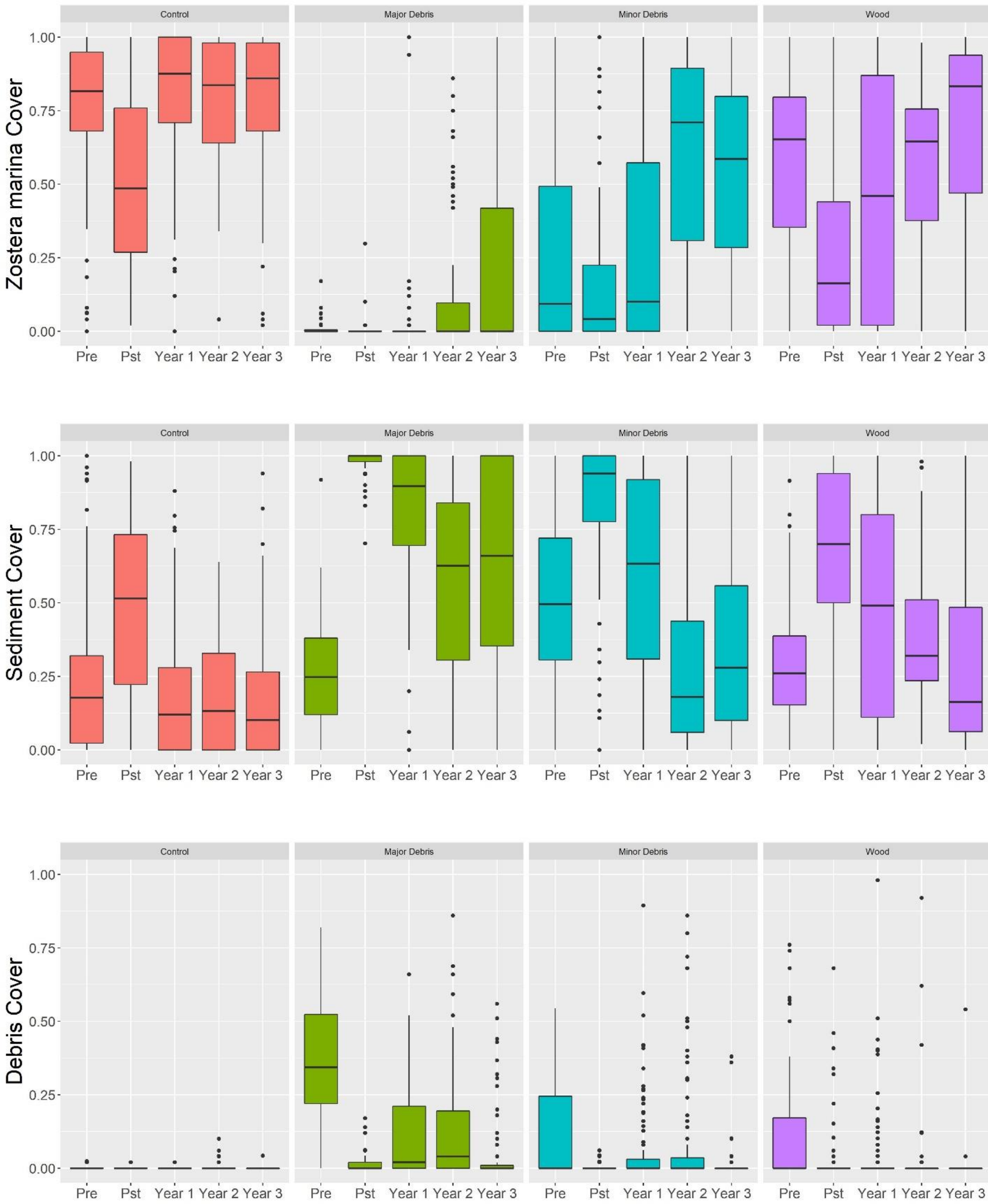

Figure 4. Eelgrass (top), sediment (middle) and debris (bottom) cover for all transects by treatment and sampling period. Note that the top left panel shows seasonality of eelgrass on control plots from early-mid fall (pre >0.75 cover), early spring Post (~0.50 cover), and late summer (Years 1 ,2, and 3: > 0.75 cover), respectively.

For the bent transects that were surveyed only in the pre-restoration periods, follow up visual and photo surveys in the area did not show any eelgrass scarring from bents being removed from the estero floor. We interpreted this as evidence for lack of large-scale scarring or eelgrass impacts from stringer removal.

Despite seasonality in eelgrass cover, major debris, low debris, and wood transects all had lower eelgrass cover than the controls (Table 3, Fig. 5). Both major and low debris transects increased in eelgrass cover from Year 1 to Year 3.

Table 3. Binomial GLMM fixed effects results explaining variation in eelgrass cover over treatment and sample period. **Control treatment and Year 1 were treated as baselines**. Major debris, low debris, and wood transect eelgrass cover were all significantly lower than controls at all time periods (all $P < 0.01$). The overall eelgrass cover for all treatments "Post-restoration" was lower than the "pre-restoration" baseline ($P < 0.01$). There were no significant interactions between treatment and time until Year 2, when low debris transects increased in eelgrass from Year 1. $p < 0.10$ in bold. Bayesian GLMM coefficients, variation and predictions were similar (Fig. B4).

Parameter	Estimate	SE	z	p<
(Intercept)	1.83	0.40	4.59	0.01
Major debris	**-6.38**	**0.71**	**-8.99**	**0.01**
Low Debris	**-3.06**	**0.59**	**-5.19**	**0.01**
Wood	**-2.00**	**0.62**	**-3.21**	**0.01**
Pre	-0.38	0.56	-0.67	0.51
Post	**-1.57**	**0.56**	**-2.80**	**0.01**
Year 2	0.02	0.57	0.04	0.97
Year 3	-0.07	0.56	-0.13	0.90
Major debris:Pre	-0.40	1.04	-0.38	0.70
Low Debris:Pre	-0.03	0.84	-0.04	0.97
Wood:Pre	0.76	0.88	0.87	0.39
Major debris:Post	-0.46	1.07	-0.43	0.66
Low debris:Post	0.56	0.84	0.68	0.50
Wood:Post	0.47	0.87	0.55	0.59
Major debris:Year 2	**1.74**	**0.98**	**1.78**	**0.08**
Low Debris:Year 2	**1.69**	**0.83**	**2.03**	**0.04**
Wood:Year 2	0.28	0.88	0.32	0.75
Major debris:Year 3	**1.97**	**0.99**	**2.00**	**0.05**
Low Debris:Year 3	**1.42**	**0.83**	**1.70**	**0.09**
Wood:Year 3	1.19	0.88	1.35	0.18

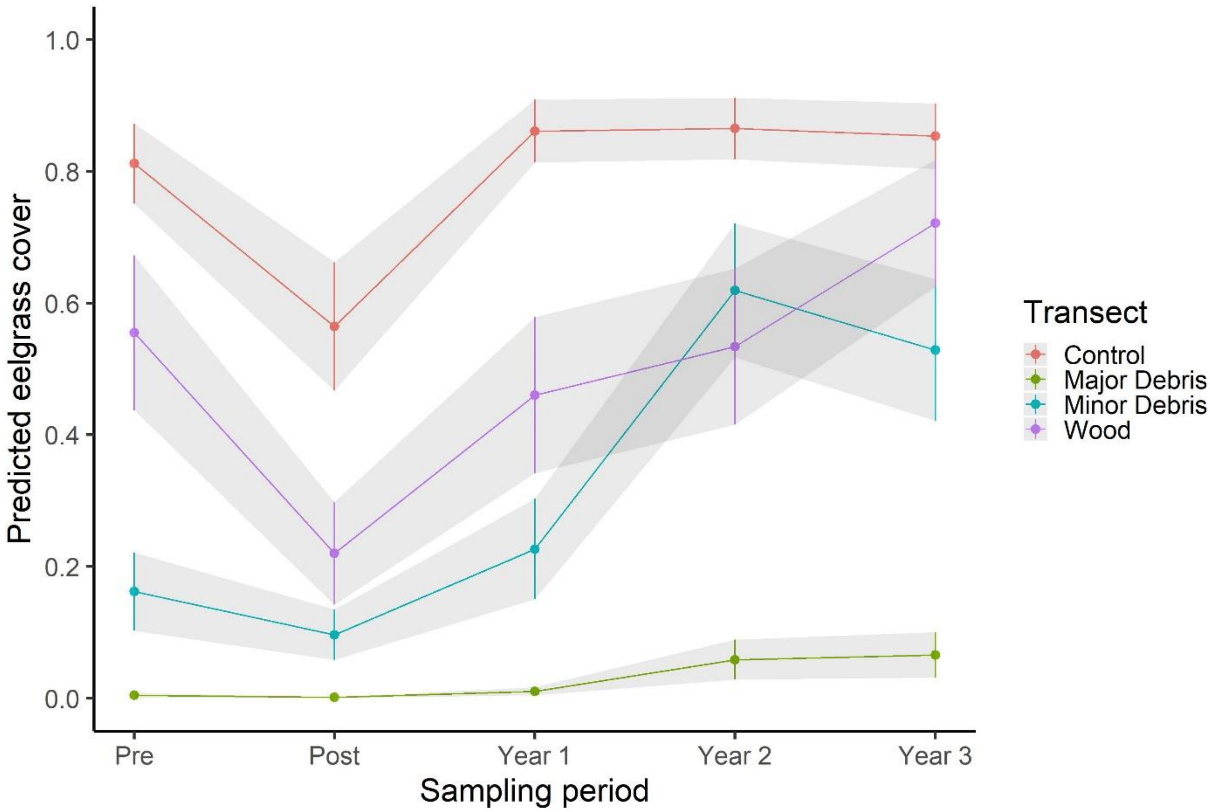

Figure 5. Predicted marginal effects from binomial GLMM of eelgrass cover by sample period and transect type. Errors represent 1 standard error. The decline in cover on *control* plots during "*post*" period is due to the winter sampling period. *Major debris* transects have gained some eelgrass cover while *minor (low) debris* transects made great gains from Year 1 to Years 2-3, and *wood* transects are continuing to increase. The results are similar to Bayesian estimates shown in Figure B4.

Eelgrass growth in Years 2 and 3 on the major debris plots was highly variable (Fig. B2). Three of the 7 transects (38A, 4G, an 8F, see Fig. B2) represented nearly all the eelgrass growth and cover, while the remaining 4 transects persisted as mostly sediment (Fig. 4). Eelgrass growth on low debris and woody plots was more consistent among transects (Fig. B3).

Two low debris transects (6K and 9A) declined in eelgrass cover from year 1 to year 3 (Fig. B2). However, we suspect that this change is due to field errors during transect swimming. If this is the case, the effect on overall eelgrass response for the sum of all low debris transects would be to decrease the estimated cover and therefore makes any increase in cover calculations more conservative. When final imagery for 2017-2019 becomes available, we will compare imagery with in-situ measurements to determine if this is a true error.

4.3 Community Analyses

The 20 different treatment (n = 4) by sampling period (n = 5) comparisons showed that communities clustered around three distinct community assemblage types (Figs. 6A-C). These were eelgrass, debris fields, and bare substrate. Debris fields mainly included debris (wood, plastic), epiphytic algae, live and dead oysters, and *Didemnum vexillum*, an invasive colonial tunicate. The patterns in this analysis are similar to the univariate results but allow a visual interpretation of the entire community assemblage. Permutation tests indicated differences among treatments, time and their interaction (Table 5).

Control plots were remarkably stable over the study period, dominated by eelgrass (Figs. 6A-C). After the restoration and in Year 1, major debris plots were primarily sediment, but in Year 2 are trending toward some opportunistic species of algae (Fig. 6A). Conversely, the low debris transects are trending as anticipated to become more like the control plots dominated by eelgrass (Fig 6B). Similarly, the woody debris transects which already had some eelgrass, are responding well and trending towards the control sites, with less debris than prior to restoration, indicating that any eelgrass disturbed appears to be recolonizing. This pattern is apparent in the eelgrass cover raw data (Fig. 4, top panel), but not detected in the statistical analysis (Table 4, Fig. 5). This is likely due to the wide variation in eelgrass cover on woody debris transects in Year 1 (Fig. 4) midway during regrowth. This high variation makes it difficult to statistically tease out a change from year 1 to year 2, even though the pattern is apparent graphically.

Table 4: Predicted mean and standard error of eelgrass percent cover for each treatment and time period based on binomial GLMM. Values are identical to those in Fig. 5, and similar to those in raw data (Fig. 4A).

Time	Control	Major Debris	Low Debris	Wood
Pre	81 ± 6	0 ± 0	16 ± 6	56 ± 12
Post	56 ± 10	0 ± 0	10 ± 4	22 ± 8
Year 1	86 ± 5	1 ± 1	23 ± 8	46 ± 12
Year 2	86 ± 5	6 ± 3	62 ± 10	53 ± 12
Year 3	85 ± 5	7 ± 3	53 ± 11	72 ± 10

4.4 Estimating Progress of Eelgrass Mitigation

Multiplying 3,803 square foot eelgrass impact estimated in Becker et al. 2018 by the state of California mitigation ratio (1.2:1) resulted in a required eelgrass mitigation area of 4,564 square feet. Progress towards this requirement can be met by using the Year 1 eelgrass cover (Table 4) as a baseline and demonstrating an increase in eelgrass cover in the low debris, major debris, or wood transects. We are not using the immediate post-restoration surveys as the baseline since they were generally in the early spring and not during peak eelgrass growth/cover. The area represented by the survey transects is the length of the transect (150 ft) multiplied by the width of a rack (12 ft) which is 1,800 sf. This is then multiplied by the number of transects in that treatment group (Table 6) and the actual percent cover in Year 1, 2 and 3 (Table 4). The required increases in percent cover for each treatment type as well as estimated Year 1 to Year 3 changes are shown in Table 6.

Table 5. Multivariate non-parametric ANOVA (Adonis) for community composition by transect type and time.

	df	SS	MS	F	R^2	>p
Transect	3	92.3	30.8	286.7	0.25	0.002
Time	4	40.5	10.1	94.4	0.11	0.002
Transect:Time	12	17.03	1.4	13.2	0.05	0.002
Residuals	2021	217.0	0.11		0.59	
Total	2040	366.9			1.00	

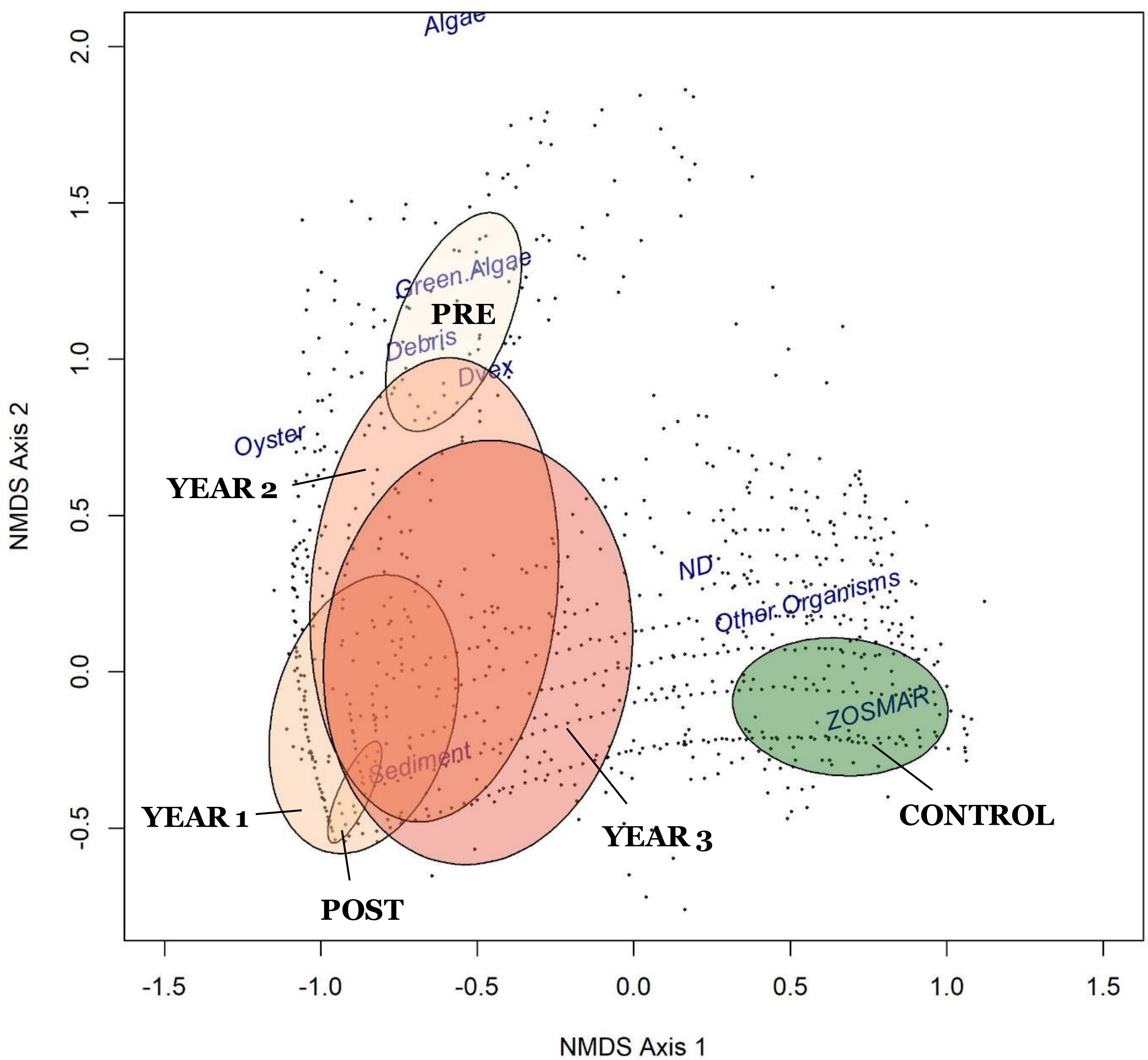

Figure 6A. NMDS plot of all treatment by time interactions for **major debris** transects for pre, post, 1-year, 2-year, and 3-year follow up sample periods. Points (n = 2,040) each represent a quadrat community composition. Polygons represent 0.30 standard deviations and colors get darker through time to aid visualization. Green polygon represents control plots dominated by eelgrass (only Year 3 control is shown for clarity, but all control years are similar). Blue italic text indicates community type represented by that location on the plot (*Dvex* = *Didemnum vexillum*). See Figure 3 for representative photo plots.

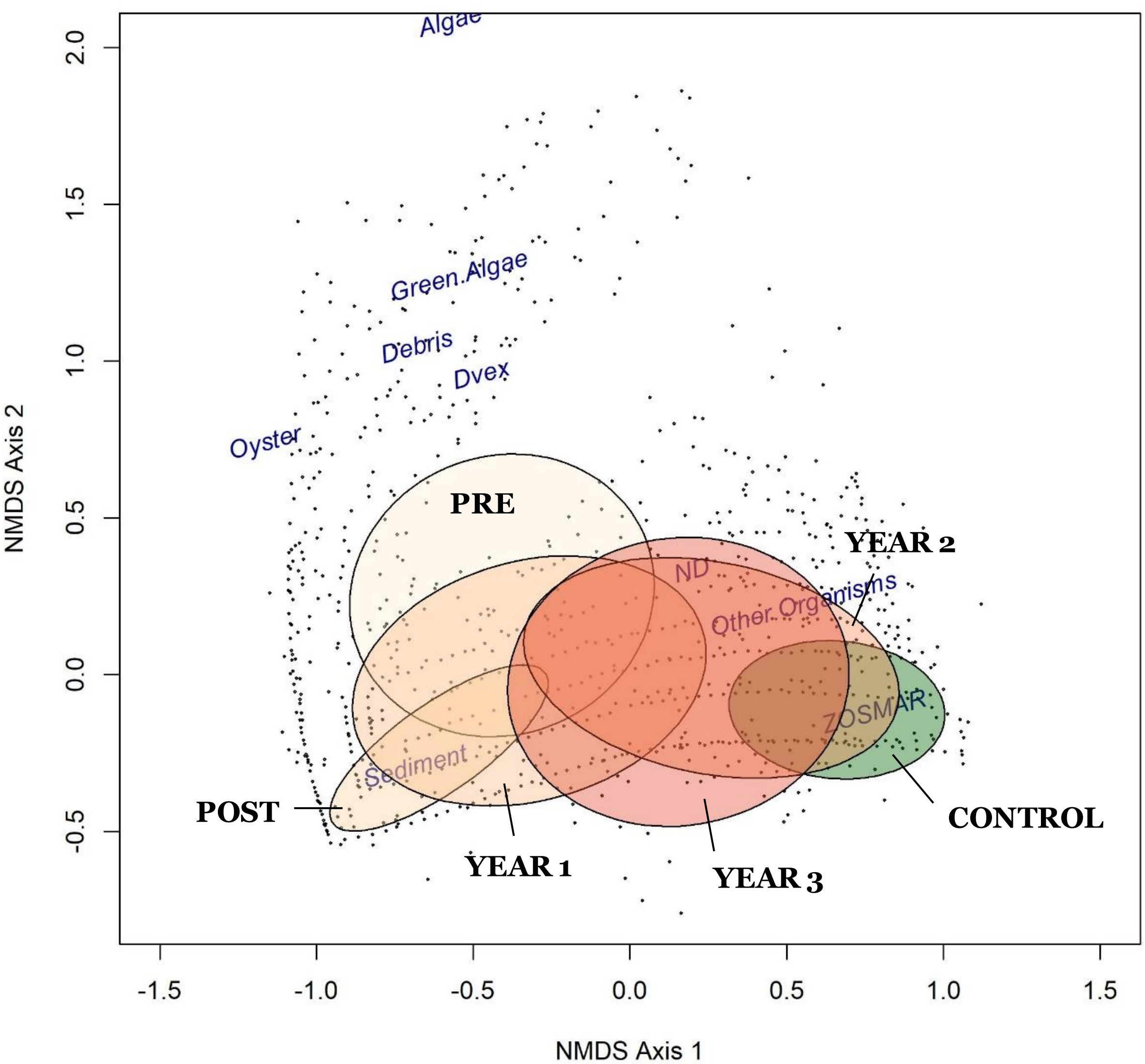

Figure 6B. NMDS plot of all treatment by time interactions for **low debris** transects and control (green). Colors get darker though time. The community trajectory from POST to YEAR 1 to YEAR 2 to YEAR 3 is converging towards the control community. However, there was no additional convergence from YEAR 2 to YEAR 3. See Figure 6A for details.

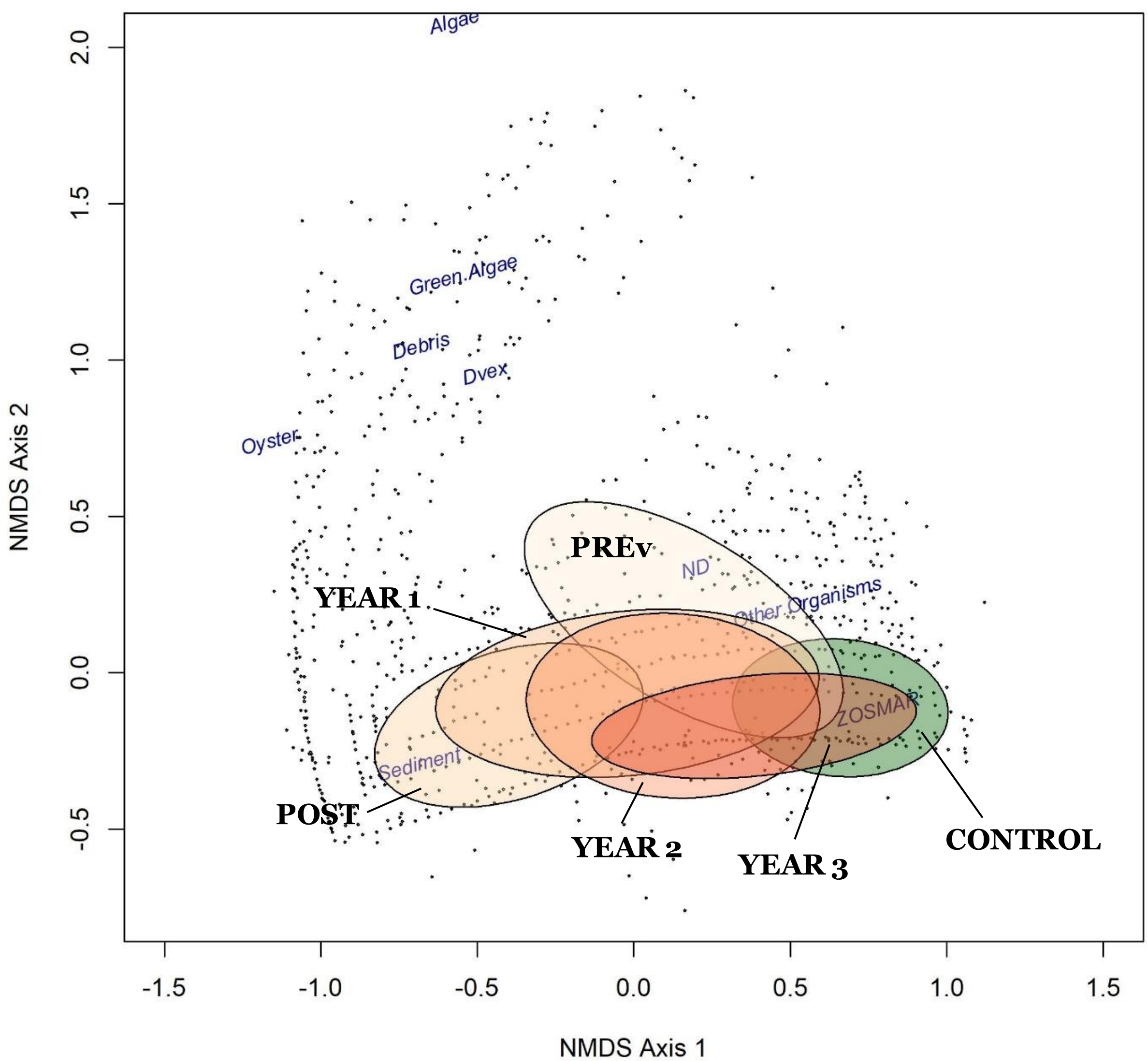

Figure 6C. NMDS plot of all treatment by time interactions for **woody** debris transects and controls (green). Colors get darker though time. The community trajectory from POST to YEAR 1 to YEAR 2 to YEAR 3 is converging towards the control community. See Figure 6A for details.

When considering *only surveyed transect area*, we estimate 11,376 sf of new eelgrass grew from Year 1 to Year 3 which is 249% of the eelgrass mitigation requirement established in our Year 1 Report (Becker et al. 2018). Therefore, we have greatly exceeded the required eelgrass mitigation area. Forthcoming analysis of aerial imagery form the all restoration areas collected during the summers of 2017, 2018, and 2019 will likely greatly refine and potentially increase our estimate based solely on in-water transect surveys.

5. Discussion

Estero floor communities are undergoing succession in a predictable fashion after restoration. In low-debris and woody transect areas post-restoration eelgrass recovery is approaching the percent cover seen on the control transects. This growth, along with the small amount of eelgrass growth on major debris transects satisfies the eelgrass mitigation requirements. While overall, major debris transect areas showed a small increase from 1 to 7% cover, all of this was due to large increases of ~20-75% on 3 transects, and essentially no eelgrass growth on the other 4 transects. Additional monitoring of major debris transects would be required to determine whether these transects will either take more time to recover or may become a weedy community dominated by algae. Currently, the major debris plots not filling in with eelgrass tend to remain sediment covered. Additional sediment studies could help explain the sharp divergence in regrowth.

Table 6. Area represented by each transect sampling treatment, percent increase in cover within any *single* treatment type required to meet mitigation requirement of 4,564 square feet, and acreage of eelgrass growth. A combination of increase among 2 or 3 treatment types would be summed to require a smaller percent increase within any single treatment type. * indicates standard errors do not overlap (see Table 4). Total eelgrass growth within surveyed area from Year 1 to Year 3

Treatment	Transects	Survey area (sf)	Percent increase needed	Percent change Year 1 to Year 3*	Eelgrass growth Year 1 to Year 3 (sf)
Control	13	NA	NA	-1	NA
Low debris	11	19,800	23	30*	5940
Major debris	7	12,600	29	6*	756
Wood	10	18,000	26	26*	4680
Sum	41	50,400			11,376

Community trajectories of the low debris transects appears to be trending towards the control transects (Fig. 6b). Conversely, the major debris transect community is trending towards the pre-restoration conditions, however, this grouping is highly variable and essentially bimodal with some transects doing well and others remaining bare. A concern would be if there is a trend towards a weedy disturbance community primarily harboring opportunistic algae such as *Ulva spp.* and *Gracilaria spp.* rather than eelgrass.

We also noted additional evidence for eelgrass regrowth in the main boating channel from the former oyster facility to the center of Home Bay. In 2018, much of the channel appears to have narrowed considerably with eelgrass filling in along the edges. We do not yet have 2017-2019 comparison imagery, but a narrowing of the channel with eelgrass infill during 2018 is shown in Fig. 8 and this is corroborated by our on the water observations.

Figure 7. Aerial image examples of eelgrass regrowth from 2017 - 2018 in Bed 38 (Home Bay) for rack 38C and D. The left panel (2017) shows racks approximately 6 months after rack and bottom debris removal. The right panel (2018) shows patches of eelgrass growing into the removal areas. Inset (bottom right) shows close up of eelgrass (species confirmed by high resolution imagery and field observations) growing into bare patches. In this example, only rack 38C (left rack) was monitored with snorkel surveys (Table 1, Fig. 2B). 2019 imagery is still being processed.

The restoration goal over time is for all the plot type communities to converge with the control plots. While the low debris and wood transects are indeed converging with the controls, the major debris transects in many cases (4 of 7) are not yet showing regrowth. While this does not affect reaching our required mitigation goal, it does affect the NPS goal to maximize eelgrass restoration potential. We are encouraged that the newly cleared low debris areas are not trending towards “weedy” sites, but additional monitoring of the major debris areas will be

Figure 8. Summer 2018 image of Schooner Bay boating channel showing growth of eelgrass in box, nearly eliminating the channel. Summer 2019 imagery is still being processed.

needed to understand how the community responds over time in these areas as they could experience a community shift to weedy species (*Ulva* spp. and other alga, tunicates etc.) rather than eelgrass (Young et al. 2001). Furthermore, such a weedy state could be temporary or long-term. Similarly, we may continue to see the same trend we have seen thus far, with some major debris transects regrowing eelgrass well and others remaining mostly bare sediment due to unknown conditions that inhibit eelgrass colonization or growth. Because many of the currently eelgrass free areas are directly adjacent to eelgrass (few m), this restoration project will be a good experiment to assess spread of weedy communities vs. eelgrass vs. no change post-restoration. Sediment, microbiome, depth alteration during restoration, and other more detailed in-situ studies would be required to explain the trends thus far (McGlathery et al. 2012, Ettinger et al. 2017).

We consider the documentation in this report to satisfy the Drakes Estero eelgrass mitigation requirements required by the California Coastal Commission, the National Marine Fisheries Service, the Regional Water Quality Control Board and the Army Corp of Engineers. As funds are available, the NPS plans to continue a reduced level of eelgrass community monitoring and ecological study in the estero and will continue to keep these agencies apprised of new developments or issues.

6. Acknowledgements

The Drakes Estero restoration and monitoring was funded by the National Park Foundation and the National Park Service Centennial Challenge Program. Restoration was performed under permits and authorizations from the California Coastal Commission, National Marine Fisheries Service (NMFS), The California Regional Water Quality Control Board (CEQA lead), US Army Corp. of Engineers, and the National Park Service (NEPA lead, Wilderness Minimum Requirements Analysis). Brian Meux (NMFS) and Cassidy Teufel (California Coastal Commission) reviewed and approved the Drakes Estero Eelgrass Monitoring plan (Becker et al. 2018, Appendix C). Fred Hetzel (SFRWQCB) provided useful feedback on previous reports and presentations. Andrew Weltz (California Department of Fish and Wildlife) provided useful information on field survey design; and Max Castorani (University of Virginia) and Thomas Bell (University of California, Santa Barbara) provided the 2017 - 2019 aerial imagery. Matt Lau, Leslie Adler-Ivanbrook, Cicely Muldoon, Steve Mietz, Sarah Wakamiya, Bella Reyes, Jeff Jewhurst, Erin Davenport, Dylan Voeller, Grey Arena, Seth Rosen, Molly Rosen, Jack Williams, Sam Kraft, Dane Horowski, and Austin Exelby assisted with on boat data collection.

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Appendix A: Bed, transect and quadrat notes related to image analysis

2018

1. Transect 11 Control 1: The tunicates *Botrylloides* and *D. vexillum* were apparent on images but were possibly underrepresented with point counts.

2. Bed 4: Control transects had heavy epiphyte cover on eelgrass.

3. Bed 22, Control 2: Eelgrass had an unidentified gray fouling organism on eelgrass. It may be dead or decaying *D. vexillum* as some portions were flesh colored like *D. vexillum*.

2019

1. **Major debris photos** showed a lot of bare sediment. Some of the oyster shells could have been buried. The major debris photos that had eelgrass probably did not block the view of wood or plastic debris but may have blocked the view of oyster shells. The difference could also be due to slight differences in where we took the photos along the transect line.

2. Filamentous *Ulva* was seen in **Bed 4** that we did not notice in prior years (although see 2018 notes above for Bed 4.

Appendix B: Additional Figures

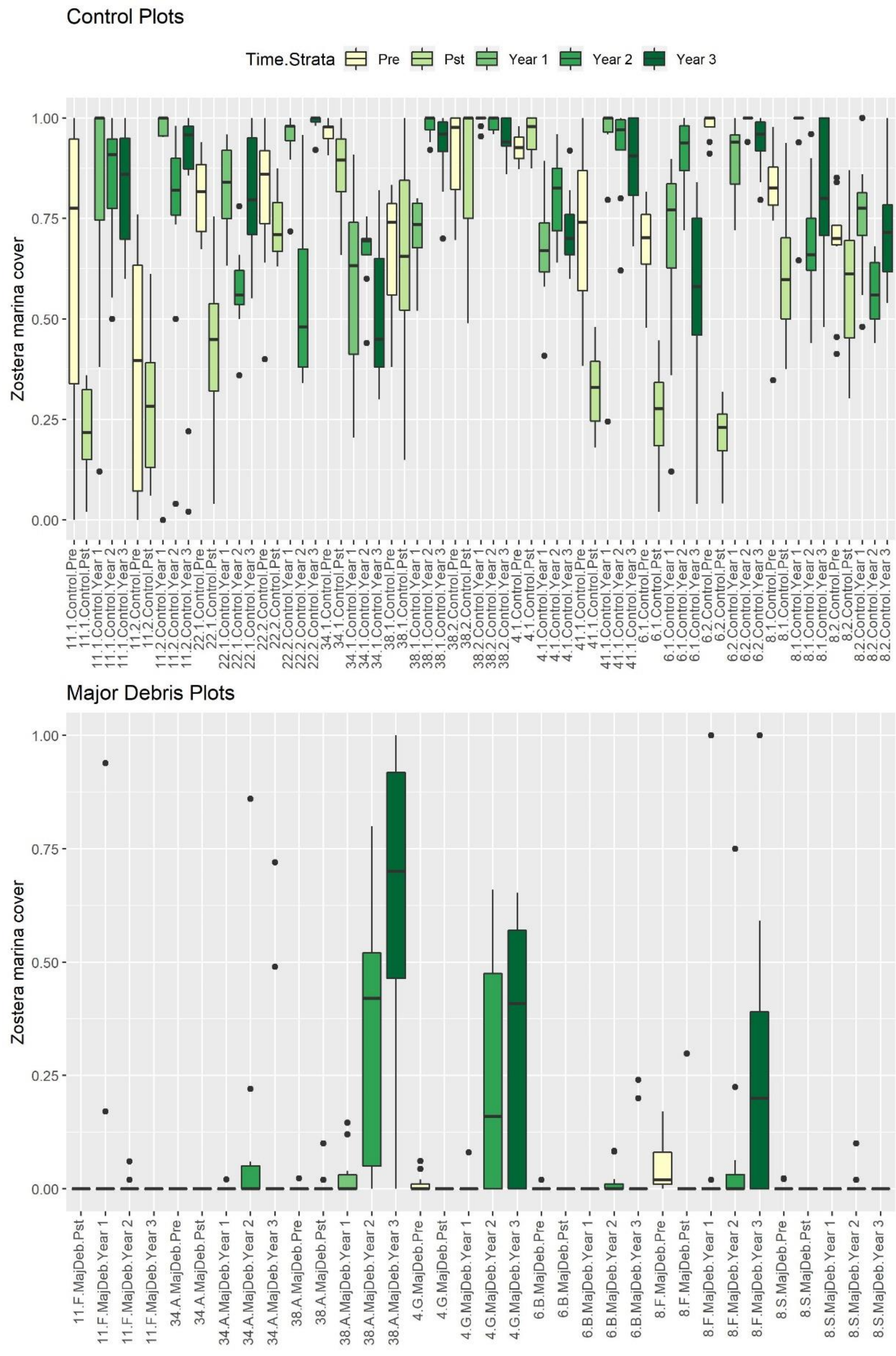

Figure B1: Transect level eelgrass cover on *control* and *Major Debris* plots through time.

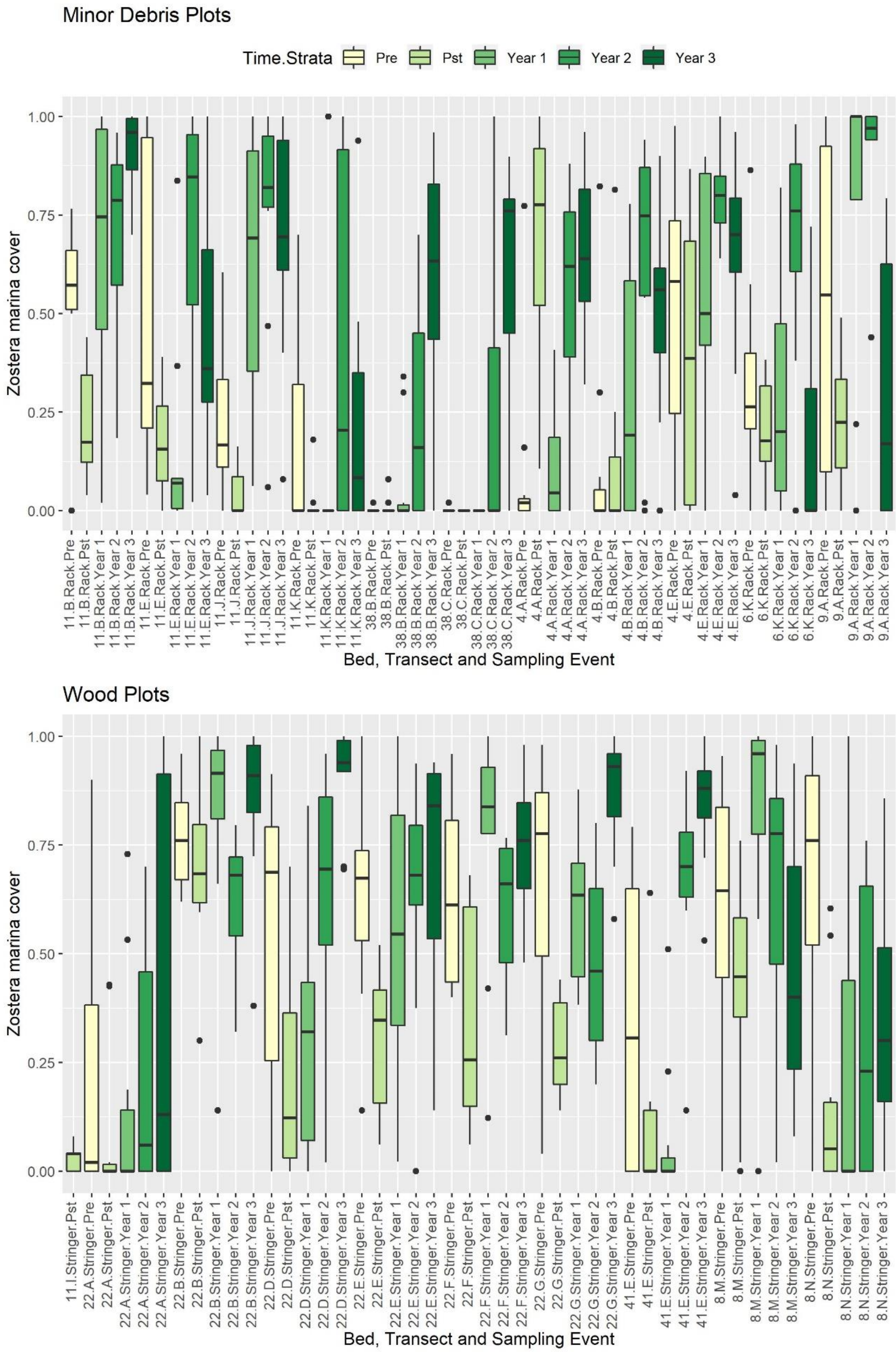

Figure B2: Transect level eelgrass cover on *low (minor) debris* and *wood* transects through time.

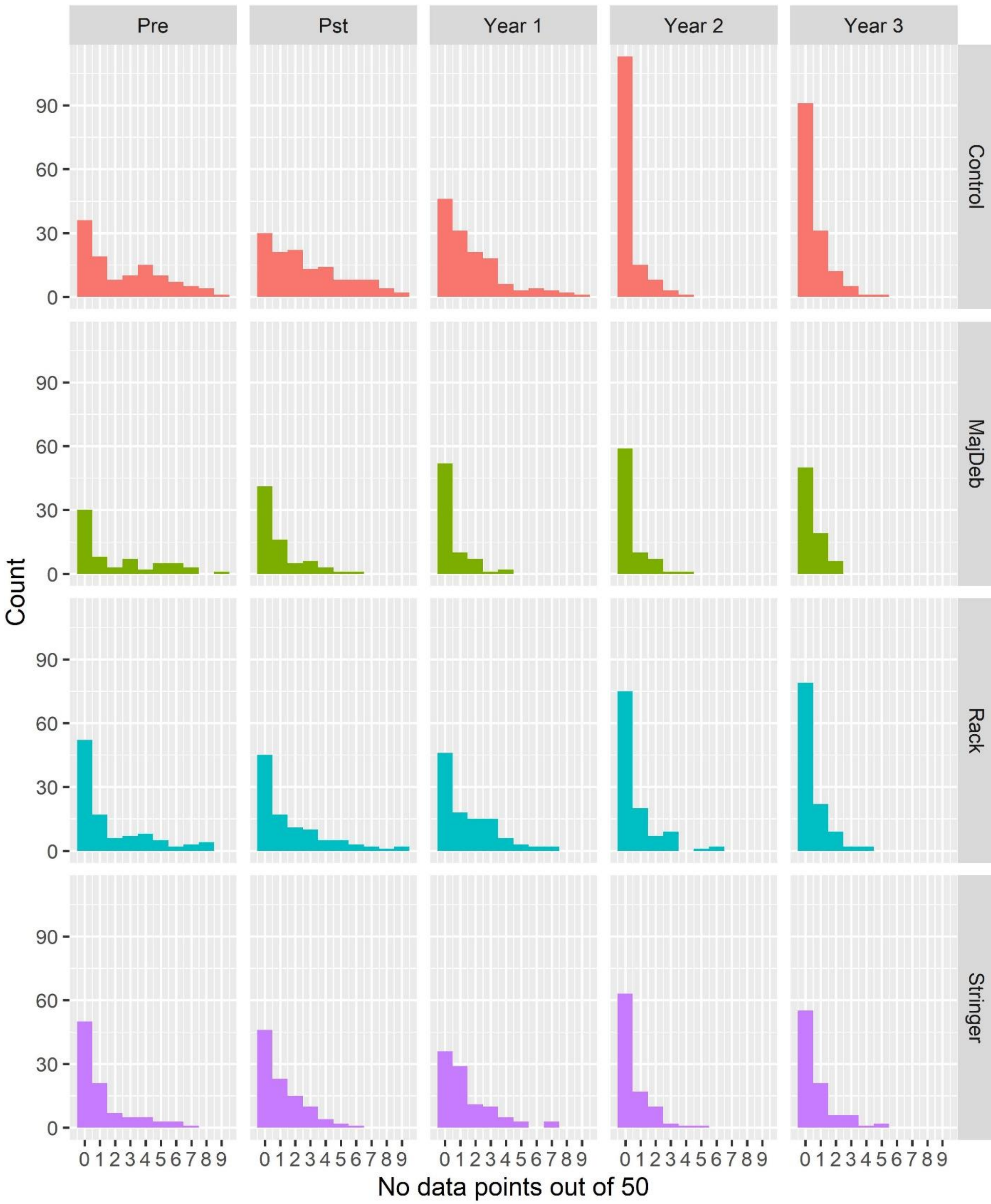

Figure B3. Frequency of "no data" points out of 50 for all quadrats. Plots with >9 "no data" points were removed from further analyses leaving an analysis dataset of 2040 plots within 41 transects over five sampling periods. The five sampling periods move from left to right and each row represents a treatment type.

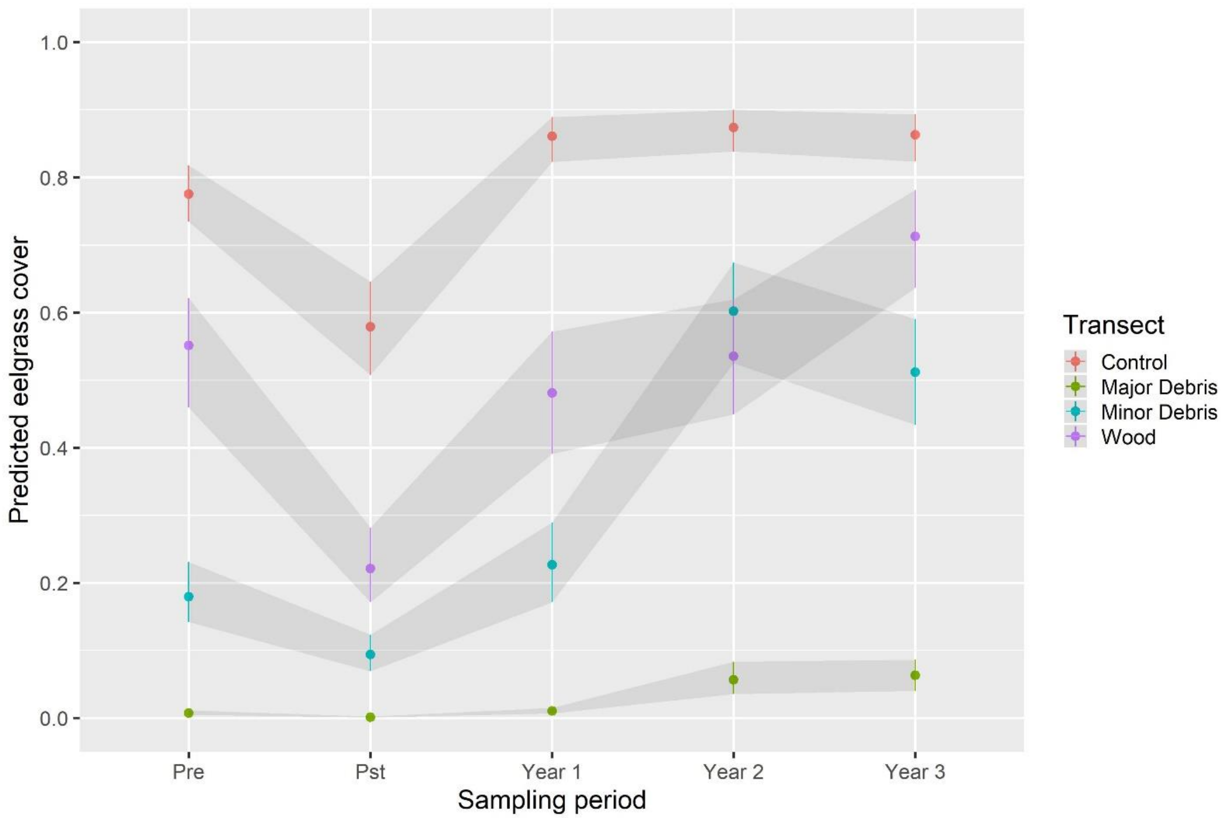

Figure B4. Predicted eelgrass cover by time and survey type from Bayesian binomial GLMM. Results are essentially identical to the frequentist binomial GLMM (Fig. 5). Error bars represent the middle 50% of the prediction which is not exactly analogous to Figure 5.