Oikos **OIK-02277**

Biswas, S. R., Mallik, A. U., Braithwaite, N. T. and Wagner, H. H. 2015. A conceptual framework for the spatial analysis of functional trait diversity. – Oikos doi: 10.1111/oik.02277

Appendix 1

Description of riparian plant community data set

Study system

We studied plant communities along lateral gradients of small headwater streams (catchment area: ~1 km^2; average width: 1.04 m with a range of 0.43–1.77 m; shoreline slope: ≤ 15%) in the boreal forest of northwestern Ontario, Canada (48°22´N, 89°19´W; ~ 200 m a.s.l.). The study area is characterized by rolling topography with bedrocks overlain by glacial tills. Here, all streams visible in a 1:50 000 scale map are protected by riparian buffers (OMNR 1988). Common riparian plant species in the area are *Alnus incana*, Cornus *stolonifera*, *Calamagrostis canadensis*, *Thalictrum dayscarpum*, *Mertensia paniculata* and *Athyrium filix-femina,* and common understory species are *Ledum groenlandicum, Acer spicatum*, *Aster macrophyllus, Aralia nudicalus*, *Lycopodium annotinum* and *L. dendroideum*. The overstory vegetation is dominated by *Picea mariana* with dispersed Picea glauca, *Pinus banksiana*, *Abies balsamea*, *Populus tremuloides* and *Betula papyrifera.* Our selected stream sites were mostly dominated by *Picea marina*. Additional site description and species composition can be found in Braithwaite and Mallik (2012).

Disturbance and control

We considered two types of disturbed habitat (clearcut with buffer and wildfire burn sites) and control (unlogged mature forest). Control sites were approximately 90 to 100-years old and wildfire-origin that had no land use activity within 500 m. Clearcut sites were 2 to 6-years old where riparian buffers were 28 to 52 m wide, extended on either side of a stream. Ages of uncut mature trees in the riparian buffers were approximately similar to that of trees in control sites. Burned sites were 2 to 7-years old, recovering from typical wildfires of similar intensity and severity.

Field sampling

Each of the two disturbance treatments and control were replicated at eight stream sites (n = 24 streams). In each stream (n = 24), we placed two perpendicular transects, at either sides of a stream.

Each transect was started at stream edge and ran through five adjacent microhabitats, riparian, ecotone, mid-slope, upland and edge (Braithwaite and Mallik 2012). In each transect, we placed continuous 1 × 1 m quadrats at 4 m intervals to reduce within microhabitat environmental heterogeneity and to minimize logistics (Braithwaite and Mallik 2012). The number of quadrats in each microhabitat was not uniform but on average had 2–3 quadrats. In each quadrat, we recorded presence of all vascular and non-vascular (moss, liverworts, ferns) plants and visually estimated their percent cover (scale: > 0–100). We also measured soil moisture (by using a Delta H2 probe) and canopy openness (by using a crown densiometer) at the quadrat level. For soil moisture, three measurements were taken at three random locations within a quadrat and averaged them to represent the quadrat. All soil moisture measurements were taken within a period of seven days without any rainfall event.

Computation of functional trait diversity

Based on the quadrat-level species presence and percent cover data, we calculated FRic, FEve and FDiv as described by Villeger et al. (2008). Functional diversity indices (FRic, FEve and FDiv) were calculated by using function 'dbFD', which implements a flexible distance-based framework to compute multidimensional functional diversity indices, in the R library 'FD' (Laliberté and Shipley 2011); we used Gower's distance and checked for correlation among traits. We used quadrat-level species percent cover matrix and a species-trait matrix with 20 categorical traits related to productivity, competitive ability, life history, stem tissue, phenology, flower colour, reproduction and adaption to compute functional trait diversity indices (Table A1). Availability of trait data somewhat constrained our trait choice. We compiled trait data were from published literature (Biswas and Mallik 2010) and the regional USDA plant database (<http://plants.usda.gov/>).

Data preparation for the spatial analysis

Quadrat level data on functional trait diversity were averaged at the level of microhabitat (Braitwaite and Mallik 2012), so that microhabitat was the grain or the finest scale of this study. Biological relevance of this grain is well known from our previous works in this site (Lamb and Mallik 2003, Biswas and Mallik 2010, Braithwaite and Mallik 2012). At each site, we had two half transects on each side of a stream containing functional trait diversity data on five adjacent microhabitats (riparian, ecotone, mid-slope, edge and upland). For spatial analysis, we joined these two half transects at each site and made a long transect for computational reasons. However, since we used a distance-based neighbor function, this joining should not have any ecological consequence.

Table A1. List of traits used to quantify functional trait diversity.

Trait	Scale	Description/categories
Raunkiaer life form	nominal	mg: mega- or meso-phanerophyte (≥ 8 m in height); mc: micro- or nano-phanerophyte (25 cm – 8 m); ch: chamaephyte (herb or shrub, but between 1 mm and 25 cm aboveground); h: hemicryptophyte (herb with bud at ground surface); g: geophyte (herb with underground bud); t: therophyte (annual)
Life cycle	ordinal	1: annual; 2: biennial; 3: perennial
Flowering phenology	nominal	sp: spring; su: summer; sf: summer-autumn
Stem tissue	nominal	w: woody; n: non-woody.
Leaf persistence	binary	0: no; 1: yes.
Principle means of reproduction	nominal	1: seeds only; 2: vegetative propagation possible but mostly seeds; 3: mostly vegetation propagation
Seed dispersal vector†	nominal	Mechanism of seed dispersal; wind, water, vertebrate, invertebrate
Seed banking	ordinal	1: temporary; 2: persistent; no.
Fire resistance	binary	0: no; 1: yes.
Flower colour	nominal	w: white; g: unattractive (green or brown); b: bright (red, pink, yellow, blue or purple)
Growth rate	ordinal	growth rate after successful establishment relative to other species within same growth habit; slow, medium, rapid
Re-sprouting	binary	re-sprouting of woody species following top removal; 0: no; 1:yes
Anaerobic tolerance	ordinal	relative tolerance to anaerobic soil conditions; none, low, medium, high
Drought tolerance	ordinal	relative tolerance to drought conditions compared to other species with same growth habit; none, low, medium, high
Fire tolerance	ordinal	relative ability to re-sprout, grow, or reestablish from residual seed after fire; none, low, medium, high

Trait	Scale	Description/categories
Moisture use	ordinal	ability to use (i.e. remove) available soil moisture relative to other species; low, medium, high
Shade tolerance	ordinal	relative tolerance; intolerant, intermediate, tolerant.
Seed abundance		amount of seeds produced by a particular plant species compared to other species with same growth habit; none, low, medium, high
Seed vigour	ordinal	expected seedling survival percentage of the plant species compare to other species with the same growth habit: low, medium, high
Seed spread rate	ordinal	capability of the plant species to spread through seed production compared to other species with the same growth habit: none, slow, moderate, rapid
Vegetative spread rate	ordinal	rate at which the plant species can spread compared to other species with same growth habit: none, slow, moderate, rapid

References

Biswas, S. R. and Mallik, A. U. 2010. Disturbance effects on species diversity and functional diversity in riparian and upland plant communities. – Ecology 91: 28–35.

Braithwaite, N. T. and Mallik, A. U. 2012. Edge effects of wildfire and riparian buffer along boreal forest streams. – J. Appl. Ecol. 49: 192–201.

Laliberté, E. and Shipley, B. 2011. FD: measuring functional diversity from multiple traits and other tools for functional ecology. <R pack ver. 1.0-11>.

Lamb, E. G. and Mallik, A. U. 2003. Plant species traits across a riparian zone/forest ecotone. – J. Veg. Sci. 14: 853–858.

Ontario Ministry of Natural Resources (OMNR). 1988. Timber management guidelines for the protection of fish habitats. – Queens Printer, Ontario.

Villeger, S. et al. 2008. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. – Ecology 89: 2290–2301.

Appendix 2

R-scripts for quantifying spatial patterns (Moran's coefficient) at multiple spatial scales and their significance testing

```
require(vegan)
require(spdep)
require(spacemakeR)

# Import data and prepare spatial weight
    data1 <- read.csv("ref.csv", header=TRUE)
    sp.cord=matrix(cbind(data1$x,data1$y), ncol=2) # spatial coordinates

#Assign distance-based neighbours and create spatial weight matrix (W)
    nb <- dnearneigh(sp.cord, 0.1,4.1) # distance-based neighbour
    listw <- nb2listw(nb,style="W")    # row standardized weight
    S0 = sum(unlist(weights(listw)))
    n = length(weights(listw))

 ## Large-scale (positive) and fine-scale (negative) spatial patterns

    sc.tri <- scores.listw(listw)
    MEM=sc.tri
    n.pos <- sum(MEM$values > 0)      ## summing all the positive eigenvalues

    y=data1$Fric ## here we are calculating for FRic, for example

    MCk <-cor(y,MEM$vectors)^2 * MEM$values
      Subset <- 1:n.pos
      S.tot.obs <- sum(MCk)           ## overall spatial pattern (eqn. 1)
      S.pos.obs <- sum(MCk[Subset])   ## large-scale spatial pattern (eqn. 2)
      S.neg.obs <- sum(MCk[-Subset])  ## fine-scale spatial pattern (eqn. 3)
    S.obs <- c(S.tot.obs, S.pos.obs, S.neg.obs)
    S.obs

## Significance testing
  R  = 999
  MC.sim <- matrix(NA, R, 3, dimnames=list(NULL, c("S.tot","S.pos","S.neg")))
    for(r in 1:R)
    {
 MCk.sim <-cor(sample(y),MEM$vectors)^2 * MEM$values ##randomization of y
       Subset <- 1:n.pos
       MC.sim[r,1] <- sum(MCk.sim)
       MC.sim[r,2] <- sum(MCk.sim[Subset])
       MC.sim[r,3] <- sum(MCk.sim[-Subset])
    }
    MC.sim <- data.frame(MC.sim)
    p.value.pos <- (sum(MC.sim$S.pos >= S.pos.obs) + 1) / (R+1)
    p.value.neg <- (sum(MC.sim$S.neg <= S.neg.obs) + 1) / (R+1)
    p.value.tot <- (sum(abs(MC.sim$S.tot - mean(MC.sim$S.tot)) >= abs(S.tot.obs
- mean(MC.sim$S.tot))) + 1) / (R+1)
    p.value <- c(p.value.tot, p.value.pos, p.value.neg)
    p.value
```

Appendix A3

Disturbance effects on the mean values of functional trait diversity

To test whether the mean values of FRic, FEve and FDiv varies among disturbed (clearcut and wildfire) and control habitats, we conducted three separate linear mixed effect model analysis of variance. In each statistical model, disturbance was treated as fixed factor and microhabitats nested within sites were treated as random factor. Models were defined as follows (Eq. A1–A3).

$$\text{FRic}\sim\text{Disturbance, random} = \sim 1|\text{Site\_No/Microhabitat} \qquad \text{(A1)}$$

$$\text{FEve}\sim\text{Disturbance, random} = \sim 1|\text{Site\_No/Microhabitat} \qquad \text{(A2)}$$

$$\text{FDiv}\sim\text{Disturbance, random} = \sim 1|\text{Site\_No/Microhabitat} \qquad \text{(A3)}$$

These models were implemented by using function ‘lme’ in the R library ‘lme4’. We also checked model residual and found slight autocorrelation. We then fitted models by including spherical correlation structure; however, models with and without correlation structure did not differ significantly or did not produce low AIC values. Thus, our final models were fitted as Eq. 1–3 without correlation structure.

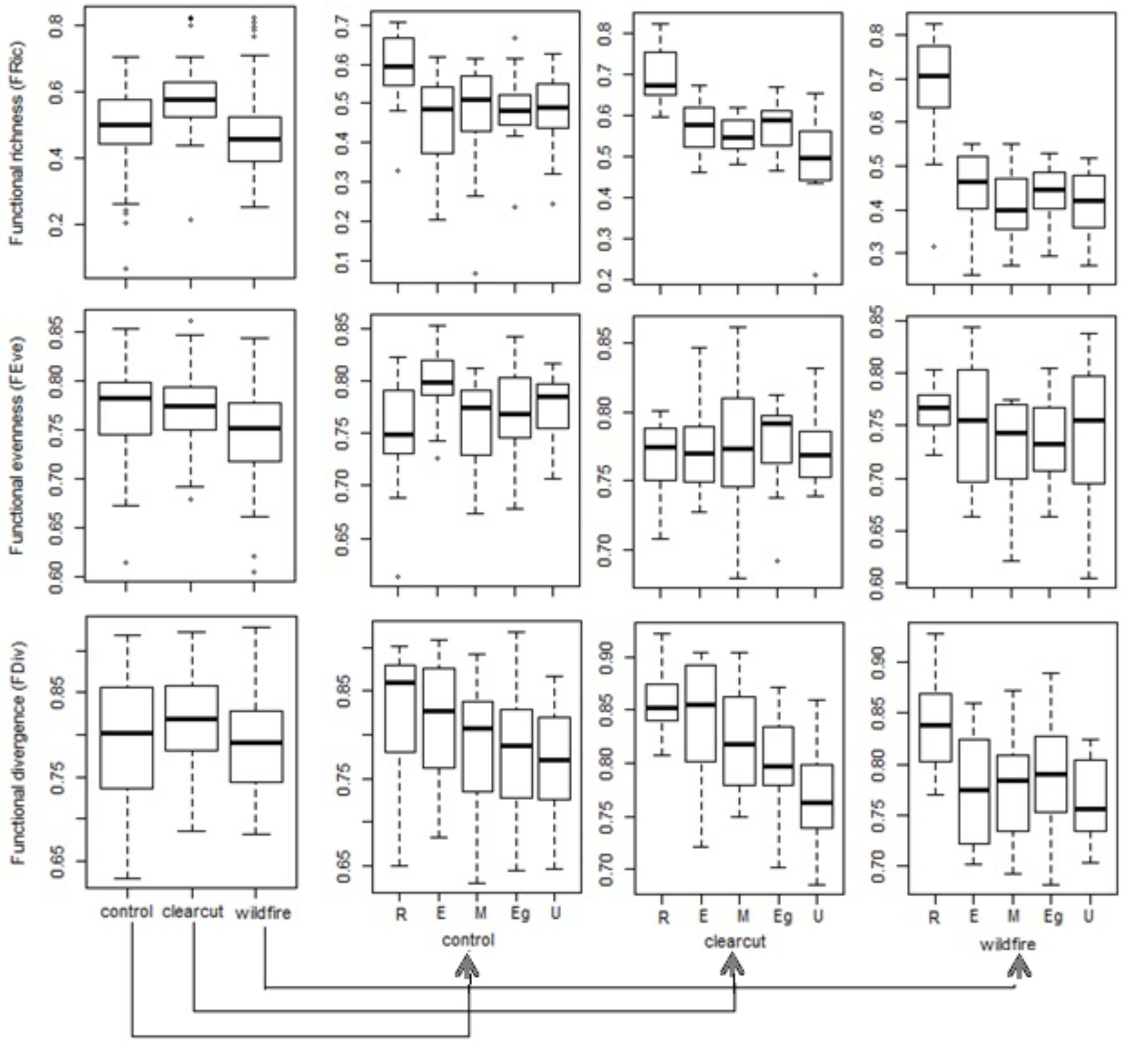

Figure. A3. Box plots showing the values of FRic, FEve and FDiv of riparian plant communities: column one shows the overall values for the disturbed and control habitats, while columns 2–4 represent the values for each habitat (column two is for the control, column three is for the clearcut and column four is for the wildfire sites), split into microhabitats along a stream bank –upland gradient (R = riparian, E = ecotone, M = mid-slope, Ed = edge, U = upland). Each box represents the middle 50% of raw data (25–75 quartiles), while median is shown by the thick line within a box.

Appendix A4

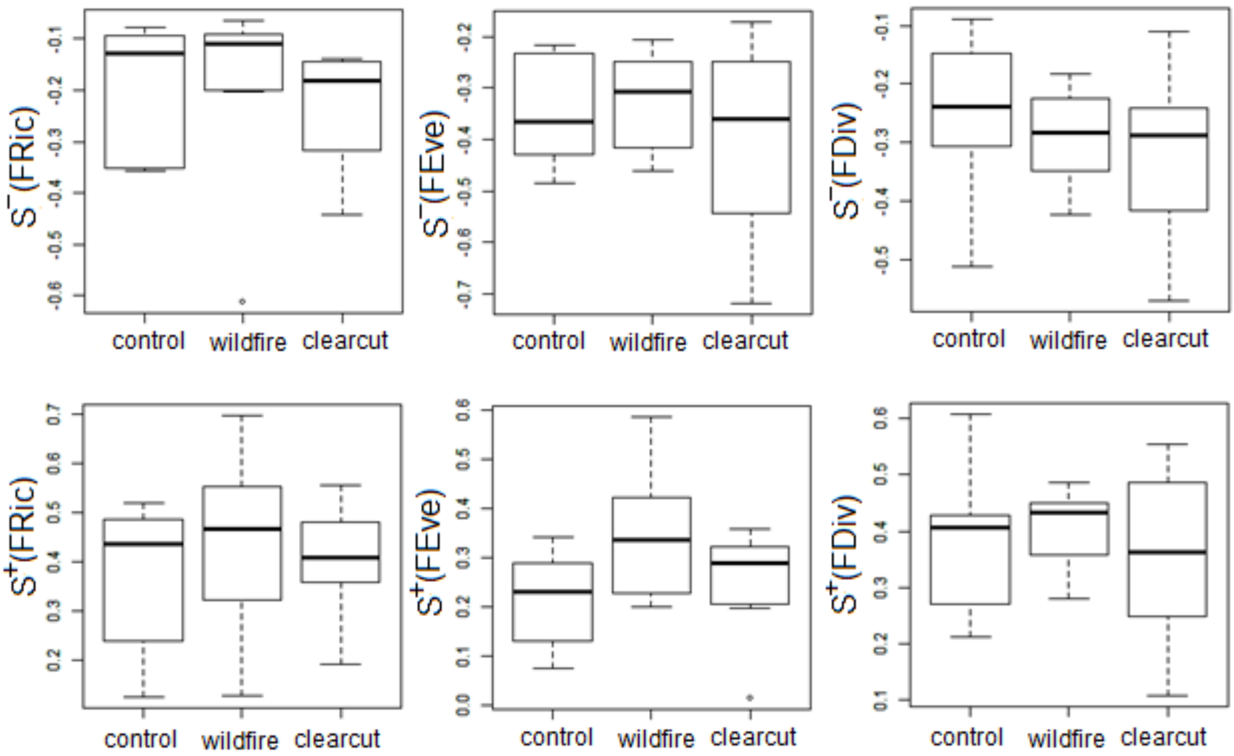

Figure. A4. Boxplots showing the fine-scale and large-scale spatial patterns of FRic, FEve and FDiv for control and disturbed habitats, based on site level analysis. Each box represents the middle 50% of raw data (25–75 quartiles), while median is shown by the thick line within a box.

Appendix A5

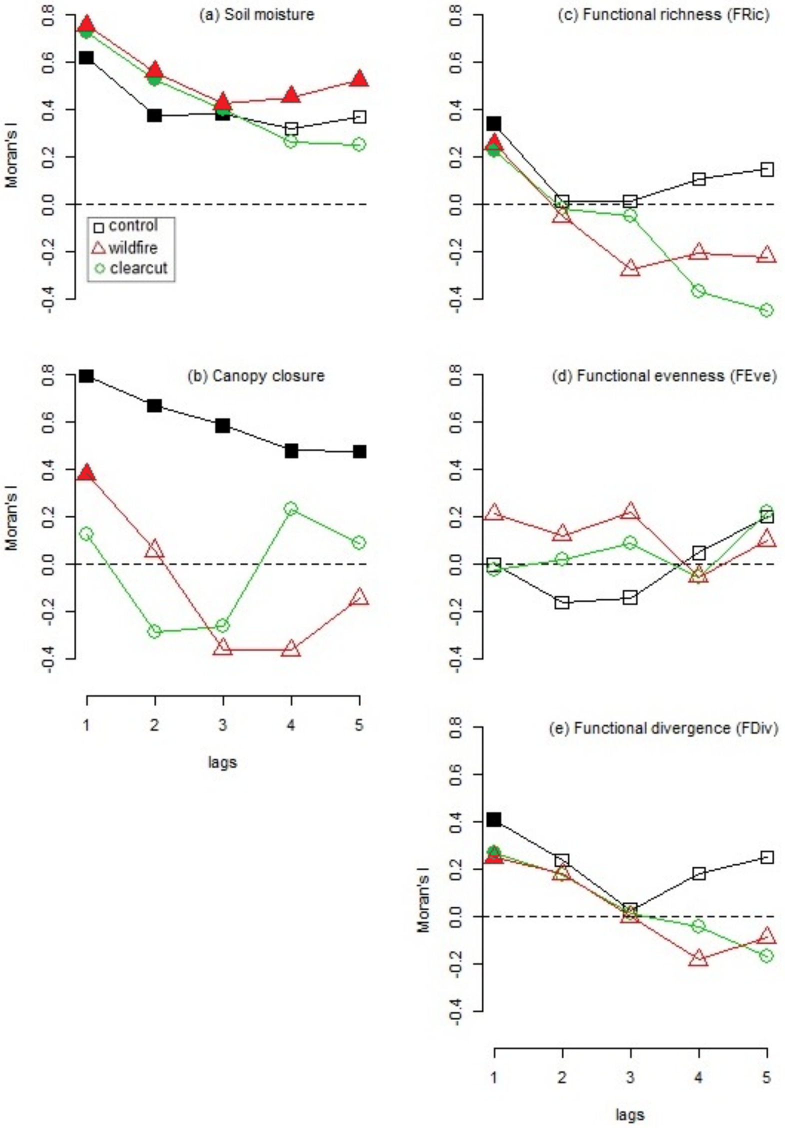

Figure. A5. Spatial correlograms (Moran's coefficient) of environmental structures (a, b) and functional structures (c, d, e) for control, clearcut and wildfire sites. Correlograms were computed (by using function 'sp.correlogram' in the R library 'spdep'; adjacent landscape positions were considered as neighbours following rooks connection; weight = binary) for 5 lag classes following the Sturge's rule (each longitudinal transect contains 10 data points, i.e. 5 landscape positions on both sides of a stream). A filled circle in each lag indicates statistically significant autocorrelation following a progressive Bonferroni correction (Hewit et al. 1997).

Reference

Hewitt, J. E. et al. 1997. Identifying relationships between adult and juvenile bivalves at different spatial scales. – J. Exp. Mar. Biol. Ecol. 216: 77–98.

Appendix A6

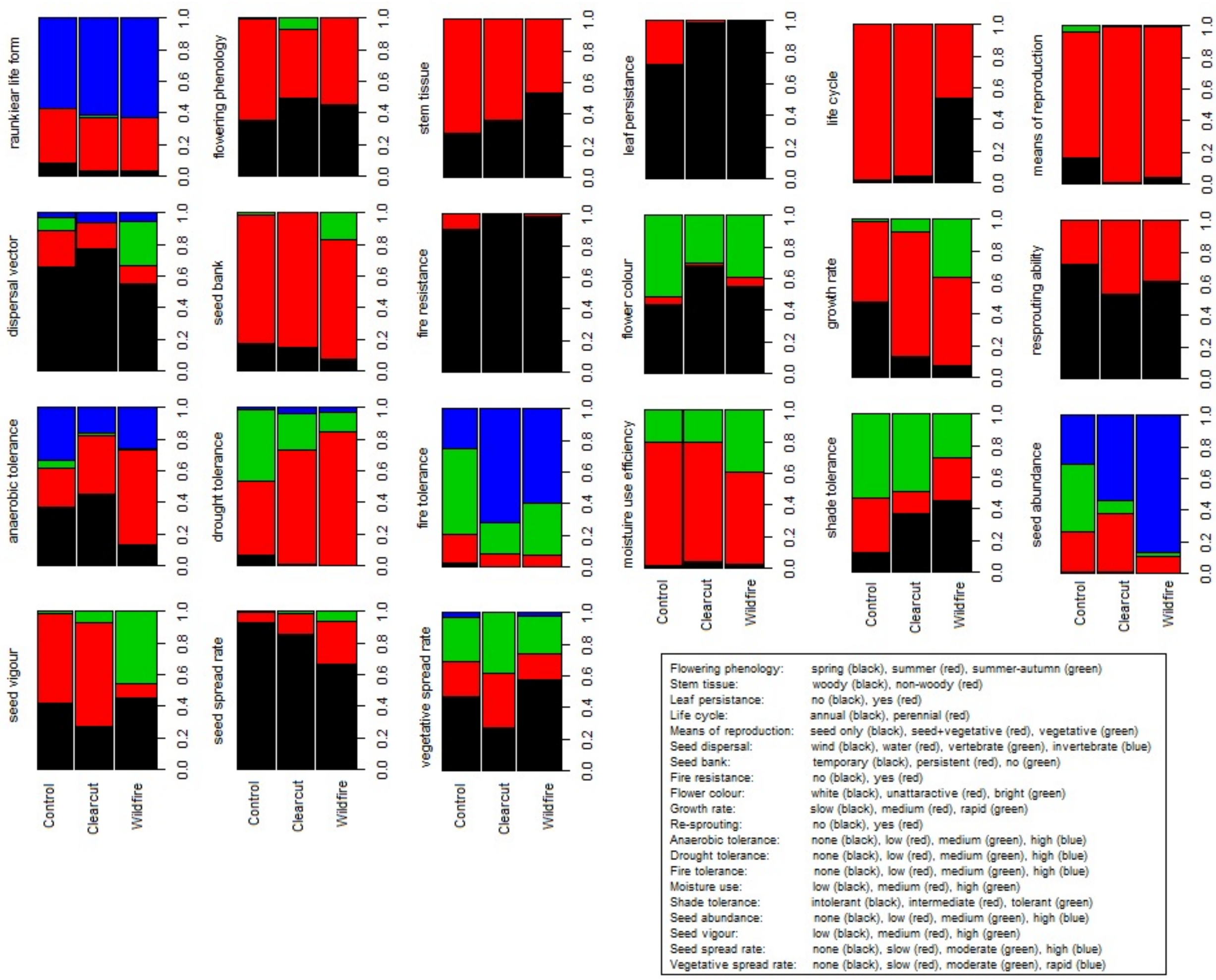

Figure. A6. Trait profile (based on community weighted mean trait) showing the proportion of quadrats dominated by a particular trait categories, for each of 21 categorical traits used in this study.