# Supplementary Materials

## Table S1.

Sample size and the levels of the categorical variables of treatment intensity by park district and treatment type

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sub-dataset | Rincon Mountain District, chemical treatment | Rincon Mountain District, mechanical treatment | Tucson Mountain District, chemical treatment | Tucson Mountain District, mechanical treatment |
| Sample size | 1508 | 590 | 510 | 554 |
| Levels of total years of treatment | 2, 3, 4, and 5+ years | 2, 3, and 4+ years | 2, 3, 4, and 5+ years | 2, 3, 4, and 5+ years |
| Levels of average years of treatment gap | 0, 1, 2, 3-4, and 5+ years | 0, 1, 2, 3-4, and 5+ years | 0, 1, and 2+ years | 0, 1, 2, and 3+ years |

## Table S2.

Pairwise comparisons within the GLS model where initial *Pennisetum ciliare* cover (log10 transformed) was the response variable and total years of treatment or average years of treatment gaps was the explanatory variable. The differences with *p* values lower than 0.05 are in **bold**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contrast | Difference in estimated marginal means of (log10 transformed) initial *P. ciliare* cover | Standard error | Degrees of freedom | *t* value | *p* value |
| Levels of total years of treatment | | | | | |
| **3 – 2** | **0.246** | **0.044** | **3073** | **5.556** | **< 0.0001** |
| **4 – 2** | **0.534** | **0.058** | **2953** | **9.193** | **< 0.0001** |
| **(5+) – 2** | **0.771** | **0.074** | **2937** | **10.373** | **< 0.0001** |
| **4 – 3** | **0.288** | **0.061** | **2733** | **4.762** | **< 0.0001** |
| **(5+) – 3** | **0.525** | **0.075** | **2785** | **6.969** | **< 0.0001** |
| **(5+) – 4** | **0.237** | **0.082** | **2654** | **2.907** | **0.004** |
| Levels of average years of treatment gaps | | | | | |
| **1 – 0** | **-0.103** | **0.049** | **3107** | **-2.111** | **0.035** |
| **2 – 0** | **-0.133** | **0.054** | **3138** | **-2.452** | **0.014** |
| **(3-4) – 0** | **-0.231** | **0.071** | **3124** | **-3.278** | **0.001** |
| **(5+) – 0** | **-0.256** | **0.097** | **3060** | **-2.649** | **0.008** |
| 2 – 1 | -0.030 | 0.060 | 3101 | -0.494 | 0.621 |
| (3-4) – 1 | -0.129 | 0.076 | 3136 | -1.699 | 0.089 |
| (5+) – 1 | -0.153 | 0.101 | 3072 | -1.514 | 0.130 |
| (3-4) – 2 | -0.099 | 0.075 | 3135 | -1.308 | 0.191 |
| (5+) – 2 | -0.123 | 0.100 | 3100 | -1.235 | 0.217 |
| (5+) – (3-4) | -0.024 | 0.108 | 3100 | -0.225 | 0.822 |

## Table S3.

Pairwise comparisons of treatment effectiveness among park districts (TMD = Tucson Mountain District, RMD = Rincon Mountain District), treatment type, and their interactions within the most parsimonious GLS model. Significant pairwise differences (*p* < 0.05) are in **bold**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contrast | Difference in estimated marginal means of treatment effectiveness index | Standard error | Degrees of freedom | *t* value | *p* value |
| TMD Chemical - RMD Chemical | 0.031 | 0.110 | 466 | 0.278 | 0.781 |
| **RMD Mechanical - RMD Chemical** | **-0.490** | **0.080** | **1007** | **-6.101** | **< 0.0001** |
| TMD Mechanical - RMD Chemical | -0.065 | 0.096 | 548 | -0.676 | 0.499 |
| **RMD Mechanical - TMD Chemical** | **-0.521** | **0.111** | **682** | **-4.710** | **< 0.0001** |
| TMD Mechanical - TMD Chemical | -0.096 | 0.116 | 764 | -0.823 | 0.411 |
| **TMD Mechanical - RMD Mechanical** | **0.425** | **0.096** | **591** | **4.411** | **< 0.0001** |

## Table S4.

Pairwise comparisons of treatment effectiveness among total years of treatment within the most parsimonious GLS models, shown by park district and treatment type. Only results from models where total years of treatment was selected as a significant variable were shown in the table. Significant pairwise differences (*p* < 0.05) are in **bold**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contrast | Difference in estimated marginal means of treatment effectiveness index | Standard error | Degrees of freedom | *t* value | *p* value |
| Rincon Mountain District, chemical treatment | | | | | |
| 3 – 2 | -0.044 | 0.061 | 1407 | -0.727 | 0.468 |
| 4 – 2 | -0.084 | 0.071 | 1418 | -1.175 | 0.240 |
| **(5+) – 2** | **-0.273** | **0.094** | **1381** | **-2.911** | **0.004** |
| 4 – 3 | -0.039 | 0.073 | 1210 | -0.542 | 0.588 |
| **(5+) – 3** | **-0.229** | **0.094** | **1310** | **-2.428** | **0.015** |
| (5+) – 4 | -0.189 | 0.098 | 1291 | -1.940 | 0.053 |
| Tucson Mountain District, mechanical treatment | | | | | |
| **3 – 2** | **0.237** | **0.108** | **538** | **2.193** | **0.029** |
| 4 – 2 | 0.306 | 0.157 | 547 | 1.946 | 0.052 |
| **(5+) – 2** | **0.523** | **0.210** | **518** | **2.490** | **0.013** |
| 4 – 3 | 0.069 | 0.173 | 535 | 0.401 | 0.689 |
| (5+) – 3 | 0.286 | 0.220 | 490 | 1.300 | 0.194 |
| (5+) – 4 | 0.216 | 0.237 | 476 | 0.912 | 0.362 |

## Table S5.

Pairwise comparisons of treatment effectiveness among average years of treatment gap within the most parsimonious GLS models, shown by park district and treatment type. Only results from models where average years of treatment gaps was selected as a significant variable were shown in the table. Significant pairwise differences (*p* < 0.05) are in **bold**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contrast | Difference in estimated marginal means of treatment effectiveness index | Standard error | Degrees of freedom | *t* value | *p* value |
| Rincon Mountain District, chemical treatment | | | | | |
| 1 – 0 | 0.092 | 0.064 | 1385 | 1.450 | 0.147 |
| 2 – 0 | -0.032 | 0.072 | 1491 | -0.449 | 0.654 |
| (3-4) – 0 | -0.170 | 0.090 | 1497 | -1.888 | 0.059 |
| **(5+) – 0** | **-0.615** | **0.116** | **1483** | **-5.297** | **< 0.0001** |
| 2 – 1 | -0.124 | 0.076 | 1456 | -1.644 | 0.100 |
| **(3-4) – 1** | **-0.262** | 0.095 | 1485 | -2.744 | 0.006 |
| **(5+) – 1** | **-0.707** | 0.121 | 1494 | -5.821 | < 0.0001 |
| (3-4) – 2 | -0.138 | 0.096 | 1433 | -1.436 | 0.151 |
| **(5+) – 2** | **-0.583** | **0.122** | **1497** | **-4.783** | **< 0.0001** |
| **(5+) – (3-4)** | **-0.445** | **0.131** | **1483** | **-3.390** | **< 0.0001** |
| Rincon Mountain District, mechanical treatment | | | | | |
| 1 – 0 | -0.098 | 0.173 | 426 | -0.567 | 0.571 |
| 2 – 0 | -0.136 | 0.114 | 429 | -1.199 | 0.231 |
| **(3-4) – 0** | **-0.381** | **0.120** | **548** | **-3.166** | **0.002** |
| **(5+) – 0** | **-0.782** | **0.179** | **463** | **-4.359** | **< 0.0001** |
| 2 – 1 | -0.038 | 0.192 | 386 | -0.200 | 0.842 |
| (3-4) – 1 | -0.283 | 0.200 | 452 | -1.419 | 0.157 |
| **(5+) – 1** | **-0.684** | **0.240** | **510** | **-2.847** | **0.005** |
| (3-4) – 2 | -0.245 | 0.145 | 485 | -1.688 | 0.092 |
| **(5+) – 2** | **-0.645** | **0.198** | **523** | **-3.253** | **0.001** |
| **(5+) – (3-4)** | **-0.401** | **0.203** | **503** | **-1.971** | **0.049** |
| Tucson Mountain District, chemical treatment | | | | | |
| 1 – 0 | -0.145 | 0.094 | 470 | -1.544 | 0.123 |
| (2+) – 0 | 0.167 | 0.123 | 492 | 1.353 | 0.177 |
| **(2+) – 1** | **0.312** | **0.136** | **482** | **2.294** | **0.022** |

## Figure S1.

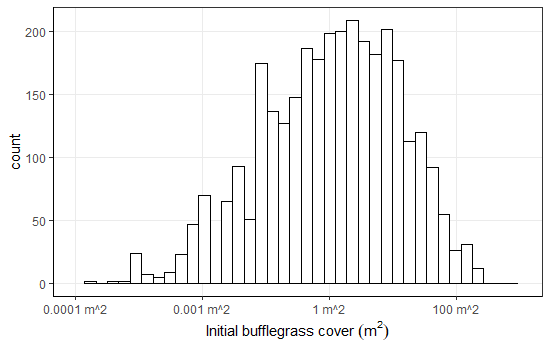
Calculation of total *Pennisetum ciliare* cover within a 20 m × 20 m grid cell. The green polygons represent polygons in which treatment and *P. ciliare* percent canopy cover were recorded within a fiscal and water year. Polygon 1 and 2, with an area of *a*1 and *a*2 fall within the same grid cell. Polygon 3 partially overlaps with grid cell A and the area of the overlapping area is *a*31. The *P. ciliare* percent canopy cover (*c*) shown in each polygon is the midpoint of the percent canopy cover class recorded in each polygon (e.g., 38% is the midpoint of 26-50%). The total *P. ciliare* cover in the grid cell, shown at the bottom of the figure, is the sum of net *P. ciliare* cover of all polygon areas that fall within the grid cell.

**Chart

Description automatically generated with medium confidence**

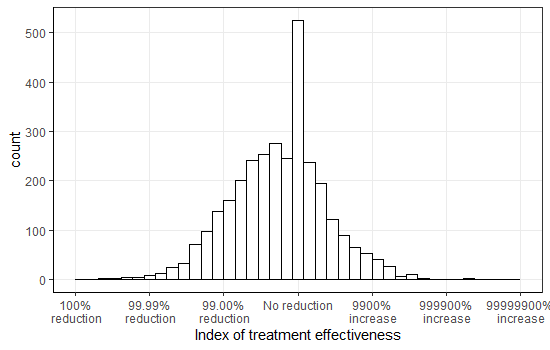
## Figure S2.

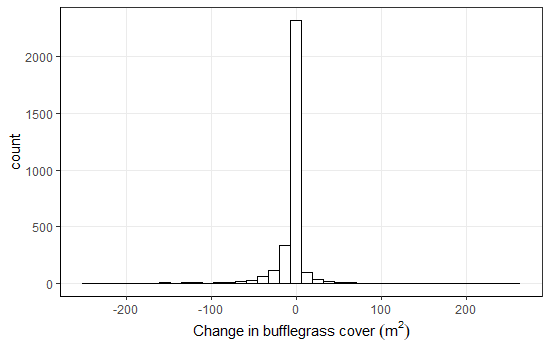
The distribution of initial buffelgrass (*Pennisetum ciliare*) cover in a 400 m2 cell did not deviate substantially from a normal distribution on a log scale and had a median of 1.29 m2 and a mean of 1.05 m2.

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## Figure S3.

(A) The distribution of the treatment effectiveness index has a normal distribution compared to (B) a difference of post-treatment and initial buffelgrass (*Pennisetum ciliare*) cover.

**A**.

**B**. 

## Figure S4.

The relationship between initial *Pennisetum ciliare* canopy cover and treatment intensity quantified by (A) total years of treatment and (B) average years of treatment gap. Crosses indicate the means and the error bars indicate the 95% confidence intervals. Significant pair-wise differences among treatment intensity levels indicated by different letters and in Table S2

## Chart Description automatically generated with low confidence

## Appendix 1.

Statistical results of all final GLS models in which AIC and log-likelihood of each model are based on restricted maximum likelihood (REML) estimation.

**1. The models determining the relationship between treatment effectiveness and treatment intensity**

***Model: treatment effectiveness index ~ total years of treatment***

Data: full dataset

AIC = 8741.093; logLik = -4363.546

Error correlation structure: spherical spatial correlation (range = 249.23 m; nugget= 0.55 m)

Error variance function: none

Residual standard error: 1.076546

Degrees of freedom: 3162 total; 3158 residual

***Model: treatment effectiveness index ~ average tears of treatment gap***

Data: full dataset

AIC = 8878.353; logLik = -4431.177

Error correlation structure: spherical spatial correlation (range = 232.35 m; nugget = 0.52 m)

Error variance function: none

Residual standard error: 1.105886

Degrees of freedom: 3162 total; 3157 residual

**2. The model determining the influence on treatment effectiveness by park district and treatment methods**

***Model: treatment effectiveness index ~ district × treatment method***

Data: full dataset

AIC = 9964.636; logLik = -4974.318

Error correlation structure: spherical spatial correlation (range = 158.11 m; nugget = 0.60 m)

Error variance function:

Structure: Different standard deviations per stratum

Formula: ~1 | treatment method

Parameter estimates: mechanical treatment = 1.000000; chemical treatment = 1.054029

Residual standard error: 1.207057

Degrees of freedom: 3162 total; 3158 residual

**3. The models determining the influence on treatment effectiveness by the initial *Pennisetum ciliare* cover, treatment intensity and physical environmental factors in each district and with each treatment method**

***Model: treatment effectiveness index ~ log10(initial P. ciliare cover) + total years of treatment + average years of treatment gap + eastness***

Data: data subset of Rincon Mountain District and chemical treatment

AIC = 4072.896; logLik = -2024.448

Error correlation Structure: spherical spatial correlation (range = 40.73 m; nugget = 0)

Error variance function: none

Residual standard error: 0.9668044

Degrees of freedom: 1508 total; 1498 residual

***Model: treatment effectiveness index ~ log10(initial P. ciliare cover) + average years of treatment gap + slope***

Data: data subset of Rincon Mountain District and mechanical treatment

AIC = 1584.113; logLik = -781.0563

Error correlation structure: spherical spatial correlation (range = 38.59; nugget = 0)

Error variance function:

Structure: different standard deviations per stratum

Formula: ~1 | total years of treatment

Parameter estimates: 2 years = 1.000000; 3 years = 1.256386; 4+ years = 1.147869

Residual standard error: 0.871096

Degrees of freedom: 590 total; 583 residual

***Model: treatment effectiveness index ~ log10(initial P. ciliare cover) + average years of treatment gap + slope + elevation + northness***

Data: data subset of Tucson Mountain District and chemical treatment

AIC = 1337.136; logLik = -659.568

Error correlation structure: spherical spatial correlation (range = 32.15 m; nugget = 0)

Residual standard error: 0.8677845

Degrees of freedom: 510 total; 503 residual

***Model: treatment effectiveness index ~ log10(initial P. ciliare cover) + total years of treatment + slope***

Data: Data subset of Tucson Mountain District and mechanical treatment

AIC = 1540.016; logLik = -762.008

Error correlation structure: spherical spatial correlation (range = 41.69 m; nugget = 0)

Residual standard error: 0.9858306

Degrees of freedom: 554 total; 548 residual