

1 Foundation Species Across a Latitudinal Gradient in
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Abstract

41

Foundation species play important roles in structuring forest communities and ecosystems. Foundation species are difficult to identify without long-term observations or experiments and their foundational roles rarely are identified before they are declining or threatened. We used new statistical criteria based on size-frequency distributions, species diversity, and spatial codispersion among woody plants to identify potential (“candidate”) foundation species in 12 large forest dynamics plots spanning 26 degrees of latitude in China. We used these data to identify a suite of candidate foundation species in Chinese forests; test the hypothesis that foundation woody plant species are more frequent in the temperate zone than in the tropics; and compare these results with comparable data from the Americas to suggest candidate foundation genera in Northern Hemisphere forests. We identified more candidate foundation species in temperate plots than in subtropical or tropical plots, and this relationship was independent of the latitudinal gradient in overall species richness. Two species of *Acer*, the canopy tree *Acer ukurunduense* and the shrubby treelet *Acer barbinerve* were the only two species that met both criteria in full to be considered as candidate foundation species. When we relaxed the diversity criteria, *Acer*, *Tilia*, and *Juglans* spp., and *Corlyus mandshurica* were frequently identified as candidate foundation species. In tropical plots, the tree *Mezzeppiopsis creagħii* and the shrubs or treelets *Aporusa yunnanensis* and *Ficus hispida* had some characteristics associated with foundation species. Species diversity of co-occurring woody species was negatively associated with basal area of candidate foundation species more frequently at 5- and 10-m spatial grains (scale) than at a 20-m grain. Conversely, Bray-Curtis dissimilarity was positively associated with basal area of candidate foundation species more frequently at 5-m than at 10- or 20-m grains. Our data support the hypothesis that foundation species should be more common in temperate than in tropical or boreal forests, and suggest that in the Northern Hemisphere that *Acer* be investigated further as a foundation tree genus.

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Keywords: Beta diversity, biodiversity, China, CForBio, codispersion analysis, forest dynamic plots, ForestGEO, latitudinal gradient.

69 Introduction

70 A foundation species is a single species (or a group of functionally similar taxa) that dom-
71 inates an assemblage numerically and in overall size (e.g., mass or area occupied), determines
72 the diversity of associated taxa through non-trophic interactions, and modulates fluxes of
73 nutrients and energy at multiple control points in the ecosystem it defines (Ellison, 2019).

74 Because foundation species are common and abundant, they generally receive less attention
75 from conservation biologists, conservation professionals, and natural-resource managers who
76 emphasize the study, management or protection of rare, threatened, or endangered species
77 (Gaston and Fuller, 2007, 2008). However, protecting foundation species before they decline
78 to non-functional levels can maintain habitat integrity, thereby protecting associated rare
79 species at lower cost and less effort (Ellison and Degrassi, 2017; Degrassi et al., 2019).

80 Identifying foundation species is difficult because it can take many years—often decades—
81 to collect enough data to distinguish foundation species from other species that also are
82 common, abundant, or dominant (*sensu* Grime, 1987) but lack “foundational” characteristics
83 (Baiser et al., 2013; Ellison, 2014, 2019). Rather than investigating one common or dominant
84 species at a time in myriad ecosystems, Ellison and his colleagues have worked with data
85 from individual and multiple large forest dynamics plots within the ForestGEO network¹ to
86 develop statistical criteria that can suggest which tree species might merit further attention
87 as candidate foundation species in forests (Buckley et al., 2016a,b; Case et al., 2016; Ellison
88 et al., 2019). Specifically, Ellison et al. (2019) proposed two statistical criteria for candidate
89 foundation tree species based on their size-frequency and abundance-diameter distributions,
90 and on their spatial effects of on the alpha diversity (as Hill numbers: Chao et al., 2014) and
91 beta diversity (e.g., Bray-Curtis dissimilarity) of co-occurring species.

92 The first criterion is that candidate foundation tree species are outliers from the expected
93 “reverse-J” size-frequency distribution observed in virtually all assemblages of co-occurring
94 species (Loehle, 2006). The departure from expected size-frequency relationships reflects the

¹<https://www.forestgeo.si.edu/>

95 abundance of foundation species and their relatively large sizes that lead to their dispropor-
96 tionate influence on overall community structure. We refer to this criterion as the “outlier
97 criterion”.

98 The second criterion (the “diversity criterion”) is that the size or abundance of candi-
99 date foundation tree species should be negatively associated with species diversity (alpha
100 diversity) of other woody plants at local (small) spatial scales but positively associated with
101 species turnover (beta diversity) across large forest plots or stands (Ellison et al., 2019). The
102 negative spatial association between the size or abundance of foundation tree species with
103 local diversity of co-occurring woody species results simply from the foundation species occu-
104 pying most of the available space in a standard 20×20-m forest plot (or, in fact, any relatively
105 small plot). In contrast, the positive spatial association between the size or abundance of
106 a foundation tree species with beta diversity results from it creating patchy assemblages at
107 landscape scales. For example, forest stands dominated by foundation species such as *Tsuga*
108 *canadensis* in eastern North America or *Pseudotsuga menziesii* in western North America
109 manifest themselves as distinctive patches on the landscape. When these foundation species
110 decline or are selectively harvested, the landscape is homogenized and beta diversity declines.
111 Indeed, Ellison et al. (2019) suggested that the preservation of landscape diversity may be
112 the most important reason to protect and manage foundation tree species before they decline
113 or disappear.

114 We emphasize that the application of these criteria to identify candidate foundation
115 species leads to the hypothesis that a particular taxon may be a foundation species, not that
116 it is one. Asserting that a species is a foundation species requires additional observational
117 and, ideally, experimental evidence (Ellison, 2014, 2019). Indeed, we derived these two
118 statistical criteria after more than a decade of observational and experimental studies of
119 *Tsuga canadensis*-dominated forests in New England, USA that lend strong support for the
120 hypothesis that *T. canadensis* is a foundation species (Orwig et al., 2013; Ellison, 2014).
121 These criteria subsequently were applied to five additional forest dynamics plots in the

¹²² western hemisphere (Buckley et al., 2016b; Ellison et al., 2019) with encouraging results.

¹²³ Here, we apply these criteria to 12 large forest dynamics plots in China that range from

¹²⁴ cold-temperate boreal forests to tropical rain forests. These plots are all part of the Chinese

¹²⁵ Forest Biodiversity Monitoring Network (CForBio)², itself a part of the ForestGEO network.

¹²⁶ There are two, fundamentally new contributions of this work. First, we test the hypoth-

¹²⁷ esis that foundation tree species should be uncommon or absent in subtropical and tropical

¹²⁸ forests. Empirical support for particular trees having foundational roles in forests is strongest

¹²⁹ for temperate forests (Schweitzer et al., 2004; Whitham et al., 2006; Ellison, 2014; Tombak

¹³⁰ et al., 2016) and low-diversity tropical forests (Ellison et al., 2005), and Ellison et al. (2005)

¹³¹ hypothesized that foundation tree species would be less likely in species-rich tropical forests

¹³² (Ellison et al., 2019). Second, the application of our statistical criteria yield new insights

¹³³ into ecological patterns and processes not only for China, but also concerning similarities

¹³⁴ between the floras of East Asia and Eastern North America (Tiffney, 1985; Pennington et al.,

¹³⁵ 2004).

¹³⁶ Methods

¹³⁷ Forest dynamics plots in China

¹³⁸ We used data from 12 of the 17 CForBio plots in our exploration of candidate foundation

¹³⁹ species in Chinese forests (Table 1). These plots span \sim 26 degrees of latitude and include:

¹⁴⁰ the 9-ha broad-leaved Korean pine mixed forest plot at Liangshui in the Xiaoxing'an Moun-

¹⁴¹ tains of Heilongjiang Province; the 25-ha *Taxus cuspidata*-dominated forest in the Muling

¹⁴² Nature Reserve, also in Heilongjiang Province; the 25-ha deciduous broad-leaved Korean

¹⁴³ pine mixed forest plot on Changbai Mountain in Jilin Province; the 20-ha warm-temperate

¹⁴⁴ deciduous broad-leaved forest plot on Dongling Mountain in Beijing; the 25-ha subtropical ev-

¹⁴⁵ ergreen broad-leaved forest plot on Tiantong Mountain in Zhejiang Province; the 25-ha mid-

²<http://www.cfbiodiv.org>

146 subtropical mountain evergreen and deciduous broad-leaved mixed forest plot on Badagong
147 Mountain in Hunan province; the 24-ha subtropical evergreen broad-leaved forest plot on
148 Gutian Mountain in Zhejiang Province; 20-ha lower subtropical evergreen broad-leaved forest
149 plot on Dinghu Mountain in Guangdong Province; the 25-ha cold-temperate spruce-fir forest
150 plot on Yulong Snow Mountain in Yunnan Province; the 25-ha karst evergreen and deciduous
151 broad-leaved mixed forest plot at Mulun in the Guangxi Zhuang Autonomous Region; the
152 15-ha karst seasonal rain-forest plot at Nonggang, also in the Guangxi Zhuang Autonomous
153 Region; and the 20-ha tropical forest plot at Xishuangbanna in Yunnan Province.

154 [Table 1 about here.]

155 The 9-ha Liangshui plot (“LS”; 47.18 °N, 128.88 °E) was established in 2005. This plot
156 is located in the Liangshui National Reserve, which has been spared from logging and other
157 major disturbance since 1952 (Liu et al., 2014), and represents the climax vegetation type
158 of Northeast China (Xu and Jin, 2013). It is considered to be one of the most typical and
159 intact mixed broad-leaved-Korean pine forests in China. The plot has an elevational range
160 from 425 to 508 m a.s.l, a mean annual temperature of −0.3°C, and receives on average 676
161 mm of precipitation annually. In the first census in 2010, 21,355 individual stems in 48
162 species, 34 genera, and 20 families were recorded. The average age of the overstory trees
163 was approximately 200 years (Liu et al., 2014). The “reverse-J” diameter distribution of
164 all individuals in LS suggested that the forest was regenerating well. The dominant tree
165 species at LS is *Pinus koraiensis*. Major associated tree species include *Tilia amurensis*, *T.*
166 *mandshurica*, *Betula costata*, and *Fraxinus mandshurica* (Xu and Jin, 2013).

167 The 25-ha Muling plot (“MLG”; 43.95 °N, 130.07 °E) was established in 2014 within the
168 Muling Nature Reserve. The elevation within the plot varies from 658–781 m, the average
169 annual temperature is −2°C, and the average annual precipitation is 530 mm. Muling is
170 a typical middle-aged, multi-storied, uneven aged forest. Dominant tree species are *Tilia*
171 *amurensis*, *Pinus koraiensis*, *Acer mono*, *Abies nephrolepis* and *Betula costata*. 63,877 in-
172 dividuals belonging to 22 families, 38 genera, and 57 woody species were recorded at the

173 first census, including the nationally endangered *Taxus cuspidata* (Diao et al., 2016). The
174 average DBH of all woody stems in MLG at the first census was 7.8 cm.

175 The 25-ha Changbai Mountain plot (“CB”; 42.28 °N, 128.08 °E), established in 2004,
176 was the first temperate forest dynamics plot in the ForestGEO network. It is considered
177 to be a typical old-growth, multi-storied, uneven-aged forest, and has neither been logged
178 nor suffered other severe human disturbances since 1960 (Wang et al., 2010). The average
179 annual temperature at CB is 3.6 °C and average annual precipitation is 700 mm. The terrain
180 of CB is relatively even, with elevations ranging from 791 to 809 m a.s.l. The height of the
181 main canopy species is ≈30 m, and the oldest trees are ≈300 years old. In the first census,
182 38,902 individuals in 52 species representing 32 genera and 18 families were recorded. The
183 most common species at CB are *Pinus koraiensis*, *Tilia amurensis*, *Quercus mongolica*, and
184 *Fraxinus mandshurica* (Hao et al., 2008). The most abundant eight species accounted for
185 83.4% of the total individuals in the plot (Wang et al., 2010).

186 The 20-ha Dongling Mountain plot (“DL”; 39.96 °N, 115.43 °E), established in 2010, is
187 in a warm temperate deciduous broad-leaved forest. The average annual temperature at DL
188 is 4.8 °C and it receives 500–650 mm of precipitation each year. The mean elevation of the
189 plot is 1395 m, but the terrain is relatively steep with an elevation change of 219 m and
190 slopes ranging from 20–60° (Liu et al., 2011). In the first census, 52,316 individuals in 58
191 species, 33 genera, and 18 families were recorded. The dominant species are all deciduous
192 trees, and include *Quercus wutaishanica*, *Acer mono*, and *Betula dahurica* (Liu et al., 2011).
193 The most common five species in the plot comprised 61% of all individuals, whilst the most
194 common 20 species comprised 92% of all individuals (Liu et al., 2011).

195 The 20-ha Tiantong plot (“TT”; 29.80 °N, 121.80 °E) represents a typical lower subtropi-
196 cal evergreen broad-leaf forest. It was established in 2009 within the core area of the Ningbo
197 Tiantong National Forest Park. Mean annual temperature at TT is 16.2 °C and mean annual
198 rainfall is 1375 mm. There have been some typhoon-caused landslides in some parts of the
199 plot (Yang et al., 2011), but it is otherwise considered to be free from human disturbance

200 (Yan et al., 2018). Like Dongling Mountain, TT has a large elevational change across the
201 plot, ranging from 304 to 603 m a.s.l. In the first census, 94,603 individuals in 152 species,
202 94 genera, and 51 families were recorded. The dominant species are *Eurya loquaiana*, *Litsea*
203 *elongata*, and *Choerospondias axiliaris* (Yang et al., 2011).

204 The 25-ha Badagong Mountain plot (“BDG”; 29.77 °N, 110.09 °E), established in 2011, is
205 located near the center of distribution of the oak genus *Fagus*. This plot is within the north
206 subtropical mountain humid monsoon climate; the average annual temperature is 11 °C and
207 average annual rainfall is 2105 mm (Lu et al., 2013). The dominant trees are a mixture
208 of evergreen (*Cyclobalanopsis multinervis*, *C. gracilis*, and *Schima parviflora*) and deciduous
209 species (*Fagus lucida*, *Carpinus fargesii*, and *Sassafras tzumu*). During the first census,
210 186,556 individuals, belonging to 53 families, 114 genera, and 232 species were recorded
211 (Qin et al., 2018). There were 38 species with ≥ 1000 individuals, most in the shrub layer (Lu
212 et al., 2013).

213 The 24-ha Gutian Mountain plot (“GT”; 29.25 °N, 118.12 °E) was established in 2005
214 as representing a typical mid-subtropical evergreen broad-leaved forest (Legendre et al.,
215 2009). Like the other montane plots, GT has a broad elevational range (446–715 m a.s.l.)
216 with steep topography (slopes 12–62°). Average annual temperature at GT is 15.3 °C and
217 average annual rainfall is 1964 mm. In the first census, 140,700 individuals in 159 species,
218 104 genera, and 49 families were recorded. Dominant species at GT include *Castanopsis*
219 *eyrei* and *Schima superba* (Legendre et al., 2009).

220 The 25-ha Yulong Snow Mountain plot (“YLXS”; 27.14 °N, 100.22 °E), established in
221 2014, is at the highest elevation (3282 m a.s.l.) of the 12 plots we studied. Although the
222 latitude of this plot is very low, the climate of this coniferous forest plot is cold-temperate
223 because of its high elevation. The average annual temperature at YL is 5.5 °C and annual
224 precipitation is 1588 mm (Huang et al., 2017). In the first census, 47,751 individuals in 62
225 species, 41 genera, and 26 families were recorded, dominated by *Berberis fallax* and *Abies*
226 *forrestii* (Huang et al., 2017).

227 The 25-ha Mulun plot (“ML”; 25.80 °N, 108.00 °E), also established in 2014, is within
228 the Mulun National Natural Reserve. The mean annual temperature at ML is 19.3 °C, and
229 the average annual rainfall is 1529 mm. The terrain of the plot is complex and varied. Rock
230 exposure exceeds 60% and soil thickness >30 cm in most areas. In the first census, 108,667
231 individuals in 227 species, 147 genera, and 61 families were recorded (Lan et al., 2016).
232 The dominant species are *Crytocarya microcarpa*, *Itoa orientalis*, *Platycarya longipes*, and
233 *Lindera communis* (Lan et al., 2016).

234 The 20-ha Dinghu Mountain plot (“DH”; 23.10 °N, 112.32 °E), established in 2005,
235 has an average annual temperature of 20.9 °C and average annual precipitation of 1927
236 mm. This steep, subtropical evergreen forest spans an elevational range of 230–470 m with
237 very steep slopes (30–50°). The first census recorded 71,617 individuals in 210 species, 119
238 genera, and 56 families (Ye et al., 2008). The three canopy-dominant species in the plot are
239 *Castanopsis chinensis*, *Schima superba* and *Engelhardtia roxburghiana*, whilst the sub-canopy
240 is dominated by *Syzgium rehderianum* and *Craibiodendron scleranthum* var. *kwangtungense*
241 (Ye et al., 2008).

242 The 15-ha Nonggang plot (“NG”; 22.45 °N, 106.95 °E), established in 2011, is in a
243 hot-spot of biodiversity in China. This region is characterized by highly vulnerable and
244 spectacular limestone karst systems. Average annual temperature at NG is 21.5 °C and
245 average annual precipitation is 1350 mm. The first census recorded 66,718 individuals in
246 223 species, 153 genera, and 54 families (Lan et al., 2016). Eight of the recorded species
247 are protected throughout China, 30 are endemic to Guangxi province, and three were new
248 records for China. Representative tree species in NG include *Excentrodendron tonkinense*,
249 *Cephalomappa sinensis*, *Deutzianthus tonkinensis*, and *Garcinia paucinervis*.

250 The 20-ha Xishuangbanna plot (“XSBN”; 21.61 °N, 101.57 °E), established in 2007,
251 is the southernmost CForBio site and is at the northern limit of typical southeast Asian
252 tropical rain forests. It receives 1532 mm of precipitation annually and has an average
253 annual temperature of 21 °C. The tropical seasonal rain forest in XSBN is one of the most

254 species-rich forest ecosystems in China. At the first census, 95,834 individuals in 468 species,
255 213 genera, and 70 families were recorded (Lan et al., 2008). The canopy height of this forest
256 is 50–60 m. The dominant emergent tree species is *Parashorea chinensis*. Subcanopy layers
257 of the forest are dominated by *Sloanea tomentosa*, *Pometia pinata*, and *Pittosporopsis kerrii*.

258 **Tree census and measurement**

259 Standard ForestGEO procedures (Condit, 1995) have been used to collect data across
260 all CForBio plots. All woody stems (free-standing trees, shrubs, and lianas) at least 1 cm
261 in diameter at breast height (“DBH”; 1.3 m above the ground level) were tagged, measured,
262 identified to species, and mapped. In all of the plots, the individuals have been censused
263 every 5 years (initial census years in these 12 plots varied between 2004 and 2014; Table 1);
264 we used the first census data from each plot in our analysis.

265 **The outlier criterion for identifying candidate foundation species**

266 Following Ellison et al. (2019), our first criterion for selecting candidate foundation tree
267 species in each plot was to determine those species that were “outliers” from the typical
268 “reverse-J” distribution of the size-frequency distribution of mean DBH plotted against the
269 number of individuals. We identified outliers by eye rather than fitting a negative exponen-
270 tial distribution with an arbitrary number of parameters to the 12 different size-frequency
271 distributions. This initial screen revealed 2–14 candidate foundation tree species in each of
272 the 12 forest dynamics plots (Fig. 1). The largest number of candidate species occurred in
273 MLG and the fewest were in YLXS. To screen species more expansively and avoid missing
274 other possible candidate foundation species, we also included in our first cut those ten species
275 with the highest importance values (IV = relative abundance + relative density + relative
276 basal area) in each of the plots. Species that were outliers on the size-frequency plots usually
277 had high importance values, but including the latter did expand our initial pool of candidate
278 species to 10–14 species per plot (Table 2).

279

[Figure 1 about here.]

280

[Table 2 about here.]

281 The diversity criterion for identifying candidate foundation species

282 The second, more stringent criterion for identifying candidate foundation species is a neg-
283 ative association between its size (or abundance), and total abundance, three measures of
284 alpha diversity (species richness, Shannon diversity, Inverse Simpson Diversity) of associated
285 woody species *and* a positive association between its size or abundance and beta diversity
286 (Ellison et al., 2019). The three measures of alpha diversity treat all species identically
287 (species richness), down-weight rare species (Shannon diversity), or down-weight common
288 species (inverse Simpson diversity) within subplots. These associations also should be con-
289 sistent across the plots when calculated at a given spatial grain (*a.k.a.* spatial scale) and at
290 most (ideally all) spatial lags (Buckley et al., 2016a; Ellison et al., 2019).

291 Forest structure and species diversity indices

292 For each plot, we calculated the total basal area, mean basal area, and total number
293 of individuals of each of the candidate foundation tree and shrub species (Table 3) within
294 contiguous 5 × 5, 10 × 10, and 20 × 20-m subplots. For species other than the candidate foun-
295 dation species, we calculated their total abundance, species richness, Shannon and inverse
296 Simpson diversity indices (as Hill numbers: Chao et al., 2014) and mean Bray-Curtis dissim-
297 ilarity (overall methods as in Ellison et al., 2019). In all the analysis, we used only the main
298 stem of each individuals (i.e., smaller stems of multi-stemmed individuals were excluded from
299 the analyses). The `diversity()` and `vegdist()` functions in the `vegan` package (Oksanen
300 et al., 2018) of the R software system (R Core Team, 2019) were used for calculating each
301 diversity metric.

302 **Codispersion analysis**

303 Codispersion describes anisotropic spatial patterns (i.e., different expected values when
304 measured in different directions) of co-occurring variables for given spatial lags and direc-
305 tions (Cuevas et al., 2013). The codispersion coefficient ranges from -1 to 1 , with positive
306 values indicating a positive spatial association and negative values indicating a negative spa-
307 tial association for a given spatial lag and direction. These values can be visualized with
308 a codisperison graph (Vallejos et al., 2015). Buckley et al. (2016a) introduced codispersion
309 analysis to ecologists through an exploration of spatial patterns of species co-occurrence.
310 That paper also provides a basic introduction to the mathematics of codispersion analysis
311 and codispersion graphs. Buckley et al. (2016b) used codispersion analysis to examine spa-
312 tial patterns of relationships between environmental characteristics and known or candidate
313 foundation tree species. Ellison et al. (2019) used codispersion analysis to quantify spatial
314 effects of candidate foundation tree species on different measures of diversity of associated
315 woody species in six forest dynamics plots in the Americas.

316 Although we computed codisperison patterns using mean basal area, total basal area,
317 and total abundance of candidate foundation species, we focus our presentation on the
318 codispersion between the total basal area of the candidate foundation species and associated
319 woody plant diversity in the differently-sized (5×5 , 10×10 , and 20×20 -m subplots)
320 contiguous subplots in each of the 12 forest dynamics plots (Ellison et al., 2019); qualitatively
321 similar patterns were observed when using mean basal area or total numbers of individuals of
322 candidate foundation species. For each candidate foundation tree species, we first computed
323 the observed codispersion coefficient between its total basal area and abundance, alpha, and
324 beta diversity of the associated woody species in the subplots. The maximum spatial lag
325 examined for each plot ranged from the length of the subplot to one-fourth of the length
326 of the shortest side of each forest plot, which ensured adequate sample sizes for reliable
327 estimation of codispersion coefficients at the largest spatial lag (Buckley et al., 2016a).

328 Statistical significance of the codispersion coefficients was determined using null model

329 analysis (Buckley et al., 2016b; Ellison et al., 2019). Codispersion coefficients for all spatial
330 lags and directions were computed for co-occurrence matrices randomized using a toroidal-
331 shift null model, which maintains the autocorrelation structure of the species and spatial
332 patterns caused by underlying environmental gradients while shifting the associated woody
333 species in random directions and distances (Buckley et al., 2016b; Ellison et al., 2019). For
334 each candidate foundation species in each plot, we ran 199 randomizations; significance
335 was determined based on empirical 95% confidence bounds. Calculation of codispersion
336 coefficients and all randomizations were done using custom C and R code written by Ronny
337 Vallejos and Hannah Buckley, respectively.

338 Data and code availability

339 Each of the CForBio plots were established at different times and are scheduled to be (or
340 already have been) censused every five years. To maximize comparability among datasets, we
341 used data collected at the first census for each plot (Table 1). All datasets are available from
342 the ForestGEO data portal <https://ctfs.si.edu/datarequest>). R code for all analyses
343 is available on GitHub (https://github.com/buckleyhannah/FS_diversity).

344 Results

345 Candidate foundation species in the CForBio plots

346 Only two species—the shrub *Acer barbinerve* (Fig. 2, 3) and the congeneric tree *Acer*
347 *ukurunduense* (Fig. 4, 5)—in one plot—MLG—satisfied both the outlier *and* diversity cri-
348 teria for all diversity measures for candidate foundation species (Figs. 2–5). For these two
349 species in MLG, both criteria were met only at the 5-m spatial grain (Table 3).

350 [Figure 2 about here.]

351 [Figure 3 about here.]

352

[Figure 4 about here.]

353

[Figure 5 about here.]

354

[Table 3 about here.]

355 More species were considered as candidate foundation species when we retained the out-
356 lier criterion (Fig. 1) but relaxed the diversity criterion to require only a positive spatial
357 relationship between the size of the candidate foundation species and beta diversity *and* a
358 negative spatial relationship between the size of the candidate foundation species and at
359 least one of the alpha-diversity measures (species indicated with an asterisk [*] in Table 3).
360 These additional candidate foundation species included two additional *Acer* species, tree
361 species in the genera *Pinus*, *Taxus*, *Fraxinus*, *Quercus*, and *Tilia*, and two shrubs (*Corylus*
362 *mandshurica* and *Aporusa yunnanensis*). However, whether we applied the stringent or re-
363 laxed diversity criterion, all but three of the candidate foundation species occurred in plots
364 with cool- or cold-temperate climates. The exceptions were the trees *Pinus massoniana* and
365 *Quercus serrata* var. *brevipetiolata* at GT and *Aporusa yunnanensis* at DH; all three of these
366 species occurred in the subtropical evergreen broad-leaved forest plots.

367 A few of our initial candidate species that had high importance values but were not
368 outliers from the expected size-frequency distributions (unstarred species in Table 2) did
369 partially meet the diversity criterion in both temperate and tropical plots (Table 3). These
370 included *Syringa reticulata* var. *amurensis* at CB, *Juglans mandshurica* at DL, *Machilus*
371 *thunbergii* at GT, *Brassaiopsis glomerulata* at ML, *Ficus hispida* at NG, and *Mezzettiaopsis*
372 *creaghii* at XSBN.

373 **Scale-dependence of candidate foundation species**

374 More candidate foundation species—including all species that met at least one of the two
375 criteria—were identified at smaller spatial grains: 15 species at the 5-m grain, 11 at the 10-m
376 grain, and six at the 20-m grain (Table 3). This pattern applied both among and within the

377 plots. Average codispersion between total basal area of the candidate foundation species and
378 Bray-Curtis dissimilarity increased significantly with spatial grain (Fig. 6; raw data in Table
379 4). In contrast, average codispersion between total basal area of the candidate foundation
380 species and measures of alpha diversity, while generally negative, were more variable and not
381 scale-dependent (Fig. 6; raw data in Table 4).

382 [Figure 6 about here.]

383 Candidate foundation species across a latitudinal gradient

384 Both the number of woody species in each plot that were outliers from the expected
385 size-frequency distribution and the number of candidate foundation species increased with
386 increasing latitude (Fig. 7A, C; slopes = 0.3 and 0.15 species/degree of latitude, respectively;
387 $P < 0.01$). As expected, within-plot species richness declined significantly with latitude (slope
388 = -10.2 species/degree of latitude, $P < 0.01$), but this relationship was unrelated to the
389 latitudinal pattern in either the number of outliers or the number of candidate foundation
390 species. There were no significant relationships between either the number of outliers or the
391 number of candidate foundation species and within-plot species richness (Fig. 7B, D; $P =$
392 0.08 and 0.18 respectively).

393 [Figure 7 about here.]

394 Spatial association (expressed as codispersion) within each plot between candidate foun-
395 dation species and total abundance, mean alpha diversities, and mean beta diversity of
396 associated woody species on average did not vary with latitude at any spatial grain (Fig.
397 8; raw data in Table 4). Quantile regression (to account for potential extreme effects of
398 foundation species) yielded similar results. There were no observed latitudinal patterns in
399 effects of candidate foundation species except for a slight strengthening of the negative effect
400 of candidate foundation species on associated woody species richness and total abundance

401 at the 5-m grain (Fig. 8, $P = 0.04$). Similar results were obtained when understory shrubs
402 were excluded from the analysis (Fig. 9).

403 [Figure 8 about here.]

404 [Figure 9 about here.]

405 Discussion

406 We applied two new statistical criteria (Ellison et al., 2019) to screen 12 of the 17 CForBio
407 Forest Dynamic plots in China for candidate foundation species. These 12 plots ranged
408 from 47 to 21 °N latitude, represented boreal, conifer-dominated, broad-leaved deciduous,
409 subtropical, and tropical forests (Table 1), and included two forest types referred to by
410 particular species (“Korean pine” mixed forests at Liangshi and Changbai Mountain, and the
411 “*Taxus cuspidata*” mixed coniferous forest at Muling). Such eponyms do suggest traditional
412 or cultural-based knowledge of foundation (or other “important”) species (Ellison et al.,
413 2005; Ellison, 2019). Whilst both Korean pine (*Pinus koraiensis*) and *Taxus cuspidata* were
414 identified as candidate foundation species (Table 3), they were only candidates in the Muling
415 *Taxus cuspidata*-dominated forest plot, not in either of the “Korean pine” mixed forests. We
416 also found a strong latitudinal gradient, unrelated to the expected (and observed) underlying
417 latitudinal gradient in woody plant species richness, in the number of candidate foundation
418 species, which were more frequent in temperate than in tropical forest plots (Fig. 7). Where
419 they occurred, candidate foundation species had comparable effects at all latitudes (Figs.
420 8, 9), suggesting that foundation species effects more likely reflect specific combinations of
421 traits and interspecific effects rather than being manifestations of “neutral” (sensu Hubbell,
422 2001) processes (Ellison et al., 2019).

423 Candidate foundation species are more common in temperate lati- 424 tudes

425 Foundation species in forests control species diversity locally within forest stands and at
426 landscape and larger scales by creating habitat for associated flora (e.g., epiphylls, epiphytes,
427 vines, lianas) and modifying soil structure and composition (e.g., Ellison et al., 2005; Brant-
428 ley et al., 2013; Baiser et al., 2013; Vallejos et al., 2018; Degrassi et al., 2019; Ellison, 2019).
429 Forest foundation species frequently are common, abundant, large trees (e.g., Schweitzer
430 et al., 2004; Ellison et al., 2005; Whitham et al., 2006; Tombak et al., 2016; Ellison et al.,
431 2019), but understory shrubs and treelets also can have foundational characteristics (Kane
432 et al., 2011; Ellison and Degrassi, 2017; Ellison et al., 2019). Ellison et al. (2005) hypoth-
433 esized that foundation species would be more likely in temperate forests because of their
434 relatively low species richness and more frequent dominance by one or a small number of
435 taxa. In contrast, tropical forests should lack foundation species as they are speciose and are
436 dominated less frequently by a small number of taxa. Our data supported this hypothesis:
437 candidate foundation species in the CForBio plots were more common at higher latitudes
438 than in the tropics (Fig. 7; Ellison et al., 2019). This pattern also may reflect the greater
439 importance of deterministic “niche” processes in temperate forests versus the stronger role
440 of “neutral” dynamics in tropical ones (Gravel et al., 2006; Qiao et al., 2015).

441 We hypothesize that tropical forests dominated by a one or a few closely-related species,
442 such as coastal mangrove forests dominated by *Rhizophora* spp. (Tomlinson, 1995) and mon-
443 odominant tropical lowland forests dominated by species of Dipterocarpaceae in southeast
444 Asia or species of Leguminosae (subfamily Caesalpinoideae) in Africa and the Neotropics
445 (Torti et al., 2001; Hall et al., 2019) may be structured by foundation species (Ellison et al.,
446 2005). Indeed, *Gilbertiodendron dewevrei* in the Ituri ForestGeo plot in the Democratic
447 Republic of Congo (Makana et al., 2004a,b) has functional characteristics similar to *Tsuga*
448 *canadensis* in northeastern US forests. *Gilbertiodendron* casts deep shade; produces leaf
449 litter that decomposes very slowly, creating a dense and deep litter layer; creates soils with

450 \approx 30% of the available nitrogen (ammonium + nitrate) relative to nearby mixed forests; and
451 has a depauperate (albeit not unique) fauna of leaf-litter ants and mites (Torti et al., 2001).
452 Analysis of species distribution and diversity associated with potential foundation species in
453 Southeast Asian forests dominated by Dipterocarpaceae, such as the ForestGeo 50-ha Pasoh
454 plot in Malaysia (Kochummen et al., 1991; Ashton et al., 2003) versus others lacking abun-
455 dant dipterocarps, such as the 30-ha ForestGeo Mo Singto plot in Thailand (Brockelman
456 et al., 2011) or the 2-ha plot in Aluoi, Vietnam (Nguyen et al., 2016) would provide useful
457 comparisons with the analyses of the CForBio plots—especially the 20-ha Xishuangbanna
458 plot—presented here.

459 Conversely, the mid-latitude peak in functional-trait diversity of trees (Lamanna et al.,
460 2014) led Ellison et al. (2019) to hypothesize that foundation tree species should be less
461 common in boreal forests at high latitudes or at high elevations in lower latitudes than
462 in more temperate ones. Our data showing no candidate foundation species at the high-
463 elevation but low-latitude Yulong Snow Mountain plot support this hypothesis (Table 3).
464 In other high-elevation and high-latitude boreal ecosystems, foundation species tend to be
465 low-growing perennial, cushion- or tussock-forming plants (e.g., Ellison and Degrassi, 2017;
466 Elumeeva et al., 2017).

467 **Foundation species effects are scale-dependent at landscape, not 468 local scales**

469 Ellison (2019) argued that foundation species increase “patchiness” (beta diversity) at
470 landscape scales, and that this effect of foundation species is of paramount importance when
471 considering whether and how to conserve or otherwise manage them (see also Ellison et al.,
472 2019). Across the 12 CForBio plots, we observed an increase in the strength of foundation
473 species effects on beta diversity, expressed as a significant increase in codispersion between
474 the candidate foundation species and diversity of associated species, at increasingly larger
475 spatial grain (Fig. 6). At the 20-m grain, the magnitude of the codispersion coefficient

476 approached that of many of the candidate foundation species in ForestGeo plots in the
477 Americas (0.25–0.35; Fig. 6), but still less than the very strong effects of *T. canadensis* in
478 northeastern US forests (Ellison et al., 2019).

479 Conversely, although foundation species can provide habitat for associated species, thus
480 increasing their local diversity, the opposite pattern and magnitude of effects has been found
481 when analyzing only associated woody plant species in forest dynamic plots (Buckley et al.,
482 2016a; Ellison et al., 2019) because foundation species occupy most of the available space. In
483 the CForBio plots, codispersion similarly was negative between candidate foundation species
484 and alpha diversity of associated woody plants (Figs. 2–6), but this relationship did not vary
485 significantly with spatial grain (Fig. 6). Additional data on faunal groups (e.g., Sackett et al.,
486 2011; Record et al., 2018) or non-woody plants (e.g., Ellison et al., 2016) could provide a
487 test of whether these candidate foundation species have a positive effect on other associated
488 species that are not competing for space with canopy or subcanopy trees, but such data
489 are collected rarely in forest dynamic plots (but see Schowalter, 1994; Ruchty et al., 2001;
490 Ellison, 2018).

491 ***Acer* as a candidate foundation genus**

492 In this study, four species of *Acer* were candidate foundation species among the three
493 cold-temperate plots in China (Liangshi, Muling, and Changbai: Table 3). Among these, *A.*
494 *ukurunduense* and *A. barbinerve* were the only two of all our candidate foundation species
495 that met the most stringent criteria for consideration. In a comparable study across a
496 latitudinal gradient in the Americas, *A. circinatum* was identified as a candidate foundation
497 species in the the Wind River ForestGeo plot in Washington State, USA (Ellison et al., 2019).
498 We hypothesize that in many forests throughout the Northen Hemishpere, that *Acer* not
499 only can be a dominant genus in terms of abundance or total basal area, but that it may
500 function as a foundation genus, akin to *Quercus* in the Tyson ForestGEO plot in central
501 North America (Ellison et al., 2019).

502 *Acer* species often are common and abundant in temperate deciduous broad-leaved, conif-
503 erous, and mixed forests throughout the Holarctic (Tiffney, 1985; Pennington et al., 2004),
504 and in subtropical montane forests in China (Xu, 1996). *Acer* includes ≥ 150 species (WFO
505 (World Flora Online), 2020), at least 99 of which (including 61 endemics) occur in China (Xu
506 et al., 2008) and more than a dozen are found in North America (Alden, 1995). *Acer* species
507 generally are shade tolerant, (i.e., they can regenerate and grow under closed canopies) and
508 have relatively high seedling and sapling survival rates (Tanaka et al., 2008). Some more
509 shade-intolerant (“photophilous”) early-successional *Acer* species create conditions that fa-
510 cilitate restoration of both later successional forests and their associated animal assemblages
511 (Zhang et al., 2010).

512 There are several forests named after *Acer* species in China, including the *Acer mono-*
513 *Tilia amurensis*–*T. mandshurica* temperate broad-leaved deciduous forest, the *Schima superba*–
514 *Acer caudatum*–*Toxicodendron succedaneum* eastern subtropical forest, and the *Cyclobal-*
515 *anopsis multinervis*–*Castanopsis eyrel* var. *caudata*–*Liquidambar acalycina*–*Acer sinense*
516 forest in southwest China (Wu, 1995). *Acer* also are considered primary “companion” species
517 in Chinese *Quercus* and mixed broad-leaved-Korean pine forests where multiple *Acer* species
518 co-occur. For example, six–seven additional *Acer* species were recorded with the three can-
519 didate foundation *Acer* species in the two broad-leaved-Korean pine mixed forests plots (LS,
520 CB). The nine *Acer* species in the CB plot account for $\geq 46\%$ of the total stems (Zhang et al.,
521 2010).

522 In North American forests, *Acer* species also define several forest types, including “Sugar
523 Maple” (i.e., *A. saccharum*), “Sugar Maple–Beech–Yellow Birch”, “Sugar Maple–Basswood”,
524 “Red Maple” (i.e., *A. rubrum*), and “Silver Maple–American Elm” (i.e., *A. saccharinum*)
525 (Eyre, 1980). In forests of the Pacific Northwest of North America, the subcanopy treelet *A.*
526 *circinatum* not only grows rapidly, has high biomass, and forms broad canopies that suppress
527 other species (Lutz and Halpern, 2006; Halpern and Lutz, 2013), which causes it to have
528 negative codispersion with other woody taxa (Ellison et al., 2019), but it also supports a high

529 diversity of epiphytes (Ruchty et al., 2001). Another North American species, *A. sacchar-*
530 *inum*, dominates floodplain forests on well-drained alluvial soils in the eastern U.S. (Gabriel,
531 1990). Although Vankat (1990) subsumed “Silver Maple–American Elm” forests within a
532 “Mixed Hardwood Wetland Forest” type and considered *A. saccharinum* to be only a minor
533 component of these forests, this species historically was a significant constituent of at least
534 some primary forests in the upper Midwestern U.S. and Canada (Cho and Boerner, 1995;
535 Simard and Bouchard, 1996; Guyon and Battaglia, 2018); supports unique assemblages of
536 birds (Yetter et al., 1999; Knutson et al., 2005; Kirsch and Wellik, 2017); and, among woody
537 species, contributes substantially to carbon fixation in tidal wetlands (Milligan et al., 2019).
538 *Acer saccharinum* may be similar to other North American (candidate) foundation species
539 whose effects are most pronounced at different successional stages (Ellison et al., 2014, 2019).
540 However, we know of no large plots in either “Silver Maple–American Elm” or “Mixed Hard-
541 wood Wetland” forests from which we could derive data to test whether *A. saccharinum*
542 meets our statistical criteria for candidate foundation species. Whilst it may be premature
543 to establish large forest dynamics plots in floodplains in either the temperate zone or the
544 tropics, or in tropical coastal habitats with low tree diversity, comparable data could be used
545 to test more general ideas about the foundational importance of particular genera, such as
546 *Acer* or *Rhizophora*, in forested wetlands worldwide.

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558 **Author contributions**

559 XQ and AME conceptualized and designed the study and wrote the manuscript; XQ
560 and all the other authors collected the data at the individual CForBio plots. All authors
561 contributed critically to the drafts and gave final approval for publication.

562 **Conflict of interest**

563 The authors declare no conflicts of interest.

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800 **Supplementary Information**

801 Table 4. Codispersion statistics for all candidate foundation species listed in Table 3.

802 [Table 4 about here.]

Table 1: Geographic data for CForBio forest dynamics plots studied here. Latitude and longitude are in °N and °E, respectively; elevation is in meters above sea level (m a.s.l.); area is in hectares (ha), and census year is the year of the first census of the plot.

Plot	Province	Latitude	Longitude	Elevation	Vegetation type	Area (ha)	Census Year
LS	Hei-longjiang	47.18	128.88	467	Broad-leaved Korean pine mixed forest	9	2010
MLG	Hei-longjiang	43.95	130.07	720	<i>Taxus cuspidata</i> -dominated mixed coniferous forest	25	2014
CB	Jinlin	42.38	128.08	802	Deciduous broad-leaved Korean pine mixed forest	25	2004
DL	Beijing	39.96	115.43	1395	Deciduous broad-leaved forest	20	2010
TT	Zhe-jiang	29.80	121.80	454	subtropical evergreen broad-leaved forest	20	2009
BDG	Hunan	29.77	110.09	1412	Mid-subtropical mountain evergreen and deciduous broad-leaved mixed forest	25	2011
GT	Zhe-jiang	29.25	118.12	581	subtropical evergreen broad-leaved forest	24	2005
YLXS	Yunnan	27.14	100.22	3282	Cool-temperate spruce-fir forest	25	2014
ML	Guangxi	25.80	108.00	550	Karst evergreen and deciduous broad-leaved mixed forest	25	2014
DH	Guang-dong	23.10	112.32	350	lower subtropical evergreen broad-leaved forest	20	2005
NG	Guangxi	22.45	106.95	260	Karst seasonal rain forest	15	2011
XSBN	Yunnan	21.61	101.57	789	Tropical rain forest	20	2007

Table 2: Initial set of candidate foundation species identified as outliers in the abundance-DBH plots (Fig. 1; here marked with an asterisk[*]) and others whose importance values IV) were in the top ten for that plot. Plots are ordered by latitude, and within each plot, species are ordered by IV. Units of diameter (DBH) are cm and units of basal area (BA) are in m²/ha.

Plot	Species	Abbreviation	Abundance	DBH	BA	Groups	IV (%)
LS	* <i>Pinus koraiensis</i>	PINKOR	1200	42.8	24.15	Canopy	23.3
	* <i>Corylus mandshurica</i>	CORMAN	4617	2.1	0.38	Shrub	10.5
	* <i>Acer mono</i>	ACEMON	2142	7.7	2.43	Canopy	8.3
	<i>Acanthopanax senticosus</i>	ACASEN	1937	1.6	0.07	Shrub	5.1
	* <i>Abies nephrolepis</i>	ABINEP	905	16.2	3.01	Canopy	5.8
	* <i>Tilia amurensis</i>	TILAMU	728	13.4	3.01	Canopy	5.1
	* <i>Acer ukurunduense</i>	ACEUKU	1262	4.3	0.43	Canopy	4.4
	* <i>Ulmus laciniata</i>	ULMLAC	71	7.7	1.48	Canopy	4.7
	<i>Euonymus pauciflorus</i>	EUOPAU	1279	1.9	0.05	Shrub	4.1
	* <i>Acer tegmentosum</i>	ACETEG	988	5.1	0.49	Canopy	3.4
	* <i>Betula costata</i>	BETCOS	601	1302	2.04	Canopy	3.4
	* <i>Fraxinus mandshurica</i>	FRAMAN	407	12.54	1.27	Canopy	2.4
MLG	* <i>Tilia amurensis</i>	TILAMU	3540	19.4	6.14	Canopy	11.3
	* <i>Acer mono</i>	ACEMON	3893	12.4	3.45	Canopy	7.9
	* <i>Corylus mandshurica</i>	CORMAN	9008	2.0	0.13	Shrub	6.9
	* <i>Abies nephrolepis</i>	ABINEP	3596	14.1	3.07	Canopy	6.9
	* <i>Pinus koraiensis</i>	PINKOR	4820	9.1	2.15	Canopy	6.8
	* <i>Acer barbinerve</i>	ACEBAR	7498	3.2	0.32	Shrub	6.7
	* <i>Acer tegmentosum</i>	ACETAG	3904	8.7	1.42	Canopy	5.8
	* <i>Betula costata</i>	BETCOS	1573	18.0	2.43	Canopy	5.1
	* <i>Acer ukurunduense</i>	ACEUKU	3391	6.1	0.57	Canopy	4.7
	* <i>Syringa reticulata</i> var. <i>amurensis</i>	SYRRET	3926	3.6	0.36	Shrub	4.1
	* <i>Ulmus laciniata</i>	ULMLAC	1361	11.1	.98	Canopy	3.3
	* <i>Fraxinus mandshurica</i>	FRAMAN	961	14.4	1.01	Canopy	2.8
	<i>Acer mandshuricum</i>	ACEMAN	1553	6.9	0.59	Canopy	2.5
	* <i>Populus davidiana</i>	POPDAT	1172	11.8	1.01	Canopy	2.4
	<i>Actinidia kolomikta</i>	ACTKOL	2170	1.8	0.03	Liana	2.3
	<i>Cerasus maximowiczii</i>	CERMAX	1501	5.6	0.27	Canopy	2.2
	<i>Acanthopanax senticosus</i>	ACASEN	1932	1.3	0.01	Shrub	2.1
	<i>Philadelphus schrenkii</i>	PHISCH	1317	1.5	0.01	Shrub	1.8
	<i>Lonicera ruprechtiana</i>	LONRUP	1021	1.5	0.01	Shrub	1.7
	<i>Aralia elata</i>	ARAEALA	1506	2.9	.05	Shrub	1.5
	* <i>Taxus cuspidata</i>	TAXCUS	172	39.4	0.93	Canopy	1.5
CB	* <i>Tilia amurensis</i>	TILAMU	2927	31.3	12.31	Canopy	14.8
	* <i>Pinus koraiensis</i>	PINKOR	2468	32.6	9.79	Canopy	12.4
	* <i>Acer mono</i>	ACEMON	6609	7.5	2.69	Canopy	10.6
	* <i>Corylus mandshurica</i>	CORMAN	7834	1.7	0.08	Shrub	9.6
	* <i>Acer pseudosieboldianum</i>	ACEPSE	5984	6.1	1.1	Canopy	8.6
	* <i>Quercus mongolica</i>	QUEMON	926	41.3	6.5	Canopy	8.0
	* <i>Fraxinus mandshurica</i>	FRAMAN	681	47.9	5.81	Canopy	6.7
	* <i>Acer barbinerve</i>	ACEBAR	3911	2.3	0.08	Shrub	5.9
	* <i>Ulmus japonica</i>	ULMJAP	1109	14.1	1.81	Canopy	4.3
	* <i>Syringa reticulata</i> var. <i>amurensis</i>	SYRRET	1598	3.8	0.09	Shrub	3.0
DL	* <i>Quercus wutaishanica</i>	QUEWUT	5274	18.9	7.36	Canopy	19.6
	* <i>Acer mono</i>	ACEMON	10539	5.7	1.32	Canopy	12.1
	* <i>Betula dahurica</i>	BETDAH	2536	17.5	3.03	Canopy	9.6
	* <i>Syringa pubescens</i>	SYRPUB	6313	3	0.22	Shrub	6.9
	* <i>Abelia biflora</i>	ABEBIF	5174	2.4	0.23	Shrub	6.0
	* <i>Corylus mandshurica</i>	CORMAN	6192	12.6	0.14	Shrub	5.8
	* <i>Rhododendron micranthum</i>	RHOMIC	71301	2.9	0.04	Shrub	1.8
	<i>Populus davidiana</i>	POPDAT	1967	18.8	1.22	Canopy	5.0
	<i>Betula platyphylla</i>	BETPLA	776	5.5	1.07	Canopy	3.8
	* <i>Fraxinus rhynchophylla</i>	FRARHY	2385	19.5	0.28	Canopy	3.8
TTT	<i>Juglans mandshurica</i>	JUGMAN	576	8.7	0.86	Canopy	2.9
	* <i>Eurya loquaiana</i>	EURLOQ	20414	2.6	16.46	Shrub	12.1
	* <i>Litsea elongata</i>	LITELO	10395	4.8	34.95	Canopy	8.2
	<i>Choerospondias axillaris</i>	CHOERO	1352	20.8	76.04	Canopy	6.5
	* <i>Distylium myricoides</i>	DISMYR	6298	6.3	40.11	Shrub	6.4
	* <i>Lithocarpus henryi</i>	LITHEN	2688	12.2	53.91	Canopy	5.5
	* <i>Cyclobalanopsis nubium</i>	CYCNUB	2484	12.4	55.11	Canopy	5.5
	* <i>Camellia fraterna</i>	CAMFRA	9279	2.4	6.45	Shrub	5.4
	<i>Schima superba</i>	SCHSUP	1237	17.3	40.67	Canopy	3.8

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Plot	Species	Abbreviation	Abundance	DBH	BA	Groups	IV (%)
	<i>Castanopsis fargesii</i>	CASFRA	750	22.7	42.81	Canopy	3.7
	<i>Machilus thunbergii</i>	MACTHU	2807	5.8	18.81	Canopy	2.9
BDG	* <i>Cyclobalanopsis multinervis</i>	CYCMUL	11503	7	5.36	Canopy	8.1
	* <i>Fagus lucida</i>	FAGLUC	2769	13.1	3.84	Canopy	4.3
	<i>Cyclobalanopsis gracilis</i>	CYCGRA	5322	6.2	2.53	Canopy	3.8
	<i>Carpinus fargesii</i>	CARFAR	2172	11.1	1.97	Canopy	2.4
	<i>Schima parviflora</i>	SCHPAR	1796	9.5	1.86	Canopy	2.2
	<i>Sassafras tzumu</i>	SASTZU	453	30.6	2.19	Canopy	2.2
	<i>Castanea seguini</i>	CASSEG	471	28.6	1.9	Canopy	1.9
	<i>Betula insignis</i>	BETINS	434	27.7	1.64	Canopy	1.7
	<i>Quercus serrata</i>	QUESER	703	20.7	1.53	Canopy	1.6
	* <i>Eurya brevistyla</i>	EURBRE	16051	3	0.81	Shrub	5.1
	<i>Nyssa sinensis</i>	NYSSIN	805	17.9	1.4	Canopy	1.5
	* <i>Rhododendron stamineum</i>	RHOSTA	9549	9.1	4.36	Canopy	6.6
	* <i>Litsea elongata</i>	LITELO	21035	2.6	0.96	Canopy	6.5
GT	* <i>Castanopsis eyrei</i>	CASEYR	12406	11.9	12.52	Canopy	15.3
	* <i>Schima superba</i>	SCHSUP	8514	10.4	6.89	Canopy	9.4
	* <i>Pinus massoniana</i>	PINMAS	2061	18.7	4.23	Canopy	4.3
	* <i>Cyclobalanopsis glauca</i>	CYCGLA	1620	10.4	0.88	Canopy	1.8
	<i>Daphniphyllum oldhami</i>	DAPOLD	2718	6.9	0.79	Shrub	2.1
	<i>Machilus thunbergii</i>	MACTHU	1384	8.6	0.76	Canopy	1.6
	<i>Cyclobalanopsis myrsinæfolia</i>	CYCMYR	375	17	0.59	Canopy	0.9
	* <i>Quercus serrata</i> var. <i>brevipetiolata</i>	QUESER	3508	10.6	1.63	Canopy	2.8
	* <i>Rhododendron ovatum</i>	RHOVA	10793	3.9	0.72	Shrub	4.2
	<i>Loropetalum chinense</i>	LORCHI	4461	5	0.64	Shrub	2.4
YLXS	* <i>Berberis fallax</i>	BERFAL	28416	1.4	0.2	Shrub	68.1
	* <i>Abies forrestii</i>	ABIFOR	5207	19.6	15.18	Canopy	51.2
	<i>Quercus guajavifolia</i>	QUEGUA	1324	45.1	12.92	Canopy	36.1
	<i>Picea likiangensis</i>	PICLIK	596	50.8	9.03	Canopy	25.5
	<i>Gamblea ciliata</i> var. <i>evodiifolia</i>	GAMCIL	1065	25.7	2.67	Canopy	14.0
	<i>Acer pectinatum</i>	ACEPEC	958	23.3	2.01	Canopy	11.7
	<i>Sorbus prattii</i>	SORPRA	915	11.8	0.49	Shrub	8.8
	<i>Viburnum betulifolium</i>	VIBBET	1114	3.8	0.06	Shrub	8.3
	<i>Rhododendron yunnanense</i>	RHOYUN	1162	11	0.67	Shrub	7.4
	<i>Padus brachypoda</i>	PADBRA	328	28.5	1.04	Canopy	5.6
ML	* <i>Cryptocarya microcarps</i>	CRYMIC	31939	4.2	2.97	Canopy	15.5
	* <i>Itoa orientalis</i>	ITOORI	3050	9.9	1.35	Canopy	4.4
	* <i>Lindera communis</i>	LINCOM	4192	4.1	0.33	Shrub	3.4
	<i>Eurycorymbus cavaleriei</i>	EURCAV	1525	10.6	0.76	Canopy	2.9
	* <i>Platycarya longipes</i>	PLALON	3520	6.6	0.85	Canopy	2.2
	<i>Brassaiopsis glomerulata</i>	BRAGLO	2910	4.3	0.27	Canopy	2.1
	<i>Radermachera sinica</i>	RADSIN	965	9.8	0.43	Canopy	1.9
	<i>Boniodendron minus</i>	BONMIN	1521	6.2	0.35	Shrub	1.8
	<i>Diospyros dumetorum</i>	DIODUM	2590	3.4	0.14	Canopy	1.8
	<i>Rubovietnamia aristata</i>	RUBARI	1614	4.7	0.16	Shrub	1.7
DH	* <i>Castanopsis chinensis</i>	CASCHI	2311	24.4	9.3	Canopy	12.3
	* <i>Schima superba</i>	SCHSUP	2296	18.9	4.13	Canopy	6.6
	* <i>Engelhardtia roxburghiana</i>	ENGROX	737	28.8	3.48	Canopy	4.8
	* <i>Machilus chinensis</i>	MACCHI	532	16.3	0.85	Canopy	1.7
	* <i>Syzygium rehderianum</i>	SYZREH	5990	4.7	0.88	Shrub	4.7
	* <i>Grarbioidendron scleranthum</i>	GRASCL	3325	8.6	1.66	Canopy	4.4
	* <i>Aidia canthioides</i>	AIDCAN	5996	2.3	0.21	Shrub	4.1
	* <i>Cryptocarya chinensis</i>	CRYCHI	2557	6.5	1.21	Canopy	3.5
	<i>Cryptocarya concinna</i>	CRYCON	4478	1.8	0.18	Canopy	3.3
	* <i>Aporusa yunnanensis</i>	APOYUN	3747	4.7	0.44	Shrub	3.0
	<i>Ardisia quinquegona</i>	ARDQUI	3702	1.9	0.08	Shrub	2.8
	<i>Blastus cochinchinensis</i>	BLACOC	4011	1.6	0.06	Shrub	2.7
	* <i>Acmena acuminatissima</i>	ACEACU	1484	8.7	1.1	Canopy	2.6
NG	* <i>Cleistanthus sumatranus</i>	CLESUM	9977	4.8	2	Canopy	9.1
	* <i>Sterculia monosperma</i>	STEMON	6328	5.7	1.59	Canopy	7.5
	* <i>Vitex kwangsiensis</i>	VITKWA	2470	11.4	1.44	Canopy	6.9
	<i>Excentrodendron tonkinense</i>	EXCTON	1502	6.5	0.77	Canopy	2.8
	<i>Diplodiscus trichosperma</i>	DIPTRI	1126	8.1	0.49	Canopy	2.4
	<i>Erythrina stricta</i>	ERYSTR	316	23.7	1.14	Canopy	2.3
	<i>Hydnocarpus hainanensis</i>	HYDHAI	2260	3.3	0.21	Canopy	2.3
	<i>Antidesma japonicum</i>	ANTJAP	2535	3	0.18	Shrub	2.2

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Plot	Species	Abbreviation	Abundance	DBH	BA	Groups	IV (%)
	<i>Ficus hispida</i>	FICHIS	2989	3.2	0.28	Shrub	2.1
	<i>Garcinia paucinervis</i>	GARPAU	1684	3.4	0.25	Canopy	2.1
XSBN	<i>*Pittosporopsis kerrii</i>	PITKER	20918	3.2	1.42	Shrub	25.8
	<i>*Parashorea chinensis</i>	PARCHI	7919	5.2	5.68	Canopy	22.4
	<i>Castanopsis echidnocarpa</i>	CASECH	1679	12.8	2.47	Canopy	7.1
	<i>Garcinia cowa</i>	GARCOW	4333	5.1	0.96	Canopy	7.3
	<i>Mezzettia creaghii</i>	MEZCRE	3300	6.2	1.26	Canopy	6.9
	<i>Baccaurea ramiflora</i>	BACRAM	3212	5.2	0.7	Canopy	5.5
	<i>Knema furfuracea</i>	KNEFUR	3160	4	0.56	Canopy	5.1
	<i>Saprosma ternata</i>	SAPTER	2698	1.9	0.05	Shrub	4.7
	<i>Phoebe lanceolata</i>	PHOLAN	2409	3.6	0.22	Canopy	3.5
	<i>Cinnamomum bejolghota</i>	CINBEJ	1337	5.4	0.44	Canopy	3.9

Table 3: A winnowed list of candidate foundation tree and shrub species (the latter indicated by a plus sign [+]) at three different spatial grains (i.e., subplot size) in 12 Chinese forest dynamics plots. Plots are ordered by latitude, and within each plot, candidate foundation species are ordered alphabetically. The two *Acer* species in **bold type** satisfied all aspects of both the outlier and the diversity criteria for candidate foundation species at the given spatial grain. The starred (*) species satisfied the outlier criterion (Fig. 1) and partially satisfied the diversity criterion at the given spatial grain: a positive spatial relationship between candidate foundation species size and beta diversity, and a negative spatial relationship between candidate foundation species size and at least one measure of alpha diversity. The remaining species did not satisfy the outlier criterion but did meet some aspects of the diversity criterion. No species met either foundation species criterion in the BDGS, TTS and YLXS plots at any spatial grain.

Plot	5 m	Spatial grain	
		10 m	20 m
LS	* <i>Acer ukurunduense</i> * <i>Corylus mandshurica</i> ⁺ * <i>Fraxinus mandshurica</i>	* <i>Acer ukurunduense</i> — —	— — —
MLG	*<i>Acer barbinerve</i>⁺ * <i>Acer tegmentosum</i> *<i>Acer ukurunduense</i> * <i>Corylus mandshurica</i> ⁺ — * <i>Taxus cuspidata</i> * <i>Tilia amurensis</i>	* <i>Acer barbinerve</i> ⁺ — — — — * <i>Pinus koraiensis</i> — * <i>Tilia amurensis</i>	— — — — * <i>Pinus koraiensis</i> — * <i>Tilia amurensis</i>
CB	* <i>Acer barbinerve</i> ⁺ * <i>Acer pseudosieboldianum</i> * <i>Corylus mandshurica</i> ⁺ <i>Syringa reticulata</i> var. <i>amurensis</i> ⁺	* <i>Acer pseudosieboldianum</i> * <i>Corylus mandshurica</i> ⁺ * <i>Syringa reticulata</i> var. <i>amurensis</i> ⁺	— — —
DL	<i>Juglans mandshurica</i>	—	—
TT	—	—	—
BDG	—	—	—
GT	<i>Machilus thunbergii</i> — —	— — —	* <i>Pinus massoniana</i> * <i>Quercus serrata</i> var. <i>brevipetiolata</i>
YLXS	—	—	—
ML	<i>Brassaiopsis glomerulata</i>	<i>Brassaiopsis glomerulata</i>	—
DH	* <i>Aporusa yunnanensis</i> ⁺	* <i>Aporusa yunnanensis</i> ⁺	* <i>Aporusa yunnanensis</i> ⁺
NG	<i>Ficus hispida</i> ⁺	<i>Ficus hispida</i> ⁺	—
XSBN	<i>Mezzettiaopsis creaghii</i>	<i>Mezzettiaopsis creaghii</i>	<i>Mezzettiaopsis creaghii</i>

Table 4: Codisperson statistics for the candidate foundation tree or understory species (the latter indicated by a $^{[+]}$) in each plot at the spatial grain (**Grain**) at which they were identified (species listed in Table 3). As in Table 3, the two *Acer* species in **bold type** satisfied all aspects of both the outlier and the diversity criteria for candidate foundation species at the given spatial grain. The starred (*) species satisfied the outlier criterion (Fig. 1) and partially satisfied the diversity criterion at the given spatial grain: a positive spatial relationship between candidate foundation species size and beta diversity, and a negative spatial relationship between candidate foundation species size and at least one measure of alpha diversity. The remaining species did not satisfy the outlier criterion but did meet some aspects of the diversity criterion. No species met either foundation species criterion in the BDGS, TTS and YLXS plots at any spatial grain. Plots are ordered by latitude, and within each plot, species are grouped alphabetically within increasing grain (subplot) sizes. Values are the minimum (**Min**), median (**Median**), mean (**Mean**), one standard deviation of the mean (**SD**), and maximum (**Max**), computed over all spatial lags, of the codispersion between the basal area of the candidate foundation species and all other woody species in square subplots with the length of a side = the spatial grain.

Plot	Grain	Species	Diversity metric	Min	Median	Mean (SD)	Max
LS	5 m	* <i>Acer ukurunduense</i>	Bray-Curtis	0.03	0.12	0.12 (0.02)	0.16
			Richness	-0.13	-0.09	-0.09 (0.02)	-0.01
			Shannon	-0.12	-0.08	-0.08 (0.02)	-0.01
			Simpson	-0.07	-0.04	-0.04 (0.01)	0.01
			Abundance	-0.14	-0.1	-0.10 (0.02)	-0.03
	* <i>Corylus mandshurica</i> ⁺		Bray-Curtis	0.01	0.06	0.06 (0.02)	0.11
			Richness	-0.15	-0.1	-0.10 (0.02)	-0.06
			Shannon	-0.14	-0.09	-0.09 (0.02)	-0.05
			Simpson	-0.09	-0.05	-0.05 (0.02)	0
			Abundance	-0.16	-0.11	-0.11 (0.02)	-0.07
10 m	* <i>Fraxinus mandshurica</i>		Bray-Curtis	0	0.05	0.05 (0.02)	0.09
			Richness	-0.09	-0.05	-0.05 (0.01)	-0.01
			Shannon	-0.09	-0.05	-0.05 (0.01)	-0.01
			Simpson	-0.09	-0.05	-0.05 (0.02)	0
			Abundance	-0.09	-0.03	-0.03 (0.01)	0.01
	* <i>Acer ukurunduense</i>		Bray-Curtis	0.15	0.21	0.21 (0.03)	0.27
			Richness	-0.23	-0.17	-0.17 (0.03)	-0.09
			Shannon	-0.19	-0.12	-0.12 (0.03)	-0.04
			Simpson	-0.10	-0.05	-0.05 (0.02)	0.01
			Abundance	-0.27	-0.21	-0.21 (0.03)	-0.14
MLG	5 m	* <i>Acer barbinerve</i> ⁺	Bray-Curtis	0.12	0.16	0.16 (0.01)	0.20
			Richness	-0.22	-0.16	-0.16 (0.02)	-0.10
			Shannon	-0.16	-0.13	-0.13 (0.01)	-0.08
			Simpson	-0.10	-0.07	-0.07 (0.01)	-0.04
			Abundance	-0.24	-0.16	-0.15 (0.03)	-0.09
	* <i>Acer tegmentosum</i>		Bray-Curtis	0.02	0.05	0.05 (0.01)	0.09
			Richness	-0.11	-0.07	-0.07 (0.01)	-0.04
			Shannon	-0.08	-0.04	-0.04 (0.01)	-0.01
			Simpson	-0.06	-0.02	-0.02 (0.01)	0.01
			Abundance	-0.15	-0.11	-0.11 (0.01)	-0.07
10 m	* <i>Acer ukurunduense</i>		Bray-Curtis	0.03	0.06	0.06 (0.01)	0.09
			Richness	-0.11	-0.07	-0.07 (0.01)	-0.04
			Shannon	-0.09	-0.05	-0.06 (0.01)	-0.01
			Simpson	-0.08	-0.05	-0.05 (0.01)	-0.01
			Abundance	-0.11	-0.08	-0.08 (0.02)	-0.03
	* <i>Corylus mandshurica</i> ⁺		Bray-Curtis	0.12	0.16	0.16 (0.01)	0.20
			Richness	-0.14	-0.10	-0.10 (0.01)	-0.07
			Shannon	-0.11	-0.08	-0.08 (0.01)	-0.04
			Simpson	-0.04	-0.01	-0.01 (0.01)	0.02
			Abundance	-0.20	-0.10	-0.11 (0.02)	-0.06
MLG	* <i>Taxus cuspidata</i>		Bray-Curtis	0.05	0.09	0.09 (0.01)	0.12
			Richness	-0.12	-0.08	-0.08 (0.02)	-0.03
			Shannon	-0.09	-0.05	-0.05 (0.01)	-0.02
			Simpson	-0.06	-0.03	-0.03 (0.01)	0
			Abundance	-0.13	-0.07	-0.07 (0.02)	-0.04
	* <i>Tilia amurensis</i>		Bray-Curtis	0.02	0.05	0.05 (0.01)	0.08
			Richness	-0.11	-0.06	-0.06 (0.02)	-0.01
			Shannon	-0.07	-0.04	-0.04 (0.01)	0
			Simpson	-0.05	-0.02	-0.02 (0.01)	0.01
			Abundance	-0.15	-0.09	-0.09 (0.02)	-0.03
10 m	* <i>Acer barbinerve</i> ⁺		Bray-Curtis	0.07	0.12	0.12 (0.02)	0.17
			Richness	-0.22	-0.11	-0.11 (0.04)	0.03
			Shannon	-0.14	-0.09	-0.09 (0.02)	-0.02

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Plot	Grain	Species	Diversity metric	Min	Median	Mean (SD)	Max
20 m	* <i>Pinus koraiensis</i>		Simpson	-0.14	-0.09	-0.09 (0.02)	-0.03
			Abundance	-0.26	-0.07	-0.07 (0.06)	0.04
			Bray-Curtis	-0.02	0.13	0.13 (0.05)	0.22
			Richness	-0.18	-0.10	-0.10 (0.04)	-0.03
			Shannon	-0.06	-0.01	0 (0.02)	0.05
	* <i>Tilia amurensis</i>		Simpson	-0.02	0.05	0.05 (0.03)	0.13
			Abundance	-0.25	-0.15	-0.16 (0.05)	-0.06
			Bray-Curtis	0.02	0.15	0.16 (0.05)	0.27
			Richness	-0.30	-0.18	-0.19 (0.05)	-0.08
			Shannon	-0.14	-0.08	-0.08 (0.02)	-0.02
CB	* <i>Pinus koraiensis</i>		Simpson	-0.05	-0.01	0 (0.02)	0.04
			Abundance	-0.32	-0.18	-0.2 (0.06)	-0.09
			Bray-Curtis	0.11	0.32	0.31 (0.09)	0.45
			Richness	-0.3	-0.18	-0.18 (0.09)	0
			Shannon	-0.03	0.05	0.05 (0.05)	0.16
	* <i>Tilia amurensis</i>		Simpson	0.01	0.15	0.14 (0.07)	0.26
			Abundance	-0.35	-0.22	-0.23 (0.08)	-0.06
			Bray-Curtis	0.10	0.35	0.37 (0.1)	0.53
			Richness	-0.56	-0.39	-0.4 (0.1)	-0.19
			Shannon	-0.25	-0.17	-0.16 (0.05)	-0.04
10 m	* <i>Acer barbinerve</i> +		Simpson	-0.15	-0.07	-0.06 (0.05)	0.07
			Abundance	-0.49	-0.30	-0.33 (0.1)	-0.16
			Bray-Curtis	0.03	0.07	0.07 (0.01)	0.10
			Richness	-0.11	-0.07	-0.07 (0.01)	-0.04
			Shannon	-0.09	-0.06	-0.06 (0.01)	-0.03
	* <i>Acer pseudosieboldianum</i>		Simpson	-0.03	0	0 (0.01)	0.03
			Abundance	-0.11	-0.08	-0.08 (0.01)	-0.05
			Bray-Curtis	0.04	0.08	0.08 (0.01)	0.10
			Richness	-0.14	-0.11	-0.11 (0.01)	-0.06
			Shannon	-0.13	-0.10	-0.10 (0.01)	-0.05
GT	* <i>Corylus mandshurica</i> +		Simpson	-0.06	-0.03	-0.03 (0.01)	0
			Abundance	-0.16	-0.13	-0.13 (0.01)	-0.07
			Bray-Curtis	0.06	0.10	0.1 (0.01)	0.13
			Richness	-0.17	-0.14	-0.14 (0.01)	-0.11
			Shannon	-0.15	-0.12	-0.12 (0.01)	-0.10
	* <i>Syringa reticulata</i> var. <i>amurensis</i> +		Simpson	-0.03	-0.01	-0.01 (0.01)	0.02
			Abundance	-0.18	-0.14	-0.14 (0.01)	-0.11
			Bray-Curtis	0.01	0.07	0.07 (0.01)	0.10
			Richness	-0.07	-0.04	-0.04 (0.01)	-0.02
			Shannon	-0.06	-0.03	-0.03 (0.01)	-0.01
DL	* <i>Acer pseudosieboldianum</i>		Simpson	-0.02	0	0 (0.01)	0.03
			Abundance	-0.08	-0.05	-0.05 (0.01)	-0.03
			Bray-Curtis	0.02	0.08	0.08 (0.02)	0.12
			Richness	-0.24	-0.18	-0.18 (0.02)	-0.09
			Shannon	-0.16	-0.12	-0.11 (0.02)	-0.05
	* <i>Corylus mandshurica</i> +		Simpson	-0.1	-0.05	-0.05 (0.02)	0
			Abundance	-0.28	-0.22	-0.22 (0.02)	-0.13
			Bray-Curtis	0.06	0.12	0.12 (0.02)	0.16
			Richness	-0.14	-0.10	-0.10 (0.02)	-0.05
			Shannon	-0.1	-0.05	-0.05 (0.02)	0
GT	* <i>Syringa reticulata</i> var. <i>amurensis</i> +		Simpson	-0.1	-0.05	-0.05 (0.02)	-0.01
			Abundance	-0.24	-0.18	-0.18 (0.02)	-0.14
			Bray-Curtis	0.07	0.13	0.13 (0.02)	0.20
			Richness	-0.09	-0.03	-0.03 (0.02)	0.04
			Shannon	-0.06	-0.01	-0.01 (0.02)	0.06
	<i>Juglans mandshurica</i>		Simpson	-0.04	0	0 (0.02)	0.05
			Abundance	-0.14	-0.08	-0.08 (0.02)	-0.03
			Bray-Curtis	0.06	0.24	0.24 (0.04)	0.31
			Richness	-0.26	-0.15	-0.15 (0.05)	-0.04
			Shannon	-0.14	-0.09	-0.09 (0.02)	-0.03
GT	5 m	<i>Machilus thunbergii</i>	Simpson	-0.15	-0.08	-0.08 (0.03)	-0.09
			Abundance	-0.26	-0.17	-0.17 (0.04)	-0.09
GT	5 m	<i>Machilus thunbergii</i>	Bray-Curtis	0	0.04	0.04 (0.01)	0.07
			Richness	-0.08	-0.05	-0.05 (0.01)	0.01

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Plot	Grain	Species	Diversity metric	Min	Median	Mean (SD)	Max
20 m	* <i>Pinus massoniana</i>		Shannon	-0.07	-0.04	-0.04 (0.01)	0.01
			Simpson	-0.06	-0.03	-0.03 (0.01)	0.01
			Abundance	-0.08	-0.06	-0.06 (0.01)	0.01
			Bray-Curtis	0.14	0.20	0.2 (0.04)	0.27
			Richness	-0.28	-0.16	-0.16 (0.06)	-0.05
	* <i>Quercus serrata</i> var. <i>brevipetiolata</i>		Shannon	-0.40	-0.27	-0.28 (0.06)	-0.12
			Simpson	-0.33	-0.21	-0.21 (0.06)	-0.06
			Abundance	0.16	0.26	0.26 (0.04)	0.35
			Bray-Curtis	0.17	0.37	0.36 (0.06)	0.44
			Richness	-0.18	-0.11	-0.11 (0.05)	0.04
ML	5 m	<i>Brassaiopsis glomerulata</i>	Shannon	-0.34	-0.29	-0.28 (0.04)	-0.13
			Simpson	-0.31	-0.25	-0.24 (0.04)	-0.09
			Abundance	0.39	0.52	0.51 (0.05)	0.58
			Bray-Curtis	0.03	0.11	0.10 (0.03)	0.17
			Richness	-0.09	-0.03	-0.03 (0.02)	0.03
	10 m	<i>Brassaiopsis glomerulata</i>	Shannon	-0.07	-0.02	-0.02 (0.02)	0.03
			Simpson	-0.05	0	0 (0.02)	0.04
			Abundance	-0.15	-0.08	-0.08 (0.04)	0.02
			Bray-Curtis	0.03	0.16	0.15 (0.06)	0.26
			Richness	-0.11	-0.04	-0.04 (0.03)	0.04
DH	5 m	* <i>Aporusa yunnanensis</i> +	Shannon	-0.05	0	0 (0.02)	0.05
			Simpson	0.03	0.12	0.12 (0.04)	0.2
			Abundance	-0.31	-0.19	-0.19 (0.07)	0
			Bray-Curtis	-0.03	0.12	0.11 (0.06)	0.21
			Richness	-0.20	-0.13	-0.12 (0.04)	0.01
	10 m	* <i>Aporusa yunnanensis</i> +	Shannon	-0.19	-0.11	-0.11 (0.04)	0.02
			Simpson	-0.15	-0.10	-0.10 (0.03)	0
			Abundance	-0.22	-0.13	-0.13 (0.04)	0
			Bray-Curtis	-0.03	0.18	0.17 (0.08)	0.29
			Richness	-0.29	-0.20	-0.19 (0.06)	-0.03
NG	5 m	* <i>Aporusa yunnanensis</i> +	Shannon	-0.21	-0.12	-0.12 (0.04)	0
			Simpson	-0.16	-0.09	-0.09 (0.03)	-0.02
			Abundance	-0.37	-0.26	-0.24 (0.07)	-0.03
			Bray-Curtis	0	0.23	0.21 (0.09)	0.35
			Richness	-0.31	-0.24	-0.23 (0.05)	-0.11
	10 m	<i>Ficus hispida</i> +	Shannon	-0.14	-0.06	-0.06 (0.05)	0.06
			Simpson	-0.12	-0.05	-0.04 (0.04)	0.05
			Abundance	-0.47	-0.37	-0.34 (0.09)	-0.14
			Bray-Curtis	0.03	0.11	0.12 (0.04)	0.21
			Richness	-0.18	-0.10	-0.11 (0.03)	-0.02
XSBN	5 m	<i>Ficus hispida</i> +	Shannon	-0.16	-0.10	-0.10 (0.03)	-0.02
			Simpson	-0.16	-0.11	-0.11 (0.03)	-0.02
			Abundance	-0.18	-0.09	-0.09 (0.03)	-0.02
			Bray-Curtis	0.08	0.16	0.17 (0.06)	0.3
			Richness	-0.23	-0.15	-0.15 (0.04)	-0.06
	10 m	<i>Mezzettiaopsis creaghii</i>	Shannon	-0.15	-0.10	-0.10 (0.02)	-0.04
			Simpson	-0.1	-0.07	-0.07 (0.01)	-0.04
			Abundance	-0.28	-0.15	-0.16 (0.05)	-0.06
			Bray-Curtis	-0.02	0.09	0.08 (0.03)	0.12
			Richness	-0.06	-0.03	-0.03 (0.01)	0.02
20 m	5 m	<i>Mezzettiaopsis creaghii</i>	Shannon	-0.05	-0.01	-0.01 (0.01)	0.02
			Simpson	-0.03	-0.01	0 (0.01)	0.04
			Abundance	-0.09	-0.06	-0.06 (0.02)	0.01
			Bray-Curtis	0	0.20	0.19 (0.05)	0.26
			Richness	-0.11	-0.05	-0.05 (0.03)	0.03
	10 m	<i>Mezzettiaopsis creaghii</i>	Shannon	-0.06	0.05	0.04 (0.04)	0.14
			Simpson	-0.01	0.09	0.09 (0.04)	0.21
			Abundance	-0.21	-0.15	-0.14 (0.04)	0.02
			Bray-Curtis	0.16	0.33	0.31 (0.06)	0.38
			Richness	-0.19	-0.09	-0.09 (0.05)	-0.01
20 m	10 m	<i>Mezzettiaopsis creaghii</i>	Shannon	-0.06	0.22	0.19 (0.09)	0.32
			Simpson	-0.03	0.23	0.21 (0.09)	0.33
			Abundance	-0.35	-0.28	-0.26 (0.06)	-0.1

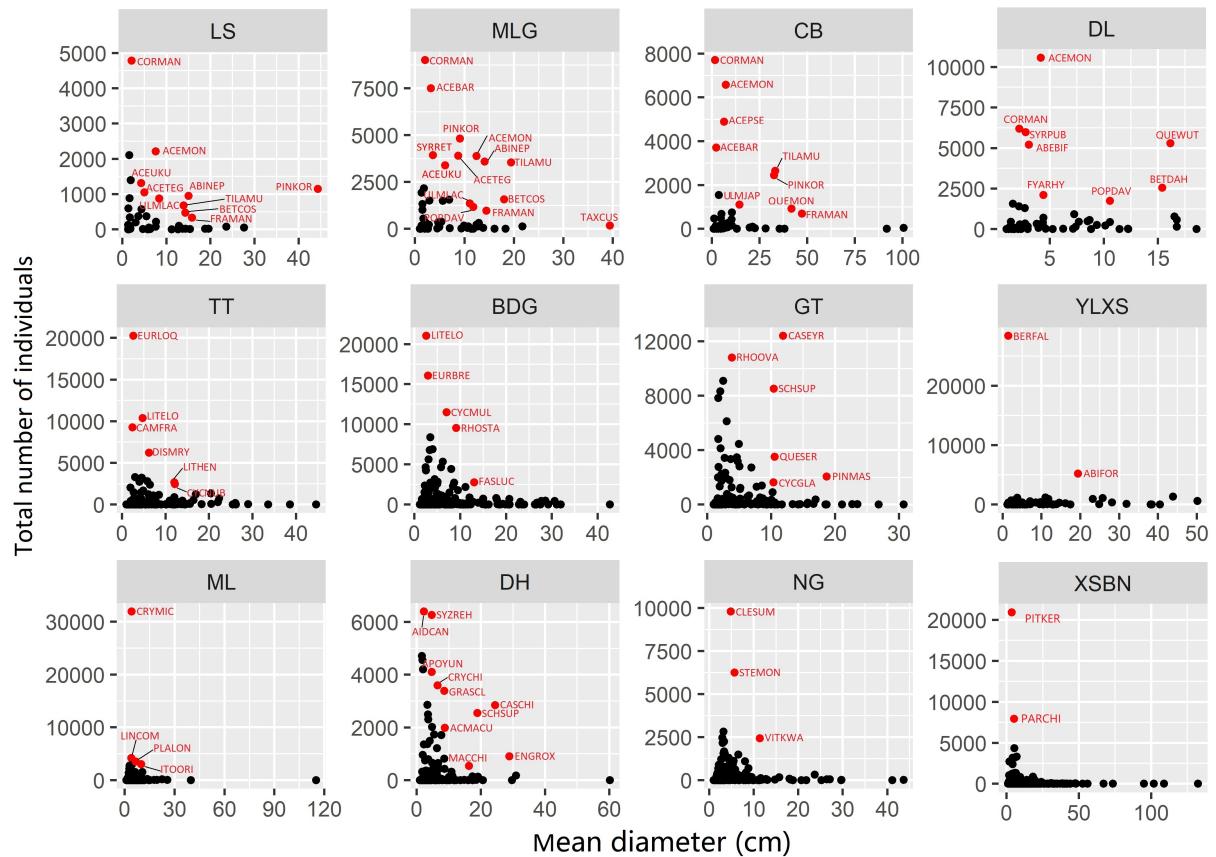


Figure 1: Size (DBH)-frequency distributions of the species in each plot. Species falling outside of the “reverse-J” line (in red) were treated in the first set of candidate foundation species. Plots are ordered left-to-right and top-to-bottom by latitude; species abbreviations are given in Table 2.

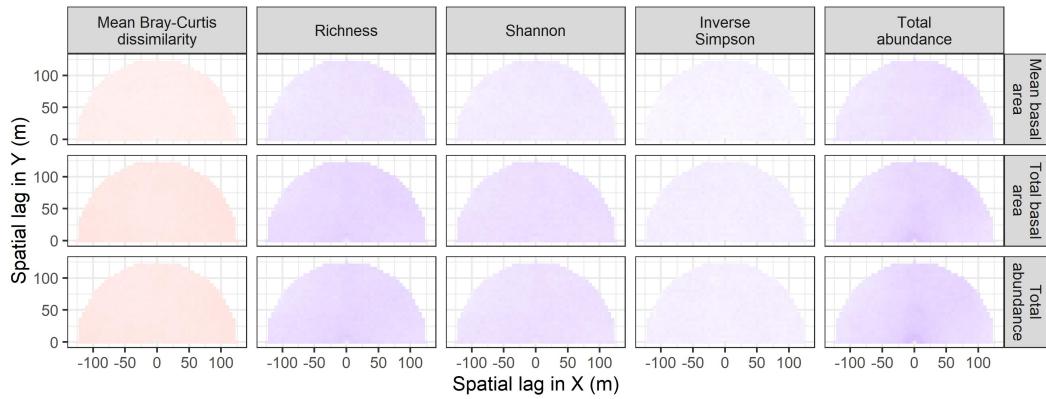


Figure 2: Codispersion between mean basal area, total basal area, or total abundance of *Acer barbinerve* and five different measures of diversity of associated woody species in 5-m subplots in the 25-ha Muling (MLG) plot. Codispersion coefficients were calculated for spatial lags ranging from 0–125 m at 5-m intervals. The values of the codispersion can range from -1 (dark blue) through 0 (white) to 1 (dark red). Statistical significance for codispersion coefficients computed at each spatial lag is shown in Fig. 3.

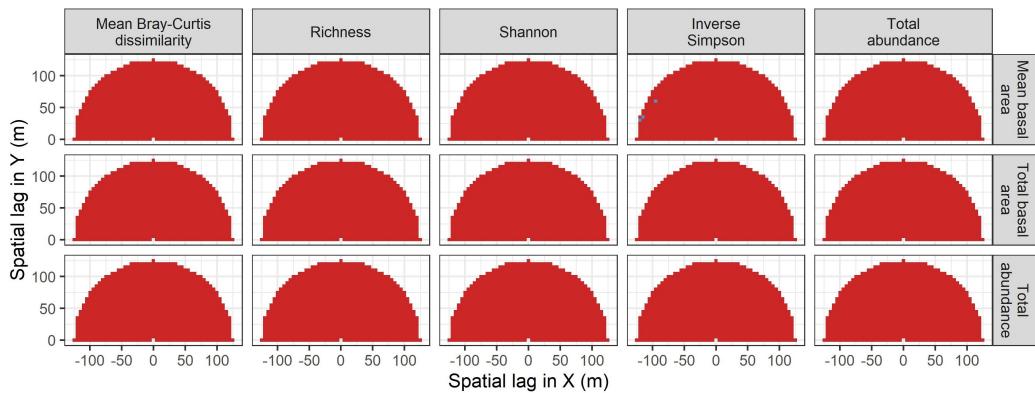


Figure 3: Statistical significance of the codispersion coefficients calculated between basal area or abundance of *Acer barbinerve* and five different measures of diversity of associated woody species in 5-m subplots in the 25-ha Muling (MLG) plot. Statistical significance was determined by comparing observed codispersion at each spatial lag with the distribution of 199 spatial randomizations of a toroidal-shift null model. Red: $P \leq 0.05$; Blue: $P > 0.05$.

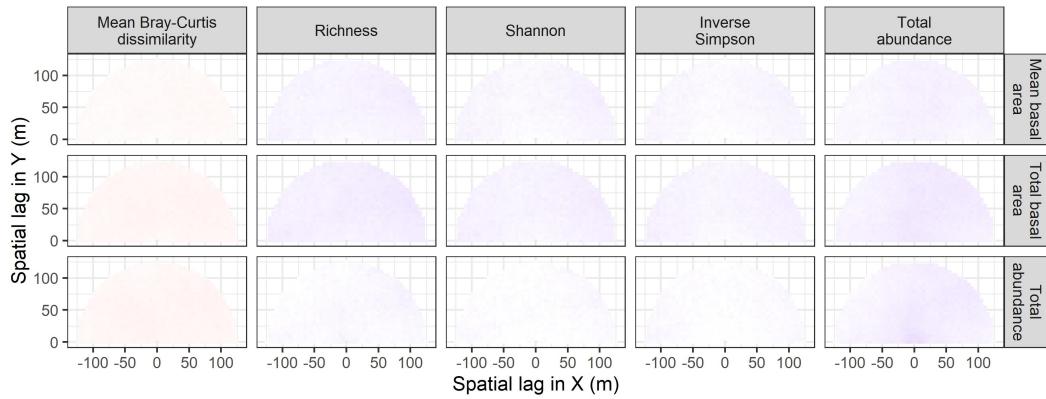


Figure 4: Codispersion between mean basal area, total basal area, or total abundance of *Acer ukurunduense* and five different measures of diversity of associated woody species in 5-m subplots in the 25-ha Muling (MLG) plot. Codispersion coefficients were calculated for spatial lags ranging from 0–125 m at 5-m intervals. The values of the codispersion can range from -1 (dark blue) through 0 (white) to 1 (dark red). Statistical significance for codispersion coefficients computed at each spatial lag is shown in Fig. 5.

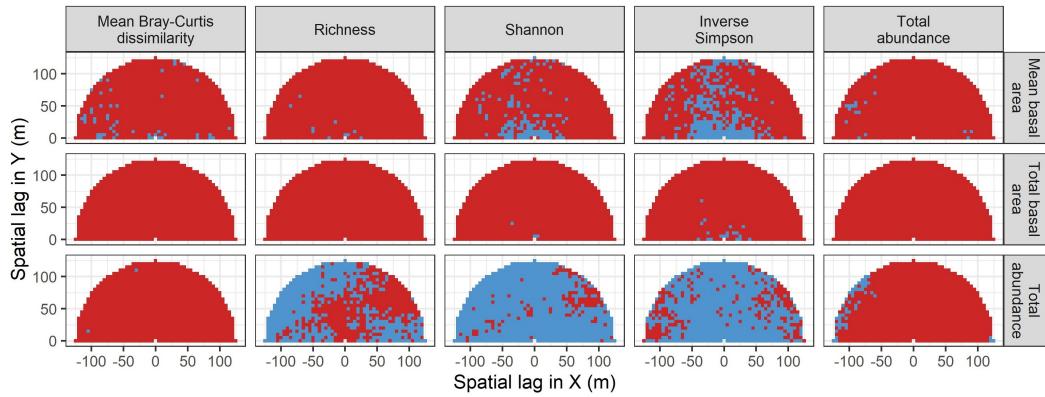


Figure 5: Statistical significance of the codispersion coefficients calculated between basal area or abundance of *Acer ukurunduense* and five different measures of diversity of associated woody species in 5-m subplots in the 25-ha Muling (MLG) plot. Statistical significance was determined by comparing observed codispersion at each spatial lag with a distribution of 199 spatial randomizations of a toroidal-shift null model. Red: $P \leq 0.05$; Blue: $P > 0.05$.

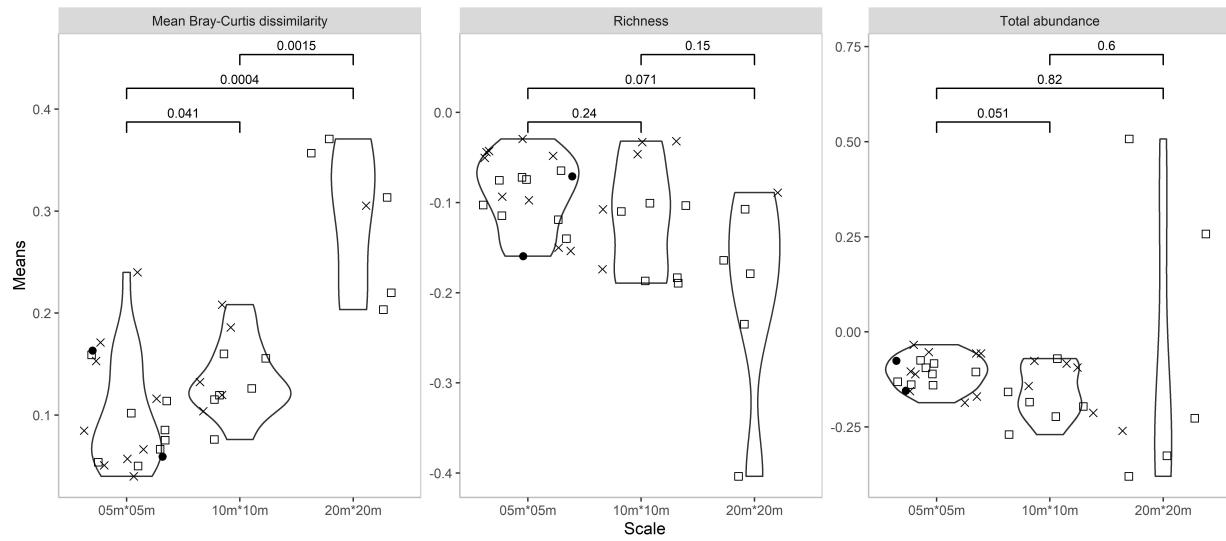


Figure 6: Distribution of average codispersion observed between total basal area of candidate foundation species and Bray-Curtis dissimilarity, species richness, and total abundance of associated woody plant species in contiguous 5×5 -, 10×10 -, and 20×20 -m subplots in the twelve CForBio plots. Points indicate mean codispersion values for each candidate foundation species listed in Table 2; solid points indicate the two candidate foundation species in the genus *Acer* that met both the outlier *and* diversity criterion for all indices; hollow squares indicate candidate species that met the outlier criterion and the relaxed diversity criterion; and crosses indicate the remaining candidate foundation species that met only the relaxed diversity criterion. *P* values for comparisons between groups are shown at the top of each panel.

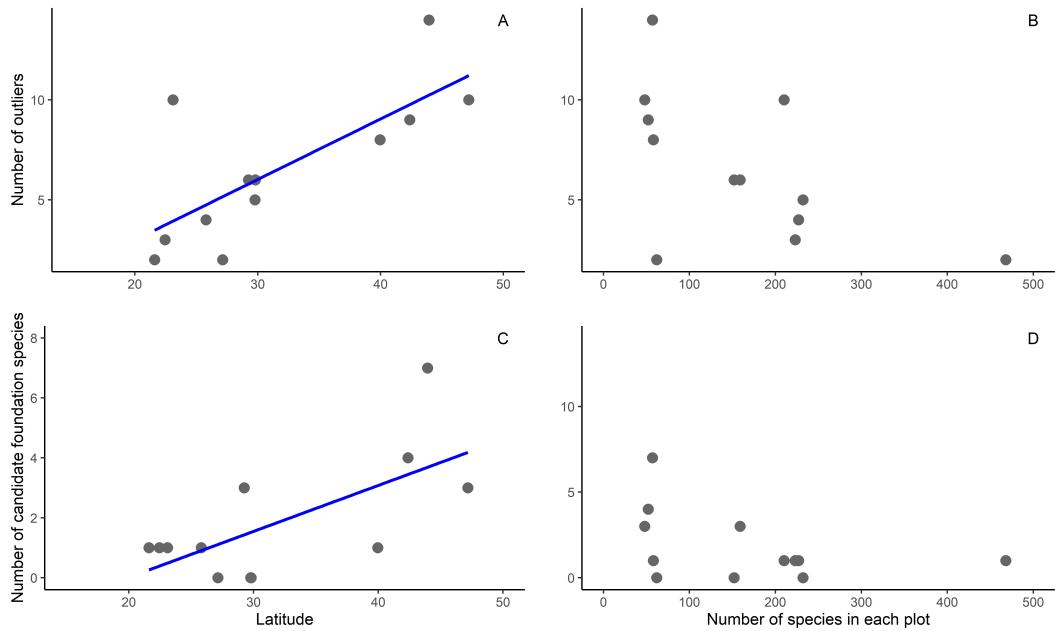


Figure 7: Number of outliers from the expected size-frequency distribution (Fig. 1) and number of candidate foundation species (Table 3) as a function of latitude (A, C) or plot-level species richness (B, D). See main text for regression statistics.

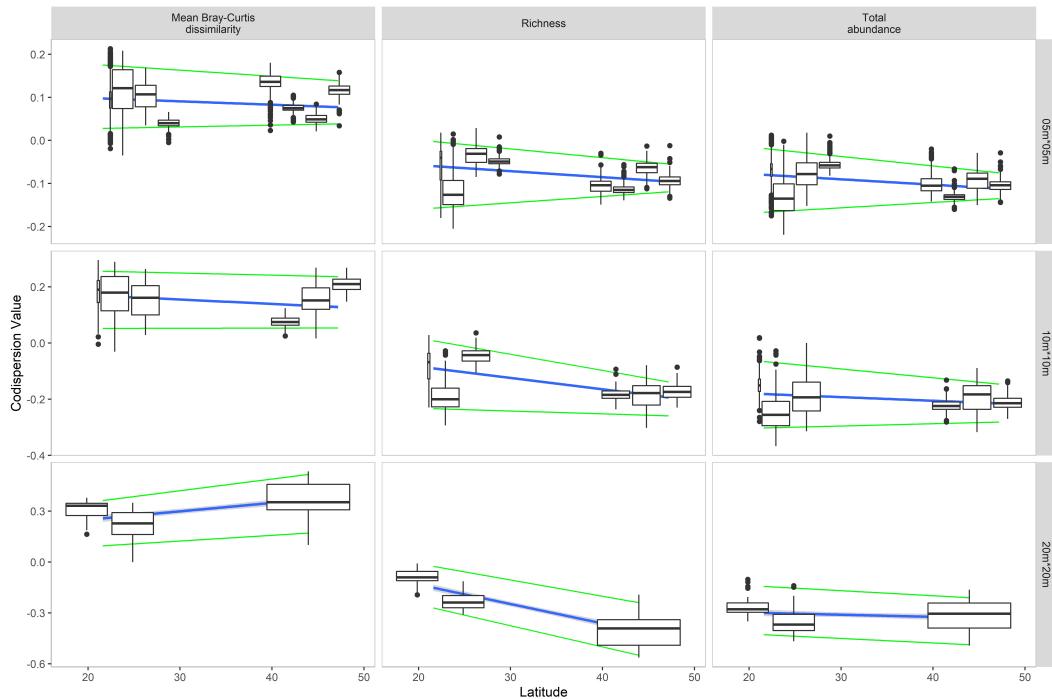


Figure 8: Relationship between latitude and codispersion between candidate foundation species (canopy trees and understory trees and shrubs) and three measures of associated woody-plant diversity at different spatial grains. Box plots illustrate median, upper and lower quartiles, and individual points outside of the upper and lower deciles of average codispersion at each latitude where candidate foundation species occurred (Table 3). Lines are regressions on all the data (blue lines), or on the 5% or 95% quantiles of the data (green lines).

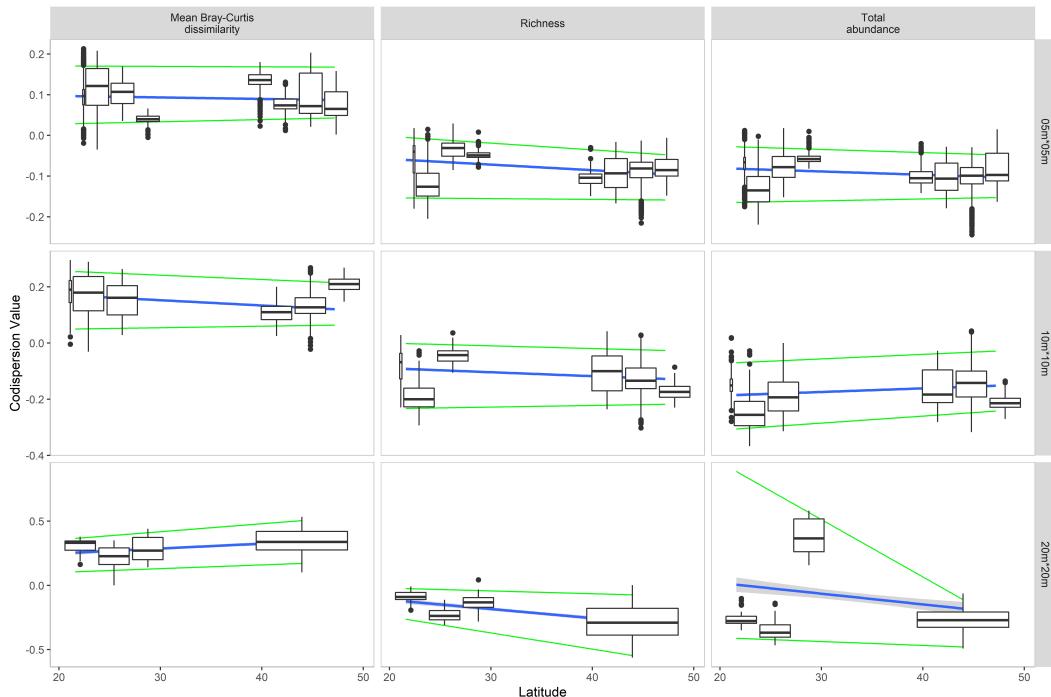


Figure 9: Relationship between latitude and codispersion between candidate foundation canopy tree species and three measures of associated woody-plant diversity at different spatial grains. Box plots illustrate median, upper and lower quartiles, and individual points outside of the upper and lower deciles of average codispersion at each latitude where candidate foundation species occurred (Table 3). Lines are regressions on all the data (blue lines), or on the 5% or 95% quantiles of the data (green lines).