

Alpha Diversity

Data and R code accompanying: Tipping points and interactive effects of chronic human disturbance and acute heat stress on coral diversity

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Site	KI2013	KI2014	KI2015a	KI2015b	KI2016b	KI2017
VL2	20	0	0	0	0	26
VL1	0	0	28	0	30	0
VL5	30	0	0	0	0	19
L5	25	0	0	0	0	29
M10	28	0	0	0	0	29
L1	0	32	0	0	0	29
H2	30	0	0	0	0	30
VH3	29	0	0	0	30	0
VH1	0	0	30	0	0	29
VH2	0	0	0	30	0	30
L4	25	0	0	0	0	30
M3	0	0	0	30	0	29
M2	26	0	0	0	30	0
M1	0	0	0	30	0	29
M4	0	21	0	0	0	30
M6	28	0	0	0	30	0
VL3	0	0	0	29	30	0

(c) Simpson 17

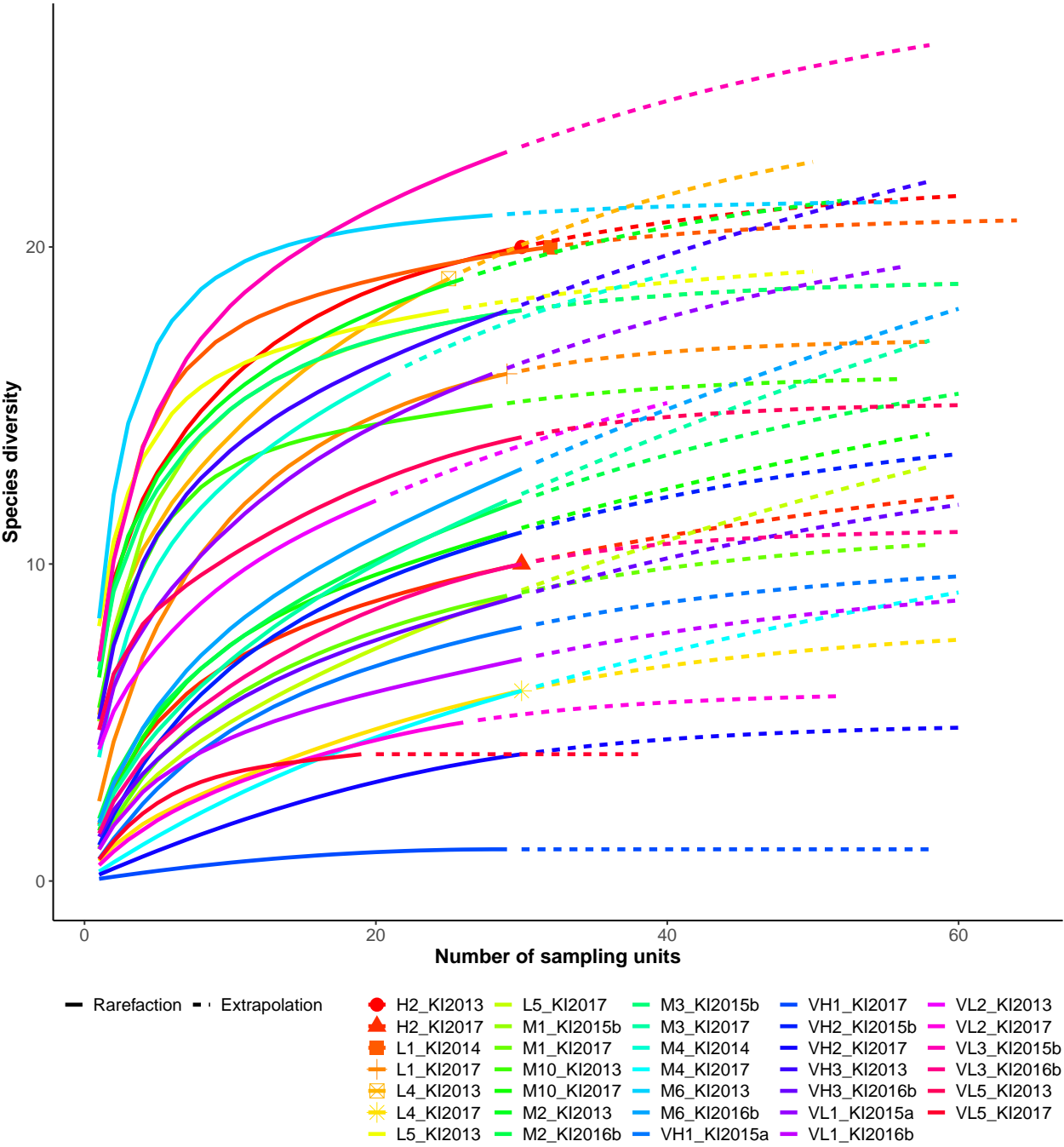
Summary of the Data

```
## [1] "total # of years"
## [1] 6
## [1] "total # of sites"
## [1] 17
## [1] "total # of site - year combinations"
## [1] 34
## [1] "total # of quadrats"
## [1] 960
```

Table S1

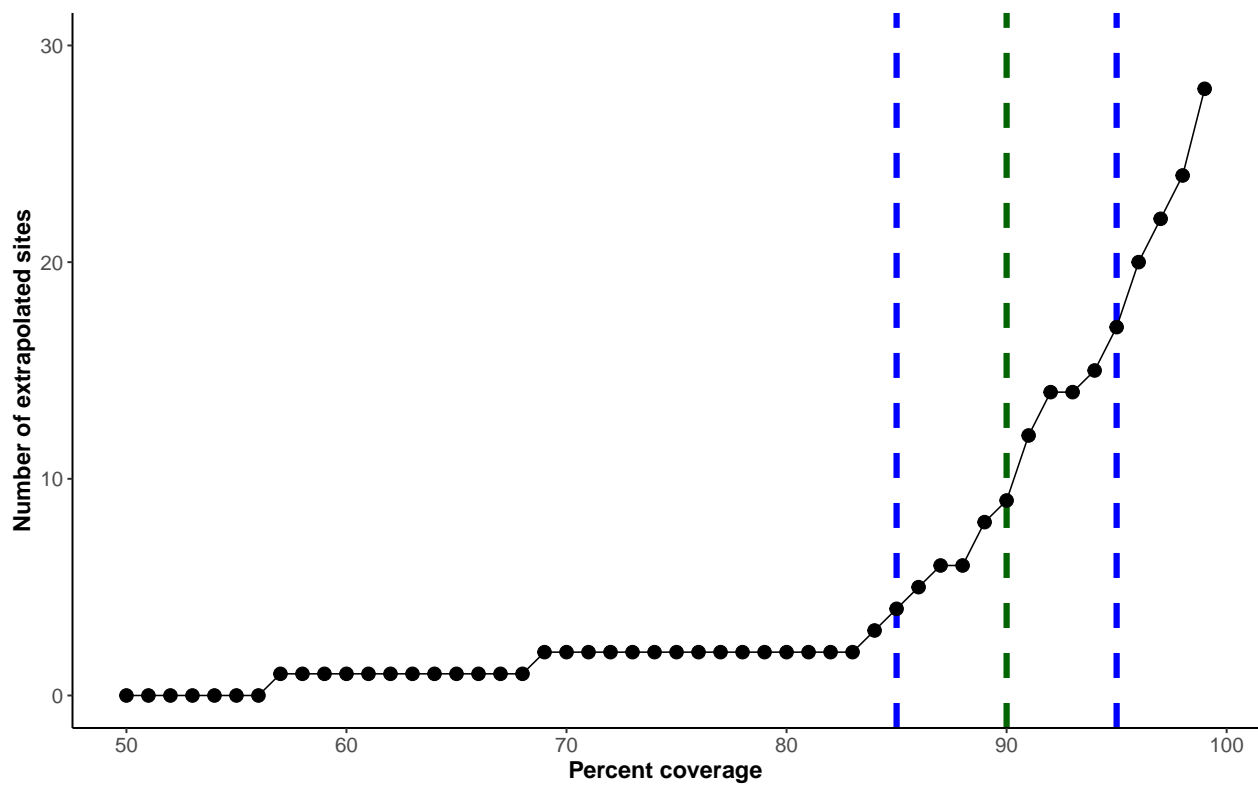
Coverage Standardizing

Figure S2



Extrapolation Trends

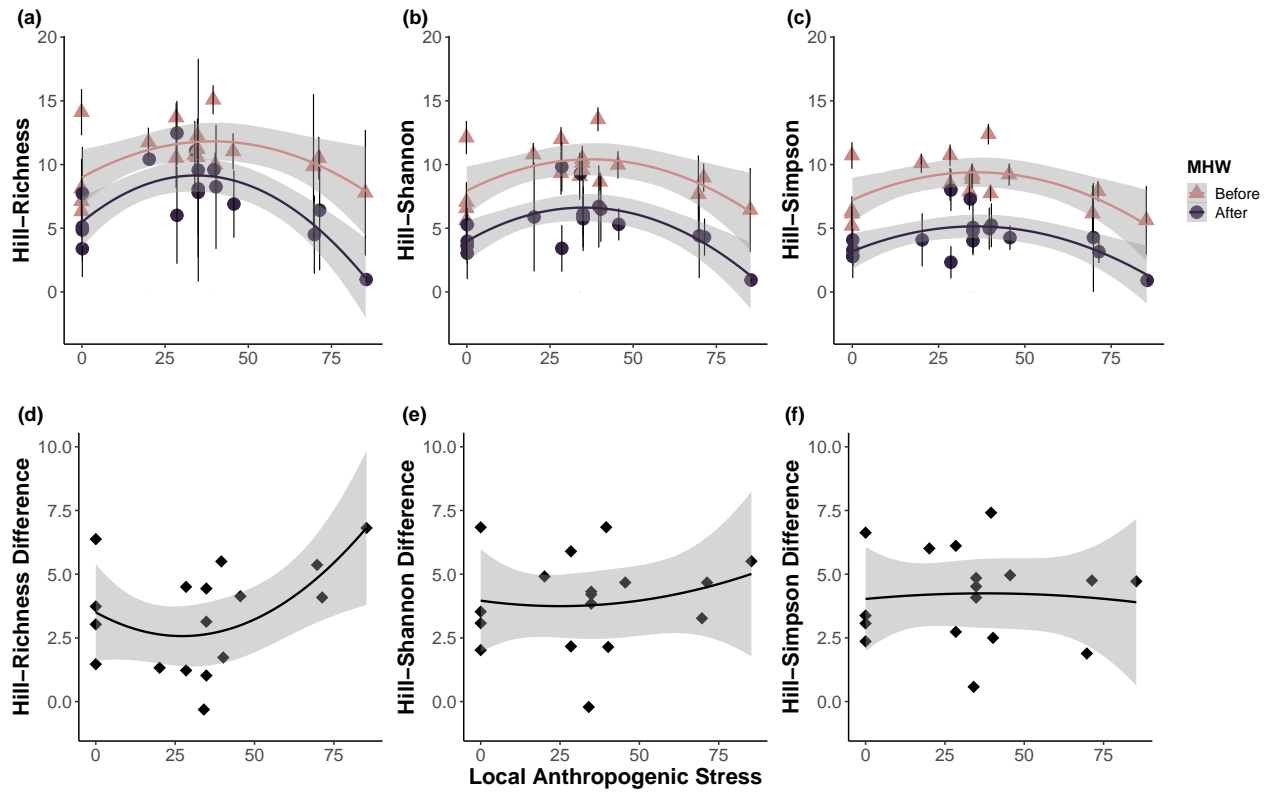
Figure S3



Hill Diversity

85% Coverage

Figure S4



90% Coverage

Figure 2

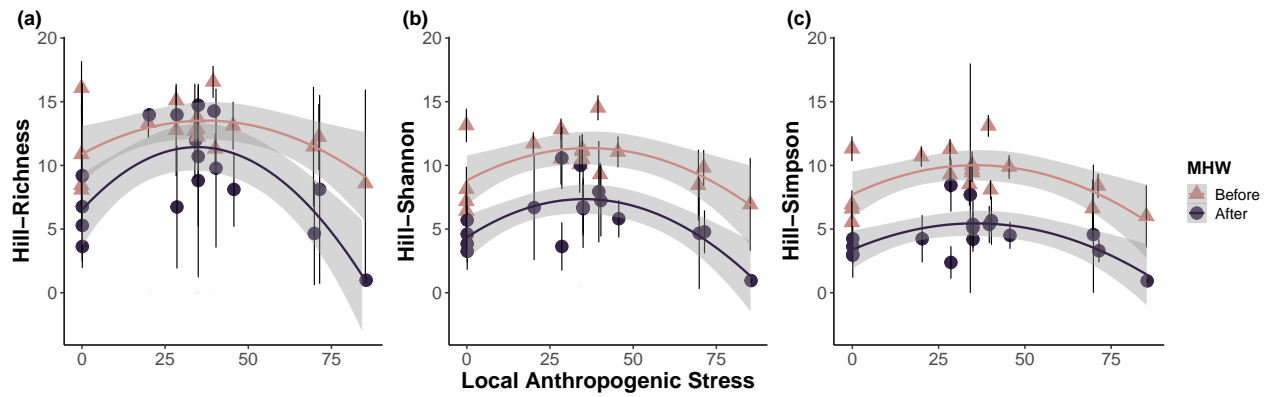
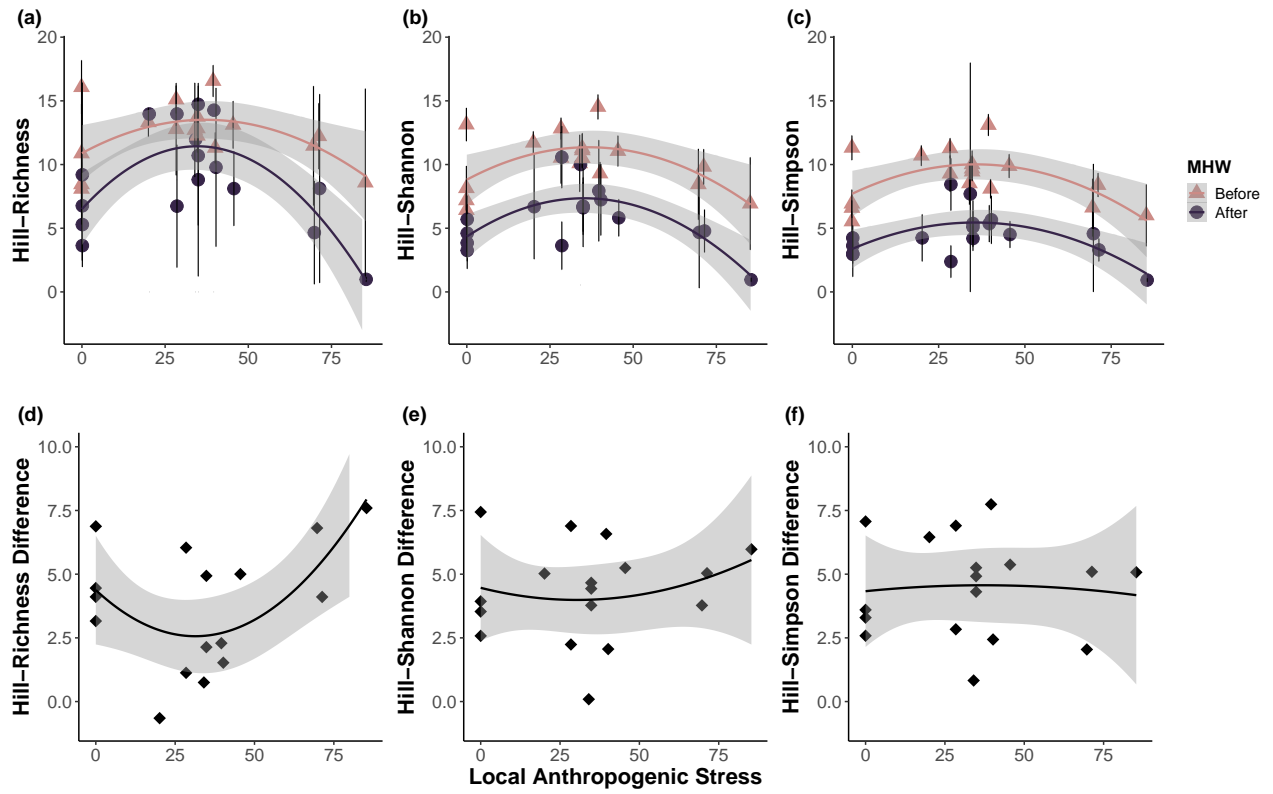
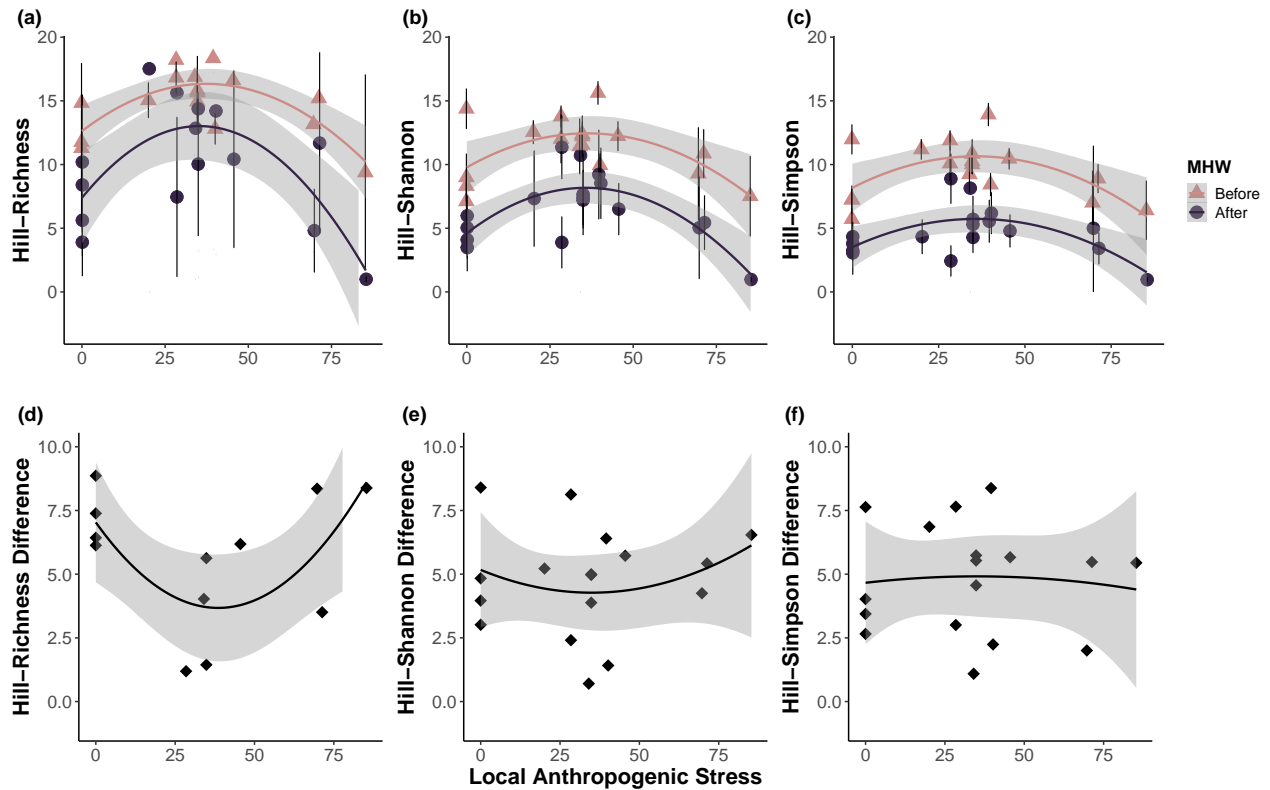


Figure S5



95% Coverage

Figure S6



Modelling

Table 1 and S3

- The following models were used to create Table 1, S3 and S5

Hill-Richness - 85% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_85 %>% filter(Order.q == 0)
##
##           AIC          BIC    logLik deviance df.resid
##          145.9          159.6     -63.9   127.9      25
##
## Random effects:
##
## Conditional model:
##   Groups   Name                Variance Std.Dev.
##   Site     (Intercept)  1.681      1.296
##   Residual                    1.345      1.160
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.34
##
## Conditional model:
##                                     Estimate Std. Error z value Pr(>|z|)
```

```
## (Intercept)                21.627418    8.951937    2.416 0.01569 *
## poly(HD_Cont, 2)1           2.803237    3.003803    0.933 0.35070
## poly(HD_Cont, 2)2          -7.392928    2.480773   -2.980 0.00288 **
## MHWAfter                   -3.386123    0.397763   -8.513 < 2e-16 ***
## NPP                        -0.010488    0.008529   -1.230 0.21880
## poly(HD_Cont, 2)1:MHWAfter -3.881003    2.319335   -1.673 0.09426 .
## poly(HD_Cont, 2)2:MHWAfter -5.319014    2.319335   -2.293 0.02183 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Shannon - 85% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_85 %>% filter(Order.q == 1)
##
##      AIC      BIC    logLik deviance df.resid
##    139.7    153.4     -60.8    121.7      25
##
## Random effects:
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Site      (Intercept) 0.6723   0.8199
##   Residual                1.5317   1.2376
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.53
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    18.874476    6.999493   2.697 0.007006 **
## poly(HD_Cont, 2)1    1.486186    2.494737   0.596 0.551357
## poly(HD_Cont, 2)2   -7.202565    2.114405  -3.406 0.000658 ***
## MHWAfter         -3.981801    0.424495  -9.380 < 2e-16 ***
## NPP              -0.009140    0.006667  -1.371 0.170425
## poly(HD_Cont, 2)1:MHWAfter -1.295889    2.475211  -0.524 0.600594
## poly(HD_Cont, 2)2:MHWAfter -1.464260    2.475211  -0.592 0.554139
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Simpson - 85% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_85 %>% filter(Order.q == 2)
##
##      AIC      BIC    logLik deviance df.resid
##    134.1    147.8     -58.0    116.1      25
##
## Random effects:
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Site      (Intercept) 0.2205   0.4696
```



```
## Residual          1.5720   1.2538
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.57
##
## Conditional model:
##
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      15.797135    5.856909   2.697 0.006993 **
## poly(HD_Cont, 2)1    0.431847    2.203590   0.196 0.844630
## poly(HD_Cont, 2)2   -6.894496    1.904976  -3.619 0.000296 ***
## MHWAfter          -4.149528    0.430046  -9.649 < 2e-16 ***
## NPP                -0.007107    0.005578  -1.274 0.202606
## poly(HD_Cont, 2)1:MHWAfter 0.006452    2.507578   0.003 0.997947
## poly(HD_Cont, 2)2:MHWAfter 0.650767    2.507578   0.260 0.795234
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Richness - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 0)
##
##      AIC      BIC    logLik deviance df.resid
##    160.6    174.3     -71.3    142.6      25
##
## Random effects:
##
## Conditional model:
## Groups   Name      Variance Std.Dev.
## Site     (Intercept) 2.248    1.499
## Residual                2.236    1.495
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 2.24
##
## Conditional model:
##
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      26.33526    10.70615   2.460 0.01390 *
## poly(HD_Cont, 2)1    2.25169    3.63551   0.619 0.53568
## poly(HD_Cont, 2)2   -7.56427    3.01898  -2.506 0.01223 *
## MHWAfter          -3.40016    0.51287  -6.630 3.36e-11 ***
## NPP                -0.01337    0.01020  -1.310 0.19006
## poly(HD_Cont, 2)1:MHWAfter -3.38301    2.99051  -1.131 0.25795
## poly(HD_Cont, 2)2:MHWAfter -9.27442    2.99051  -3.101 0.00193 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Shannon - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 1)
##
##      AIC      BIC    logLik deviance df.resid
```

```
##      142.2      155.9      -62.1      124.2      25
##
## Random effects:
##
## Conditional model:
## Groups      Name      Variance Std.Dev.
## Site      (Intercept) 0.7734  0.8794
## Residual              1.6135  1.2702
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.61
##
## Conditional model:
##
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      20.647140    7.336939   2.814 0.004891 **
## poly(HD_Cont, 2)1      1.309290    2.601744   0.503 0.614799
## poly(HD_Cont, 2)2     -7.654438    2.200658  -3.478 0.000505 ***
## MHWAfter          -4.310017    0.435690  -9.892 < 2e-16 ***
## NPP              -0.009987    0.006989  -1.429 0.153020
## poly(HD_Cont, 2)1:MHWAfter -1.134566    2.540487  -0.447 0.655168
## poly(HD_Cont, 2)2:MHWAfter -2.188292    2.540487  -0.861 0.389036
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Simpson - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 2)
##
##      AIC      BIC    logLik deviance df.resid
##    137.4    151.1    -59.7    119.4      25
##
## Random effects:
##
## Conditional model:
## Groups      Name      Variance Std.Dev.
## Site      (Intercept) 0.1706  0.413
## Residual              1.7981  1.341
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.8
##
## Conditional model:
##
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      16.355969    6.038214   2.709 0.006754 **
## poly(HD_Cont, 2)1      0.333748    2.299570   0.145 0.884604
## poly(HD_Cont, 2)2     -7.333595    1.996033  -3.674 0.000239 ***
## MHWAfter          -4.459612    0.459937  -9.696 < 2e-16 ***
## NPP              -0.007108    0.005750  -1.236 0.216424
## poly(HD_Cont, 2)1:MHWAfter 0.032907    2.681869   0.012 0.990210
## poly(HD_Cont, 2)2:MHWAfter 0.710243    2.681869   0.265 0.791139
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Richness - 95% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_95 %>% filter(Order.q == 0)
##
##      AIC      BIC    logLik deviance df.resid
##    190.6    204.3    -86.3    172.6      25
##
## Random effects:
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Site     (Intercept) 1.099    1.049
##   Residual                8.339    2.888
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 8.34
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      33.23388   13.40053   2.480  0.01314 *
## poly(HD_Cont, 2)1      0.09279    5.05260   0.018  0.98535
## poly(HD_Cont, 2)2     -8.14172    4.37108  -1.863  0.06251 .
## MHWAfter          -3.72362    0.99046  -3.759  0.00017 ***
## NPP                -0.01735    0.01276  -1.359  0.17405
## poly(HD_Cont, 2)1:MHWAfter  0.98449    5.77534   0.170  0.86464
## poly(HD_Cont, 2)2:MHWAfter -15.78242    5.77534  -2.733  0.00628 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Shannon - 95% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_95 %>% filter(Order.q == 1)
##
##      AIC      BIC    logLik deviance df.resid
##    146.3    160.0    -64.1    128.3      25
##
## Random effects:
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Site     (Intercept) 0.7406    0.8606
##   Residual                1.9126    1.3830
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.91
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      22.415702    7.603577   2.948  0.003198 **
## poly(HD_Cont, 2)1      1.149400    2.729324   0.421  0.673660
## poly(HD_Cont, 2)2     -8.224279    2.319628  -3.546  0.000392 ***
```

```
## MHWAfter          -4.722210    0.474357   -9.955 < 2e-16 ***
## NPP                -0.010712    0.007243   -1.479 0.139113
## poly(HD_Cont, 2)1:MHWAfter -0.619336    2.765955   -0.224 0.822824
## poly(HD_Cont, 2)2:MHWAfter -3.092995    2.765955   -1.118 0.263466
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Simpson - 95% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + NPP + (1 | Site)
## Data: estimates_95 %>% filter(Order.q == 2)
##
##      AIC      BIC    logLik deviance df.resid
##    142.1    155.9     -62.1    124.1      25
##
## Random effects:
##
## Conditional model:
## Groups   Name      Variance Std.Dev.
## Site     (Intercept) 0.07091  0.2663
## Residual                2.18515  1.4782
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 2.19
##
## Conditional model:
##
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    16.845214    6.298051   2.675 0.00748 **
## poly(HD_Cont, 2)1      0.281470    2.445658   0.115 0.90837
## poly(HD_Cont, 2)2     -7.867812    2.136113  -3.683 0.00023 ***
## MHWAfter         -4.788453    0.507027  -9.444 < 2e-16 ***
## NPP              -0.007045    0.005997  -1.175 0.24012
## poly(HD_Cont, 2)1:MHWAfter 0.163696    2.956453   0.055 0.95584
## poly(HD_Cont, 2)2:MHWAfter 0.863167    2.956453   0.292 0.77032
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

NPP Sensitivity for 90% Coverage Models

Hill-Richness - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 0)
##
##      AIC      BIC    logLik deviance df.resid
##    160.2    172.4     -72.1    144.2      26
##
## Random effects:
##
## Conditional model:
## Groups   Name      Variance Std.Dev.
## Site     (Intercept) 2.588    1.609
## Residual                2.236    1.495
```

```
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 2.24
##
## Conditional model:
##
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      12.3219    0.5327  23.132 < 2e-16 ***
## poly(HD_Cont, 2)1    -0.4501    3.1060  -0.145  0.88479
## poly(HD_Cont, 2)2    -8.0667    3.1060  -2.597  0.00940 **
## MHWAfter           -3.4002    0.5129  -6.630 3.36e-11 ***
## poly(HD_Cont, 2)1:MHWAfter -3.3826    2.9905  -1.131  0.25800
## poly(HD_Cont, 2)2:MHWAfter -9.2746    2.9905  -3.101  0.00193 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Shannon - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 1)
##
##      AIC      BIC   logLik deviance df.resid
##    142.1    154.3    -63.1    126.1      26
##
## Random effects:
##
## Conditional model:
## Groups   Name      Variance Std.Dev.
## Site     (Intercept) 0.9632   0.9814
## Residual                1.6135   1.2702
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.61
##
## Conditional model:
##
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      10.1768    0.3893  26.140 < 2e-16 ***
## poly(HD_Cont, 2)1    -0.7091    2.2701  -0.312  0.754748
## poly(HD_Cont, 2)2    -8.0300    2.2701  -3.537  0.000404 ***
## MHWAfter           -4.3100    0.4357  -9.892 < 2e-16 ***
## poly(HD_Cont, 2)1:MHWAfter -1.1346    2.5405  -0.447  0.655171
## poly(HD_Cont, 2)2:MHWAfter -2.1883    2.5405  -0.861  0.389039
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hill-Simpson - 90% Coverage

```
## Family: gaussian ( identity )
## Formula:          qD ~ poly(HD_Cont, 2) * MHW + (1 | Site)
## Data: estimates_90 %>% filter(Order.q == 2)
##
##      AIC      BIC   logLik deviance df.resid
##    136.9    149.1    -60.4    120.9      26
##
## Random effects:
```

HD_Cat	HillRichness	SEM_HillRichness	HillShannon	SEM_HillShannon	HillSimpson	SEM_HillSimpson
Low	2.171669	2.0012430	4.718067	1.351232	5.398287	1.2872725
Medium	1.528426	0.9849155	3.599975	0.920359	4.247973	0.9774367
Very High	5.878684	0.8023107	5.008173	0.457817	4.396447	0.7869922
Very Low	4.650593	0.7913677	4.370886	1.061707	4.136228	1.0002427

```
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Site      (Intercept) 0.2667   0.5165
##   Residual              1.7981   1.3409
## Number of obs: 34, groups: Site, 17
##
## Dispersion estimate for gaussian family (sigma^2): 1.8
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      8.90404    0.34851  25.549 < 2e-16 ***
## poly(HD_Cont, 2)1 -1.10294    2.03216  -0.543 0.587307
## poly(HD_Cont, 2)2 -7.60083    2.03216  -3.740 0.000184 ***
## MHWAfter         -4.45961    0.45994  -9.696 < 2e-16 ***
## poly(HD_Cont, 2)1:MHWAfter 0.03313    2.68187   0.012 0.990145
## poly(HD_Cont, 2)2:MHWAfter 0.71020    2.68187   0.265 0.791151
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Average Losses

Table S4

```
## # A tibble: 1 x 2
##   HillRichness SEM_HillRichness
##   <dbl>         <dbl>
## 1      3.40         0.677

## # A tibble: 1 x 2
##   HillShannon SEM_HillShannon
##   <dbl>         <dbl>
## 1      4.31         0.461

## # A tibble: 1 x 2
##   HillSimpson SEM_HillSimpson
##   <dbl>         <dbl>
## 1      4.46         0.475
```

Stressor Responses

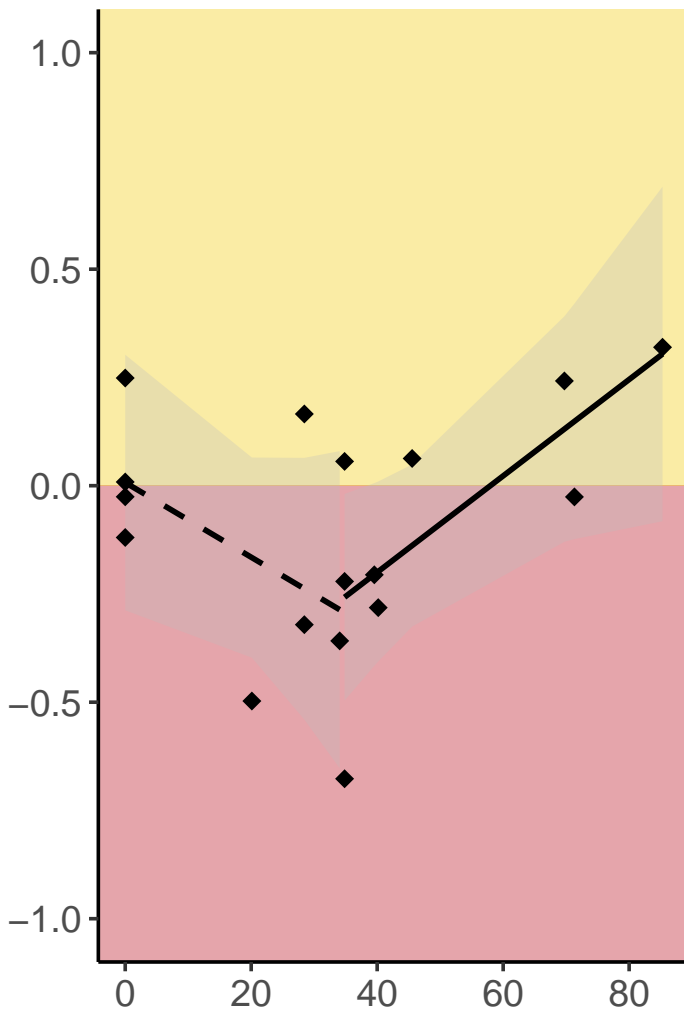
Note: Notation in code is the same as the notation used in the manuscript equations. ## Figure 4 (a-c)
 ### (a) Richness

```
##
## supF test
##
## data: fs.AR_Richness
```

```

## sup.F = 11.747, p-value = 0.04207
##
## Optimal 2-segment partition:
##
## Call:
## breakpoints.Fstats(obj = fs.AR_Richness)
##
## Breakpoints at observation number:
## 9
##
## Corresponding to breakdates:
## 0.4705882
##
## Call:
## lm(formula = ARi ~ HD_Cont, data = subset(AR_Richness, HD_Cont <=
## 34.82568))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.33120 -0.09404 -0.05247  0.06128  0.40353
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.007277   0.120623   0.060   0.954
## HD_Cont     -0.008624   0.006049  -1.426   0.204
##
## Residual standard error: 0.245 on 6 degrees of freedom
## Multiple R-squared:  0.253, Adjusted R-squared:  0.1285
## F-statistic: 2.032 on 1 and 6 DF, p-value: 0.2039
##
## Call:
## lm(formula = ARi ~ HD_Cont, data = subset(AR_Richness, HD_Cont >=
## 34.82568))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.41924 -0.08346  0.01550  0.11109  0.31368
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.645270   0.224780  -2.871   0.0240 *
## HD_Cont      0.011131   0.004173   2.667   0.0321 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2286 on 7 degrees of freedom
## Multiple R-squared:  0.5041, Adjusted R-squared:  0.4332
## F-statistic: 7.115 on 1 and 7 DF, p-value: 0.03212

```

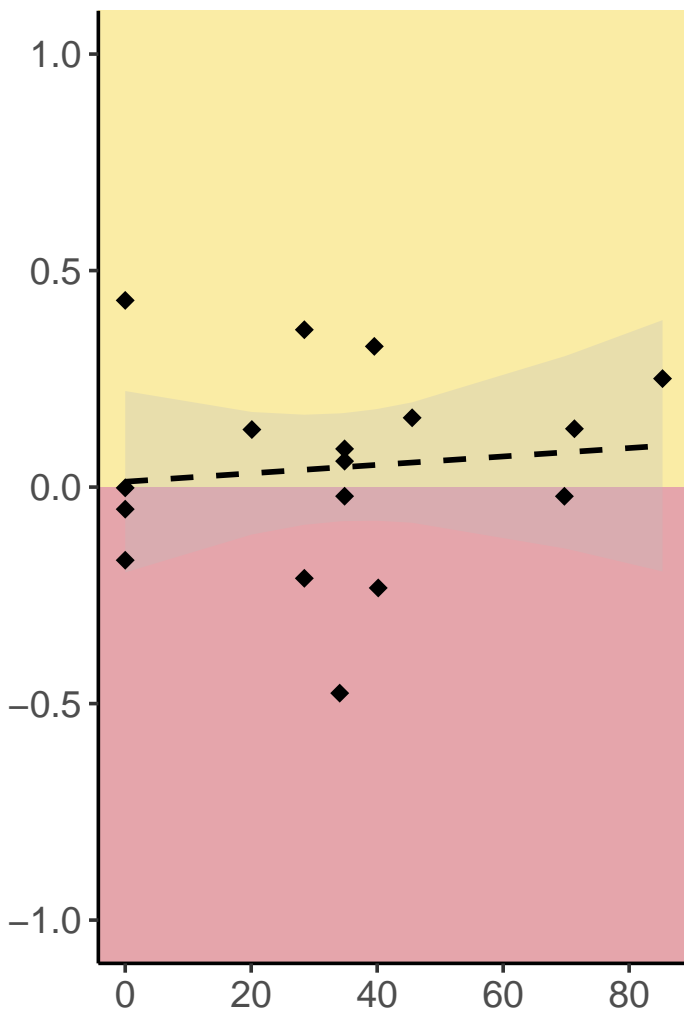


(b) Shannon

```
##
##  supF test
##
## data:  fs.AR_Shannon
## sup.F = 4.1874, p-value = 0.6603
##
##  Optimal 2-segment partition:
##
## Call:
## breakpoints.Fstats(obj = fs.AR_Shannon)
##
## Breakpoints at observation number:
## 6
##
## Corresponding to breakdates:
## 0.2941176
##
```



```
## Call:
## lm(formula = ARi ~ HD_Cont, data = AR_Shannon)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.52141 -0.10142  0.01363  0.10337  0.41874
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.0123912  0.0982697   0.126   0.901
## HD_Cont      0.0009721  0.0023673   0.411   0.687
##
## Residual standard error: 0.2411 on 15 degrees of freedom
## Multiple R-squared:  0.01112,    Adjusted R-squared:  -0.05481
## F-statistic: 0.1686 on 1 and 15 DF,  p-value: 0.6871
```



(c) Simpson

```
##
## supF test
##
```

```

## data:  fs.AR_Simpson
## sup.F = 3.0115, p-value = 0.8588

##
##   Optimal 2-segment partition:
##
## Call:
## breakpoints.Fstats(obj = fs.AR_Simpson)
##
## Breakpoints at observation number:
## 6
##
## Corresponding to breakdates:
## 0.2941176

##
## Call:
## lm(formula = ARi ~ HD_Cont, data = AR_Simpson)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.51342 -0.22950  0.06513  0.12951  0.46411
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.029e-01  1.165e-01   0.883   0.391
## HD_Cont      -3.229e-05  2.807e-03  -0.012   0.991
##
## Residual standard error: 0.2859 on 15 degrees of freedom
## Multiple R-squared:  8.825e-06, Adjusted R-squared:  -0.06666
## F-statistic: 0.0001324 on 1 and 15 DF, p-value: 0.991

```

