**Supplementary Online Material for “Applying Functional Traits to Ecogeomorphic Processes in Riparian Ecosystems”**

Rebecca M. Diehl, David M. Merritt, Andrew C. Wilcox, Michael L. Scott

***Trait Measurement Methodology***

We measured plant traits for 130 individual plants that represented 34 species common to the Yampa River and Green Rivers in Dinosaur National Monument during the summer of 2015. Plant sampling occurred along ~0.5 km reaches at three sites: Deerlodge Park and Harding Hole on the Yampa River at river mile 46 and 20, relative to the downstream confluence with the Green River, and Island Park on the middle Green River located 13 river miles downstream from the confluence. We identified plants growing in settings typical for that species along these river systems and targeted species to ensure representation across a wide environmental gradient. For each species, we strove to collect data for at least three healthy mature individuals, however, traits for 5 of the 34 species in our dataset represent samples for less than 3 individuals (supplement Table S1).

Our approach to characterizing the three dominant woody species, *Populus fremontii*, *Salix exigua*, and *Tamarix ramosissima*, differed. In addition to collecting traits for three mature, healthy individuals, we also identified individuals that spanned a range of sizes and therefore life-history stages, from small seedlings to mature plants. For *Tamarix* and *Populus*, we categorized the data into three life-history stages (seedling with a 0.5 m height cutoff, sapling with a 1.5 m height cutoff for *Tamarix* and 2.0 m height cutoff for *Populus*, mature) and for *Salix*, we categorized the data into two life-history stages because of the smaller range in plant height (seedling with a 0.5 m cutoff and mature).

For each individual we measured a suite of traits in the field, took photographs, and collected stem and leaf samples for laboratory analysis. Plant height was identified as the distance between the upper boundary of the main photosynthetic tissue and the ground (Perez-Harguindeguy et al. 2013) and measured using either a measuring tape or laser finder (Compas Tools TruPulse 200). Plant diameter was measured as the basal diameter immediately above the ground surface. For mature woody plants, we measured the diameter at breast height of the dominant stem and for plants with multiple stems growing from the ground, diameter was measured for all stems, but the representative diameter is that of the dominant stem.

Projected frontal area was quantified from digital photographs taken of individual plants against a solid red background. We found that the red background provided the greatest contrast with the foliage and stems for most plants. Photographs were taken looking generally downstream with a simple point-and-shoot camera positioned parallel to the ground surface and focused on the mid-point of the plant. Each photo was edited in Adobe Photoshop, saturating the background to remove shading and shadows and removing any extraneous leaves or stems from neighboring plants. Pixels were classified as either plant or background in Easy Leaf Area (Easlon and Bloom 2014) and the number of plant pixels were used to calculate the frontal area, based on a 2.5-cm square scale included in each photo. Errors associated with the central photographic method used here includes the occlusion and distortion of stems and leaves. Compared to more robust field methods, the central photographic method captures 87% of the variability (Warmink 2007). We deemed this an acceptable level of variability, given our interest in a wide range of plant sizes. Frontal area for the 34 species differed by 5 orders of magnitude.

Plant flexibility, or more formally the flexural rigidity defined as the product of the modulus of elasticity (*E*) and the second moment of area (*I*), was measured in the field as the resistance of the dominant stem to bending. With the following equation, we calculated flexural rigidity (Usherwood et al. 1997),

$$EI=\frac{H^{3}\frac{dF}{dδ}}{48}$$

where *H* is the height of the stem in meters for which the measurement was made and $\frac{dF}{dδ}$ is the relationship between the change in applied force (*F*) in Newtons and the deflection (*δ*) in meters,. We measured $\frac{dF}{dδ}$ on the dominant stem by affixing a force gage to the stem’s mid-point. Slowly the force gage was pulled in the downstream direction parallel to the ground surface. For each force measurement (*F*) manually read off of the gage, a displacement distance (*δ*), defined as the distance between the starting position of the stem and the current position measured parallel to the ground surface, was also recorded. A minimum of three force-displacement measurements were made on each plant to identify the rate of change. We stopped applying a force to the stem either when we began to pull on the base of the plant thereby no longer measuring the resistance of the stem, but instead of the roots or when the force required to pull the stem was greater than which we could apply manually. Force-displacement measurements for flexural rigidity calculations were made on 64 individual plants, providing data on 21 of the 34 species. The flexural rigidity of the remaining 14 species was either too small, such that sensitivity of our force gage was not sufficient (0.01 g), or too large, such that we could not manually pull on the stems. For these plants, we assigned a value of 0.001 N m2 or 1000 N m2 for highly flexible and rigid species, respectively.

Plant density measurements (# plants m-2) were collected for 20 plots, characterizing 11 species. For the remaining species values we looked in the literature to identify typical values. Where a range was provided, we used values on the higher end. Additionally, we went to the literature to define the maximum root depth (root length) and the seed weight.

After all field measurements were made, we collected stem and leaf samples following the protocol of Perez-Harguindeguy et al. (2013) for quantification of stem tissue density (g cm-3) and specific leaf area (g cm-2) in the laboratory. The nature of stem samples differed and depended on the size of the plant, its form, and the dominant stem tissue. For woody plants, if the diameter of the plant was 10 cm, we took a core at breast height. For woody plants whose diameter was less than 10 cm and herbaceous plants with a prominent above-ground stem, we took a 10 cm long sample of the dominant stem from the ground surface. Where possible, we collected the culm of grasses and sedges close to the ground surface. For each individual plant, three young healthy leaves were removed from the stem at the petiole. For grasses and sedges we sampled a total of 9 lamina for each species. A photograph of each leaf pressed flat behind a clear cover against a white background was collected in the field and used to calculate the one-sided leaf area using Easy Leaf Area back in the laboratory. For those species for which leaves are not the main photosynthetic organs, including *Equisetum*, *Juncus arcticus*, *Eleocharis palustris*, and *Schoenoplectus pungens*, we estimated the surface area of the tubular photosynthetic support structure (i.e. the stem) by measuring multiple diameters along the stem from the base to the tip in the field, and then in the lab calculating one half of the surface area of geometric shape most-similar to the individuals form (e.g. conical frustum). All stem and leaf samples were labeled and placed with a moist paper towel in a plastic bag and kept cool.

Within 48 hours of returning from the field we processed all field samples. Bark and cambium, if present, were removed from cores and stem samples. We measured the stem volume using the water displacement method before placing the stems in a drying oven for at least 72 hours (or until dry) at 101 degrees for woody samples and 70 degrees for herbaceous samples. Leaves were placed in the oven for at least 72 hours at 70 degrees. All samples were weighed immediately after removing them from the oven.

**Works Cited**

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Pérez-Harguindeguy N, et al. 2013. New Handbook for standardized measurment of plant functional traits worldwide. Australian Journal of Botany 23:167–234.

Usherwood JR, Ennos AR, Ball DJ. 1997. Mechanical and anatomical adaptations in terrestrial and aquatic buttercups to their respective environments. 48:1469–1475.

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Table S1. Trait summary for 34 species, and 8 life history stages, measured along the Yampa and Green Rivers, Colorado.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Species symbol | Number of Individuals Sampled | Height (m) | Diameter (mm) | Stem Tissue Density (g cm-3) | Max Plant Density Groupe,h | Frontal Area (m2) | EI (N m2)h | Plant Architecturef | Specific Leaf Area (cm2 g-1) | Seed Weight (for 1000 seeds in g) | Root Depth Groupg,h | Max Plant Density (# m-2) |
| Acer negundo | Aceneg | 3 | 3.5 | 120.6 | 0.76d | *1* | 4.330 | *1000.00* | 1 | 179.3 | 36.0 | 5 | *0.01* |
| Ambrosia tomentosa | Ambtom  | 3 | 0.1 | 1.7 | 0.31c,d | *4* | 0.003 | *0.001* | 1 | 183.6 | N/A | N/A | N/A |
| Apocynum cannabinum | Apocan | 3 | 0.8 | 8.2 | 0.31 | *4* | 0.069 | **0.101** | 1 | 122.6 | 0.90 | 3 | *20* |
| Argentina anserina | Argans | 3 | 0.1 | 3.1 | 0.26 | *5* | 0.003 | *0.001* | 2 | 159.8 | 0.38 | 1 | *261* |
| Carex emoryi | Caremo | 3 | 0.6 | 1.5 | 0.43b,d | **5** | 0.002 | *0.001* | 0 | 139.1 | 0.46 | 2 | **595** |
| Celtis laevigata var. reticulata | Cellae | 1 | 2.4 | 73.1 | 0.83d | *1* | 2.972 | **306.5** | 1 | 93.7 | 92.0 | 5 | *0.02* |
| Chrysothamnus viscidiflorus | Chrvis | 1 | 0.9 | 16.7 | 0.66 | *1* | 0.928 | **0.755** | 2 | 119.3 | 1.2 | 4 | *0.09* |
| Conyza canadensis | Concan | 2 | 1.0 | 5.8 | 0.45 | *4* | 0.032 | **0.110** | 1 | 62.6 | 0.08 | 2 | *22* |
| Echinochloa crus-galli | Echcru | 3 | 0.6 | 4.4 | 0.26c,d | *4* | 0.010 | *0.001* | 2 | 289.2 | 1.3 | 4 | *56* |
| Elaeagnus angustifolia  | Elaang | 1 | 4.7 | 60.0 | 0.81 | *1* | 5.198 | **380.4** | 1 | 192.3 | 126.8 | 5 | *0.01* |
| Eleocharis palustris | Elepal | 3 | 0.2 | 0.6 | 0.30b,d | **6** | 0.0002 | *0.001* | 0 | 63.4 | 0.75 | 2 | **3436** |
| Equisetum hyemale | Equhye | 3 | 0.7 | 3.5 | 0.31b,d | **4** | 0.003 | **0.019** | 0 | 31.3 | 0.05 | 4 | **81** |
| Euthamia occidentalis | Eutocc | 3 | 1.4 | 7.4 | 0.30 | **4** | 0.035 | **0.282** | 0 | 131.7 | 0.11 | 4 | **26** |
| Glycyrrhiza lepidota | Glylep | 3 | 0.6 | 6.2 | 0.16 | **4** | 0.044 | **0.031** | 1 | 145.9 | 7.0 | 5 | **72** |
| Gnaphalium palustre | Gnapal | 3 | 0.0 | 1.5 | 0.38c,d | *4* | 0.001 | *0.001* | 2 | 579.0 | 0.18 | N/A | *21* |
| Helenium autumnale | Helaut | 3 | 0.3 | 2.4 | 0.42 | *3* | 0.005 | *0.001* | 1 | 43.9 | 0.50 | 2 | *6* |
| Juncus arcticus | Junarc | 3 | 0.7 | 1.5 | 0.32b,d | **6** | 0.0002 | *0.001* | 0 | 85.9 | 0.02 | 1 | **1100** |
| Juncus bufonius | Junbuf | 3 | 0.1 | 1.0 | N/A | *4* | 0.0973 | *0.001* | 2 | 343.5 | 0.02 | 1 | *20* |
| Phragmites australis | Phraus | 3 | 1.6 | 7.4 | 0.37 | **5** | 0.040 | **0.230** | 0 | 87.9 | 0.10 | 3 | **119** |
| Polygonum amphibium | Polamp | 3 | 0.1 | 2.3 | 0.39 | *4* | 0.004 | *0.001* | 1 | 112.5 | 0.67 | 2 | *13* |
| Populus fremontii, mature | Popfre(ma) | 3 | 17.0 | 361.7 | 0.56 | *2* | 17.125 | *1000.0* | 1 | 110.9 | 2.6 | 4 | *0.12* |
| Populus fremontii, sapling | Popfre(sa) | 9a | 2.0 | 19.7 | 0.40 | *3* | 0.295 | **1.95** | 1 | 93.1 | 2.6 | 3 | *10* |
| Populus fremontii, seedling | Popfre(se) | 9a | 0.5 | 4.4 | 0.33 | *5* | 0.021 | **0.014** | 1 | 91.4 | 2.6 | 2 | *350* |
| Rhus trilobata | Rhutri | 1 | 2.7 | 37.2 | 0.57 | **3** | 2.590 | **79.9** | 2 | 133.7 | 25.5 | 4 | **9** |
| Ribes aureum | Ribaur | 2 | 2.4 | 23.9 | 0.56 | **3** | 0.219 | **9.54** | 2 | 151.6 | 1.7 | 2 | **7** |
| Rosa woodsii | Roswoo | 3 | 0.7 | 10.2 | 0.53 | *4* | 0.210 | **0.520** | 2 | 149.2 | 9.4 | 4 | *13* |
| Salix exigua, mature | Salexi(ma) | 3 | 2.0 | 14.8 | 0.49 | *3* | 0.242 | **1.95** | 1 | 175.5 | 0.05 | 3 | *5* |
| Salix exigua, seedling | Salexi(se) | 12a | 0.5 | 7.0 | 0.57 | *5* | 0.021 | **0.039** | 1 | 95.2 | 0.05 | 2 | *350* |
| Schoenoplectus pungens | Schpun | 3 | 0.5 | 4.6 | 0.22b,d | **5** | 0.000 | **0.002** | 0 | 205.6 | 2.1 | 1 | **337** |
| Shepherdia argentea  | Shearg | 3 | 4.1 | 320.3 | 0.51 | *1* | 11.770 | *1000.00* | 1 | 124.3 | 6.6 | 3 | *0.01* |
| Solidago gigantea  | Solgig | 3 | 1.0 | 6.1 | 0.38 | *5* | 0.072 | **0.200** | 0 | 261.2 | 0.22 | 3 | *165* |
| Spartina pectinata | Spapec | 3 | 1.1 | 3.8 | 0.54 | **4** | 0.014 | **0.154** | 1 | 88.4 | 33.5 | 4 | **96** |
| Symphoricarpos occidentalis | Symocc | 3 | 1.0 | 12.1 | 0.60 | *4* | 0.162 | **0.340** | 1 | 104.9 | 6.0 | 4 | *27* |
| Tamarix ramosissima, mature | Tamram(ma) | 3 | 3.8 | 26.9 | 0.68 | *2* | 3.913 | **27.4** | 2 | 59.5 | 0.15 | 6 | *0.25* |
| Tamarix ramosissima, sapling | Tamram(sa) | 7a | 1.5 | 16.6 | 0.68 | *3* | 0.452 | **5.72** | 2 | 59.5 | 0.15 | 3 | *10* |
| Tamarix ramosissima, seedling | Tamram(se) | 7a | 0.5 | 9.4 | 0.68 | *5* | 0.035 | **0.971** | 1 | 59.5 | 0.15 | 2 | *350* |
| Xanthium strumarium | Xanstr | 3 | 0.5 | 10.3 | 0.30 | *5* | 0.130 | **1.07** | 1 | 122.0 | 203.4 | 4 | *132* |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| a. number of individuals measured in the field and used in the regression of height vs other trait |  |  |  |  |  |  |  |  |
| b. represents value derived from less than three individuals |  |  |  |  |  |  |  |  |  |  |  |
| c. bundled individual samples into a single sample |  |  |  |  |  |  |  |  |  |  |  |
| d. Sample volume was measured after they had been oven dried by rehydrating the tissue.  |  |  |  |  |  |  |  |  |  |
| e. in # of plants m-2; 1=<0.1; 2=0.1-1; 3=1-10; 4=10-100; 5=100-1000; 6=>1000 |  |  |  |  |  |  |  |  |  |
| f. 0= single-stemmed, 1= branching, 2= multi-stemmed |  |  |  |  |  |  |  |  |  |  |  |
| g. 1 = 0-0.25 m; 2 = 0.25-0.5 m; 3 = 0.5-1 m; 4 = 1-3 m; 5 = 3-6 m; 6 = >6m |  |  |  |  |  |  |  |  |  |  |
| h. Bold represents values measured in the field; italicized are either assigned or derived from the literature |  |  |  |  |  |

Table S2. Results from linear regression model predicting topographic change accounting for both abiotic factors that includes the elevation above the baseflow channel (Elev\_Abv\_BF) for each flood at each of the three sites (Harding Hole, Laddie Park, and Seacliff) and the biotic factors that includes the total vegetation cover within each plot (cover) and the proportion of each of the six guilds present (prop\_guild).

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Coefficient | Standard Error | p-value |
| *Intercept* | 0.006 | 0.058 | *0.91* |
| *Elev\_Abv\_BF* | 0.022 | 0.092 | *0.81* |
| *HardingHole2014* | -0.198 | 0.079 | ***0.01*** |
| *HardingHole2015* | 0.001 | 0.104 | *0.99* |
| *LaddiePark2013* | 0.072 | 0.117 | 0.54 |
| *LaddiePark2014* | 0.767 | 0.084 | **<0.001** |
| *LaddiePark2015* | -0.784 | 0.107 | ***<0.001*** |
| *Seacliff2013* | -0.059 | 0.086 | *0.49* |
| *Seacliff2014* | -0.078 | 0.127 | *0.37* |
| *Seacliff2015* | 0.058 | 0.117 | 0.65 |
| *Elev\_Abv\_BF\***HardingHole2014* | 0.139 | 0.117 | *0.24* |
| *Elev\_Abv\_BF\***HardingHole2015* | -0.23 | 0.161 | *0.15* |
| *Elev\_Abv\_BF\***LaddiePark2013* | -0.145 | 0.147 | *0.32* |
| *Elev\_Abv\_BF\** *LaddiePark2014* | -0.245 | 0.101 | ***0.016*** |
| *Elev\_Abv\_BF\** *LaddiePark2015* | 0.290 | 0.120 | ***0.015*** |
| *Elev\_Abv\_BF\** *Seacliff2013* | -0.016 | 0.135 | *0.91* |
| *Elev\_Abv\_BF\** *Seacliff2014* | -0.018 | 0.118 | *0.88* |
| *Elev\_Abv\_BF\** *Seacliff2015* | -0.403 | 0.147 | ***0.006*** |
| *Cover* | 0.022 | 0.006 | ***<0.001*** |
| *Prop\_hydric herb* | 0.026 | 0.067 | *0.70* |
| *Prop\_hydric pioneer*  *tree/shrub seedlings* | 0.100 | 0.063 | *0.11* |
| *Prop\_short mesic herb* | 0.077 | 0.096 | *0.43* |
| *Prop\_tall mesic herb* | 0.036 | 0.108 | *0.74* |
| *Prop\_mesic shrub/tree* | 0.511 | 0.150 | ***<0.001*** |
| *Prop\_xeric late-seral tree* | 0.132 | 0.292 | *0.65* |
| *Cover\*Prop\_hydric herb* | -0.021 | 0.008 | ***<0.001*** |
| *Cover\*Prop\_hydric pioneer*  *tree/shrub seedlings* | -0.021 | 0.007 | ***0.003*** |
| *Cover\*Prop\_short mesic herb* | -0.026 | 0.007 | ***<0.001*** |
| *Cover\*Prop\_tall mesic herb* | -0.021 | 0.012 | ***0.08*** |
| *Cover\*Prop\_mesic shrub/tree* | -0.027 | 0.006 | ***<0.001*** |
| *Cover\*Prop\_xeric late-seral*  *tree* | -0.006 | 0.02 | *0.78* |

|  |  |  |  |
| --- | --- | --- | --- |
| *Model adjusted R-squared: 0.43* |  |  |  |
| *F-statistic: 15.8 on 30 and 557 degrees of freedom; p-value:* ***<0.001*** |  |