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Seed Size-Number Trade-Off Exists in Graminoids but not in Forbs or Legumes: A Study from 11 Common Species in Alpine Steppe Communities

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Abstract

Seed size and number are two important components of plant reproductive traits. Previous theoretical studies have suggested that resource limitations lead to a strong trade-off between seed size and seed number. However, empirical evidence from natural communities remains scarce. In this study, the relationship between seed size and seed number was tested at the community level and in three functional groups—graminoids, forbs and legumes—in a natural alpine steppe community in the Tianshan Mountains. The role of limiting resources in reproduction and in determining trade-off patterns was also examined by treating the reproductive biomass and allocation of each species as a resource pool for producing seeds. Our results showed a significant negative relationship between seed size and seed number at the community level, which indicated that a trade-off between seed size and number existed and that the species that produced large seeds produced fewer seeds and vice versa. This trade-off was detected for the graminoid group but not for the forb or legume group. Moreover, the graminoid group presented lower reproductive biomass and allocation than the forb and legume groups did, indicating that the graminoid species were more strictly limited by reproductive resources. Our study provides evidence of a seed size–number trade-off in a natural alpine steppe community, and the important role of reproductive resources in determining the trade-off.

Keywords: seed size; seed number; trade-off; functional group; alpine steppe

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1. Introduction

In the long process of natural selection, resource allocation trade-offs between different functions (e.g., competitive ability vs. dispersal ability, vegetative growth vs. reproduction) during the plant life cycle are closely related to life history strategies [1–4]. The issue of plant life history strategies is a topic of current interest in model studies and has been widely investigated in empirical research [5–8]. Many famous theories have been proposed in previous studies, including the r–K theory [9,10] and the leaf–height–seed (LHS) scheme [11]. In these theories, seed characteristics, as key functional traits of plants, are closely associated with reproductive strategies [3,12,13] and play crucial roles in determining plant fitness.

Previous studies on reproductive strategies have assessed the balancing mechanisms associated with seed size and seed number [14–17]. This is because seed size is closely associated with seed dispersal, germination, seedling establishment, and the distribution patterns of plant populations [18–20]. Many studies have shown that larger seeds typically have a greater chance of germinating and surviving to maturity than smaller seeds do [21,22]. This is because larger seeds contain more nutrients, which provide the seedling with the energy it needs to grow and develop [23]. However, producing larger seeds is more costly for the plant, as it requires more resources to produce a single

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large seed than multiple small seeds [24]. Therefore, plants must carefully balance the benefits of producing larger seeds with the cost of doing so [24,25]. In contrast, plants that produce many small seeds have a greater chance of producing at least some offspring that will survive and reproduce [26,27]. This is because producing a large number of seeds increases the chance that at least some of them will find suitable conditions for germination and growth [28]. However, producing a large number of seeds is also costly for the plant, as it requires a significant amount of resources to produce and maintain those small seeds [29,30]. In summary, plants must balance the trade-off between seed size and seed number to maximize their reproductive success and fitness because the resources they acquire from the environment are limited.

The relationships between seed size and number for plants depends on several factors, including environmental conditions [31,32], resource competition [8,33] and phenotypic plasticity [34]. Among these factors, the variation in environmental conditions is the most important. For example, plants growing in resource-poor environments may produce abundant small seeds to increase the chances of offspring survival [13], whereas plants growing in resource-rich environments may produce a few large seeds to ensure the survival of high-quality offspring [35]. Additionally, the seed traits variation depended on different functional groups such as graminoid, forb and legume. In general, legume species produced a few large seeds [36], but forb species tended to produce many small seeds in alpine grassland [37]. The graminoid species enable to produce several different types of seeds from small and spherical to large and non-spherical seeds [38]. Therefore, both abiotic and biotic factors affect the trade-off patterns between seed size and seed number, but the underlying mechanisms are still not clear [39].

Research on seed size–seed number trade-offs has a long history, and many studies have indicated that this trade-off plays a critical role in promoting successful reproduction and population maintenance in plant species [40,41]. To date, most previous studies have concentrated on theoretical theories and specific models [20,22,42], but empirical evidence is still rare. Moreover, previous empirical studies either focused on specific environments or compared seed size and number in sparse species communities [5,26,43]. Evidence from multispecies natural communities and different plant functional groups is still scarce [44]. In addition, in general, most researchers have shown that resource limitation plays an important role in determining seed size and number trade-off in theory [17,45], but evidence from an experimental approach to this is still lacking.

In this study, we aimed to examine whether a trade-off between seed size and seed number exists in a multispecies natural alpine steppe community and in functional groups of forbs, graminoids and legumes. The role of limiting resources in determining trade-off patterns was also tested by treating reproductive biomass and allocation as a resource pool that a plant can distributed to reproductive part [46–48]. Specifically, three closely related questions were asked:

1. Does a trade-off between seed size and number exist in a multispecies natural alpine steppe community?
2. Are the trade-off patterns different in different functional groups?
3. What is the role of limiting resources in determining seed size and number trade-offs?

2. Results

Both seed size per grain and seed number per ramet varied considerably among the 11 common species at our study site. Stipa purpurea (2.64 mg in 2018, 2.72 mg in 2019) and Astragalus multicaulis (1.13 mg in 2018, 3.74 mg in 2019) had greater grain weights than the other species did. The two grass species Festuca ovina (1772 in 2018, 858 in 2019) and Koeleria cristata (539 in 2018, 2301 in 2019) produced more seeds per ramet than the other species did (Table 1, Figure 1). Although the seed size and number of seeds of the species changed between 2018 and 2019, the ranks of the species were similar in those two years (Figure 1).

Table 1. The seed size per grain, seed number per ramet and reproduction types of 11 common species in our study site (the mean value for 2018 and 2019).

Species	Functional group	Seed size (mg)	Seed number	Reproduction type
Agropyron cristatum	graminoid	0.9879	98	sexual+ clonal
Festuca ovina	graminoid	0.2458	1315	sexual+ clonal
Koeleria cristata	graminoid	0.2102	1420	sexual+ clonal
Poa crymophila	graminoid	0.2	273	sexual+ clonal
Stipa purpurea	graminoid	2.68	113	sexual+ clonal
Leontopodium leontopodioides	forb	0.0547	191	sexual
Potentilla bifurca	forb	0.3431	36	sexual
Potentilla fragarioides	forb	0.2315	551	sexual
Potentilla multifida	forb	0.131	91	sexual
Astragalus multicaulis	legume	2.435	45	sexual
Oxytrois glabra	legume	1.216	42	sexual

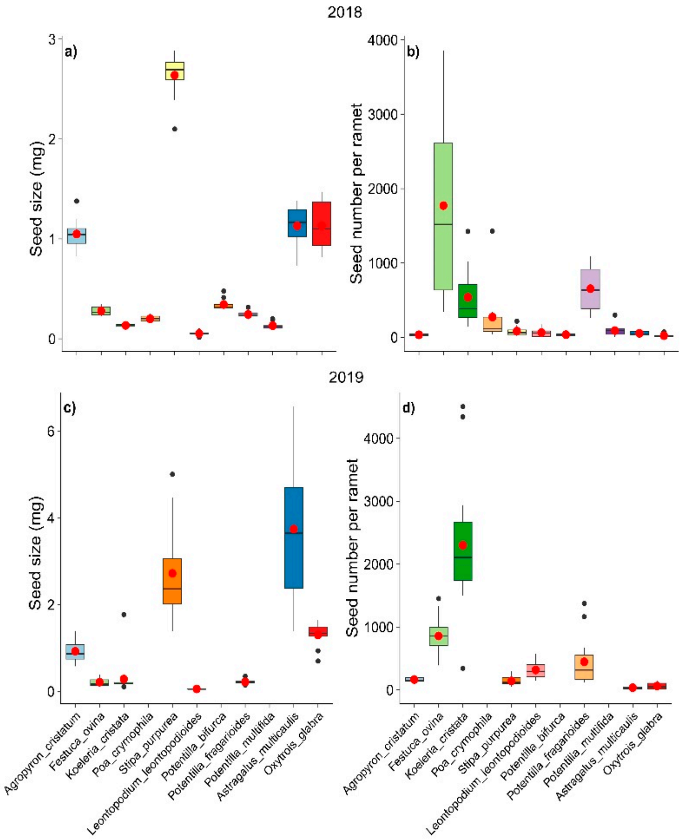

Figure 1. Seed size and seed number per ramet of 11 common species at our study site in 2018 and 2019.

A significant negative linear relationship existed between seed size and seed number at the community level in 2018 and 2019, which indicated a trade-off between seed number and seed size in the alpine steppe community (Figure 2 a, c). In 2018, the negative relationship between seed number and seed size was not very strong (Figure 2a), with an R^2 value of 0.092, although the relationship was statistically significant ($p = 0.0011$). In 2019, the relationship between seed number and seed size was strong (Figure 2c), with a high R^2 and low p value ($R^2 = 0.47$, $p < 0.001$). At the functional level, for graminoids, there were significant negative relationships between seed number and seed size in both 2018 and 2019 (Figure 2 b, d); in contrast, for forbs and legumes, the relationships between seed number and seed size were not significant (Figure 2 b, d). In line with these results, significant negative relationships also appeared between the mean value of seed size and number

(Figure A2). After the phylogenetically independent contrasts (PICs), the negative linear relationships were still significant in 2018 ($R^2 = 0.34$, $p < 0.05$) and marginally significant in 2019 ($R^2 = 0.45$, $p = 0.06$), which indicated that the phylogenetic effect did not change the trade-off relationships (Table A1). After the two years data pooled, the relationships between seed size and number were consistent with each year (Figure A4).

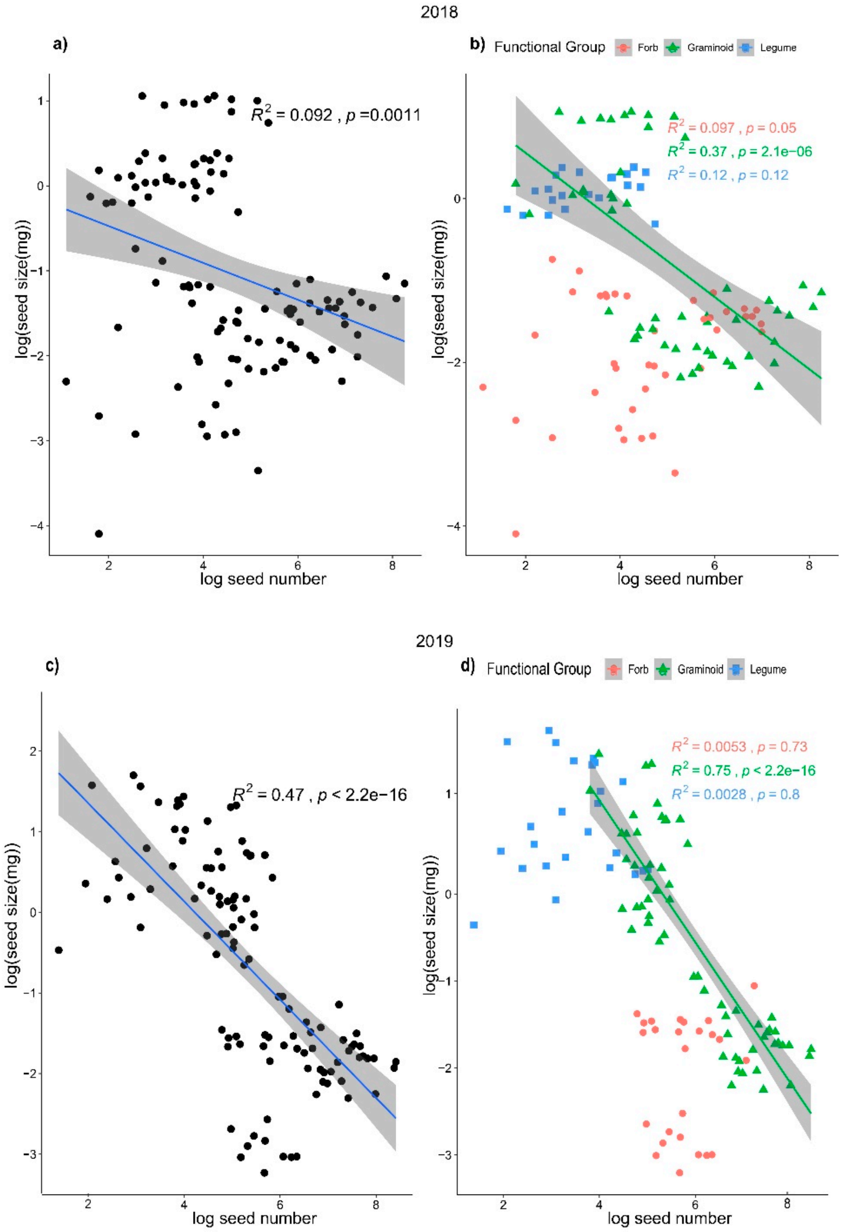

Figure 2. Relationships between seed size and seed number at the community level a) and c) and at the functional group level b) and d) in 2018 and 2019. The seed size and seed number data were log transformed.

The ANOVA and HSD test results showed that the reproductive biomass and reproductive allocation of graminoids were significantly lower than those of forbs and legumes in both 2018 and 2019 (Figure 3). In 2018, the mean reproductive biomasses of graminoids, forbs, and legumes were 0.097 g, 0.165 g and 0.178 g, respectively. In 2019, legumes had the highest reproductive biomass (0.306 g), the reproductive biomass of forbs was 0.259 g, and grass had the lowest reproductive biomass (0.164 g).

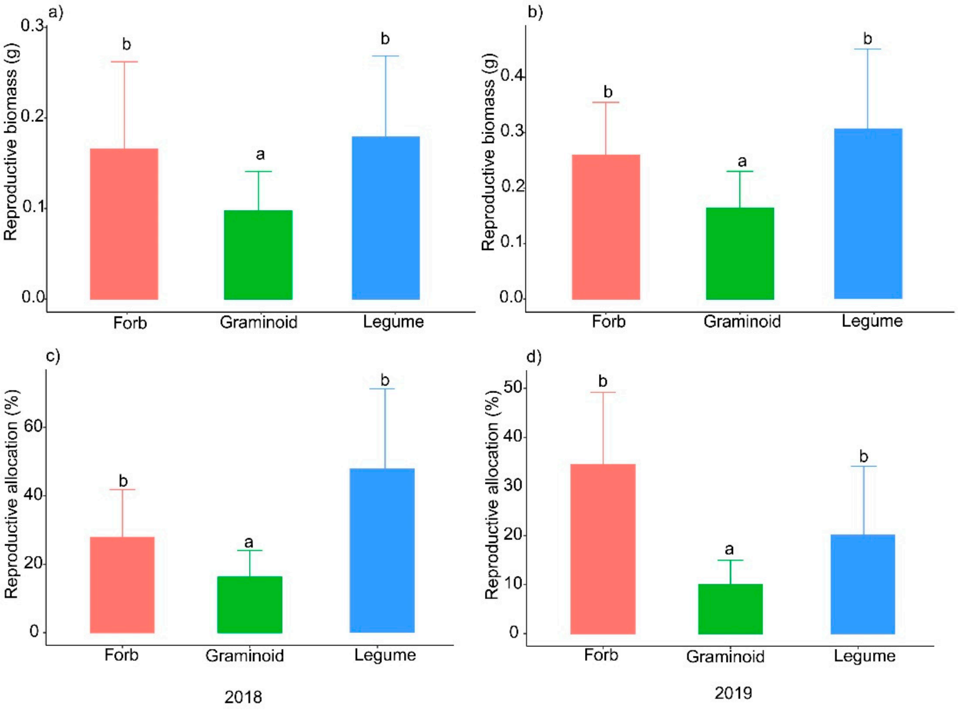

Figure 3. Reproductive biomass and allocation of the three functional groups in 2018 and 2019.

The seed traits varied among the three functional groups (Figure 4), which suggested that the adaptive strategies of the three functional groups may differ. The legume species had the greatest seed size and highest seed nitrogen content but the lowest seed number (Figure 4 a, b, g), whereas the forb species had the lowest seed size, seed nitrogen content and phosphorus content (Figure 4 b, g, h); the seed number and length of graminoids were higher than those in legumes and forbs, while the seed chemical traits were between the two groups (Figure 4 a, f, g, h). The PCA results indicated that the seed traits between forbs and legumes were distinct, but graminoids were not separated from forbs and legumes (Figure A3).

3. Discussion

In a two-year field experiment, our results revealed that a trade-off between seed size and number existed in a multispecies alpine steppe community (Figure 2 a, c). However, the relationships between seed size and number were inconsistent across the different functional groups, as a trade-off existed in the graminoid group but not in the forb or legume groups (Figure 2 b, d). Thus, the seed size–number trade-off at the community level was determined primarily by graminoid species may cause by their low reproductive biomass and allocation, which indicated that resource limitations were present for graminoid species but not for forb or legume species (Figure 3). In this study, we tested the seed size–number trade-off in multispecies communities and different functional groups and documented that resource limitations play an important role in determining trade-off patterns. Our results were robust across different years and after the effects of phylogenetic relationships among species were eliminated.

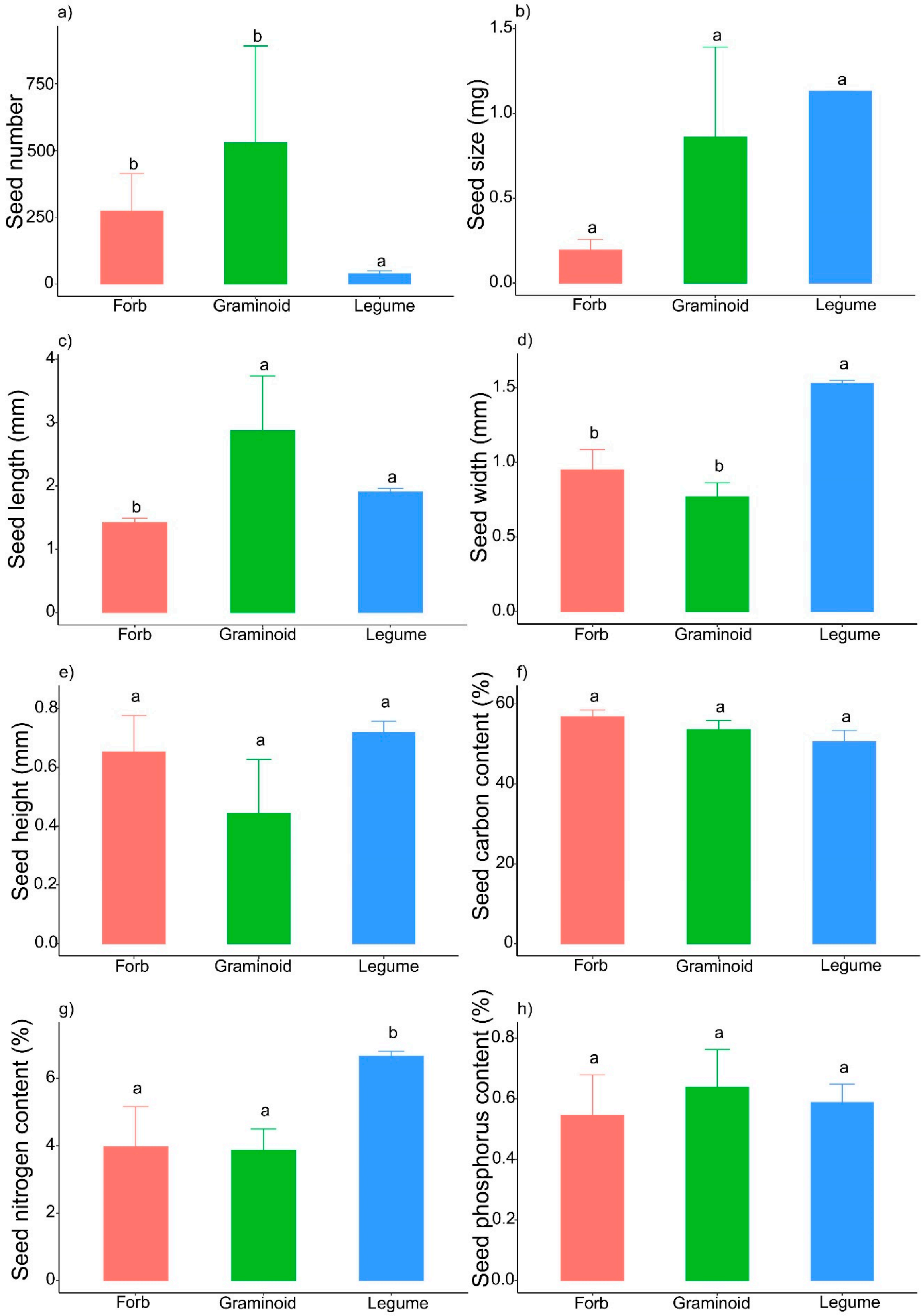

Figure 4. The seed traits of three functional groups.

The trade-off between seed size and number varies across different plant species, and ecologists have conducted extensive theoretical research on this relationship [49,50]. For example, life history strategy theory suggests that different species evolve different life history strategies (i.e., trade-offs between survival, growth, and reproduction) to maximize survival and reproductive success,

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including the r-strategy and K-strategy [9,10]. Other studies have explored the effects of resource availability decisions on plants in different growing environments, which is called resource availability theory [45,51,52]. Ben-Hur and Kadmon (2015) explained the coexistence of competing species in terms of a trade-off between competitive ability and colonization ability on the basis of competition–colonization trade-off models [53]. Germain et al discovered through the cultivation of populations of each species in both humid and arid environments that there is a strong trade-off between seed size and number among species but no consistent trade-off within species, highlighting the importance of the maternal environment in terms of ecological dynamics, particularly in the context of multispecies coexistence [31,54]. Despite the plethora of theoretical studies and a handful of experimental evidence on seed size–number trade-offs, research has been based on either a particular model or a controlled experiment, and studies of natural communities with multiple species are still lacking. In this study, we provide definitive evidence for this theory in a natural alpine steppe community involving multiple species.

Resource limitations played a crucial role in determining the trade-off between seed size and number at our study site. This refers to the fact that plants have finite resources available to allocate towards seed production, and they need to make strategic decisions on how to distribute these resources effectively based on the environment [22,55,56]. In this study, we used reproductive biomass and allocation to indicate the resource pool that is available for allocation to seeds in each species. Our results revealed that the reproductive biomass and allocation of graminoids were significantly lower than those of forbs and legumes in 2018 and 2019, which suggests that the reproductive resource pool of graminoids was lower than that of forbs and that legume and graminoid species experienced stricter resource limitations in terms of reproduction. A probable explanation is that the graminoid species undergo both sexual and clonal reproduction at our study site, but the forb and legume species only carry out sexual reproduction (Table 1). Unlike forb and legume species, graminoid species do not need to allocate vast resources to their reproduction because they are also able to produce offspring through tillering. As previous studies have shown, the two reproductive modes, i.e., sexual and asexual, affect resource allocation patterns and the seed size–number trade–off in perennial plants [57]. Species with asexual propagation can establish local populations via rapid, short-distance dispersal and forage in high-quality environments by escaping from poor sites and proliferating at richer sites [58,59]; thus, sexual reproduction enhances the competitive ability of these species, especially under nutrient enrichment conditions. In contrast, sexually reproducing plants are able to disperse seeds long distances, easily colonize new environments and tolerate more severe habitats [60,61]. At our study site, the soil type is chestnut soil, which contains a high percentage of humus (19.8%) and is a fertile soil. The precipitation was 409 mm and 469 mm in 2018 and 2019, respectively, which was greater than the mean annual precipitation (265.7 mm) in recent decades. Thus, graminoid species may not need to allocate many resources to sexual reproduction due to the current environmental situation. Previous studies have suggested that the constraining resources in alpine plant communities may include low temperatures and precipitation [54,62–64]. Specifically, previous studies have documented that water (the mean annual precipitation is only 265.7 mm) and nitrogen limited the above-ground biomass in our study site [65]. In the future, more studies are needed to distinguish the important roles of these resources in determining the patterns of seed size–number trade-offs.

The seed size–number trade-off was detected in graminoids but not in forbs or legumes (Figure 2). As the resource allocation theory predicts, different environments will select for different optimal patterns of resource allocation to reproductive versus vegetative functions [30,66] and different trade-offs in optimal seed size [45,67] with fecundity [68]. Our experimental results strongly support this idea (Figure 2). Moreover, the strategies used by plants to adapt to the alpine environment differed among the three functional groups. At our study site, the legume species had the lowest seed number; in contrast, the legume species had the greatest seed size and largest seed volume (Figure 3). The seed nitrogen content of legumes is significantly greater than that of forbs and graminoids (Figure 3), which may be caused by the nitrogen-fixing ability of legume species and the high level of nitrogen in their tissues [69,70]. Thus, legume species tend to exhibit competitive strategies because high seed size and large seed volume are often closely related to a high survival rate of seedlings [36], and the high seed nitrogen content also indicates that their seeds contain more nutrients for seedling survival and growth. In contrast, forb species produced small, round seeds with the lowest seed size and seed length, while the seed carbon content in the forb group was slightly greater than that in the graminoid and legume groups (Figure 3). These characteristics indicate that forb species prioritize tolerance strategies because small and high-carbon-content seeds might be buried more deeply and persist longer in the soil than large and nonspherical seeds [37]. Moreover, the graminoid group, which had intermediate seed sizes and nutrient contents, selected a compromise strategy between competition and tolerance. In fact, the five graminoid species produced two types of seeds: *Stipa purpurea* and *Agropyron cristatum* produced large, nonspherical seeds, whereas *Poa crymophila*, *Koeleria cristata* and *Festuca ovina* produced small, spherical seeds. The compromise strategy was well adapted to alpine conditions; thus, more graminoid species coexisted at our study site than forb and legume species did.

In this study, we demonstrated the existence of trade-offs between seed size and number in a multispecies alpine steppe community, particularly in graminoids. The seed size–number trade-off was determined by the reproductive resources and mode of the plant. In addition, species in different functional groups may adopt different strategies to adapt to alpine habitats during the seed stage. In the future, more comprehensive studies are needed to test the seed size–number trade-off pattern in other ecosystems and explore the underlying mechanisms in natural communities. Additionally, the role of the seed size–number trade-off in affecting community composition should be investigated because both seed size and seed number are closely related to species fitness in the plant community.

4. Materials and Methods

4.1. Study Site

This study was conducted in Bayanbulak grassland, near the Bayanbulak Grassland Ecosystem Research Station (42°52′N, 83°42′E), which is located in the southern Tianshan Mountains within Hejing County, Xinjiang Uygur Autonomous Region, China. This region is one of the largest stock-breeding bases in Xinjiang and is recognized as a biodiversity hotspot in Central Asia. At our study site, the altitude is approximately 2470 m. On the basis of meteorological data from recent decades (2014-2023), the mean annual precipitation is 265.7 mm (mostly concentrated from May to August), the mean annual temperature is -4.8 °C, the amount of evaporation is 1022.9-1247.5 mm, the total annual sunshine duration is 2466-2616 h, and the annual snow cover duration is 150-180 days. There is no absolute frost-free period, and the climate is typically alpine. The vegetation is alpine steppe, and the dominant plant species are *Stipa purpurea*, *Festuca ovina*, *Agropyron cristatum* (Poaceae) and *Astragalus polycladus* (Leguminosae). The average aboveground dry biomass is 71–382 g/m2, and the richness is 9–13 species/m2.

4.2. Experimental Design and Seed Trait Measurements

In 2018 and 2019, from the middle of August to the end of September, 11 common species were sampled from an enclosed and flat alpine steppe community (approximately 5 hectares). This area has been fenced since 2018, and livestock such as sheep and horses have been forbidden throughout the year, but wild animals, including marmots (*Marmota bobac*) and zokors (*Myospalax* spp.), have been allowed inside. These 11 species accounted for more than 97% of the above-ground biomass and 92% of the cover at our study site. For each species, when the seeds ripened naturally, 12–15 healthy plant individuals were randomly sampled, then clipped and placed in an envelope, each individual was at least 10 meters apart in this process.

In the laboratory, after the seeds were air-dried, we removed the reproductive part of each individual and then weighed them on an electronic balance to 0.0001 g to represent reproductive biomass. The reproductive allocation was defined as the ratio of reproductive biomass to ramet biomass of each species. Then, the number of seeds was counted, and the mass of the seeds in each reproductive part was weighed. In our study, we defined seed size as the seed mass per capita, that is, the seed mass divided by the number of seeds for each individual. We then measured the other six seed traits, which included three morphological traits (seed length, width and height) and three chemical traits (seed carbon, nitrogen and phosphorus contents), of each species. To measure morphological traits, 10 randomly selected seeds from each species were scanned, and the image was analysed with Epson Expression 10000XL and imaging software (Win SEEDLETM, Canada). Next, about 2 g seeds were crushed with a ball mill and used to measure the carbon, nitrogen and phosphorus contents. The carbon content was measured via the potassium dichromate external heating method. The nitrogen and phosphorus concentrations were analysed via a continuous flow injection analyser (SKALAR, Breda, the Netherlands).

4.3. Statistical Analysis

All 11 species in our study were divided into three functional groups: forb, graminoid and legume (Table 1). First, the seed number and size data were log-transformed prior to analysis. Next, we described the distribution of seed size and number of seeds per ramet for different plant species. Next, we used simple linear regression to examine the relationship between seed size and seed number at the community level and among the three functional groups for each year (2018 and 2019) and two years data pooled, respectively [44]. Then, the means of seed size and seed number for each species were calculated, and simple linear regression was used to detect the relationship between them; in this way, we eliminated the random effects of different species. A phylogenetically independent contrasts (PICs) analysis was subsequently performed to test the potential effects of the phylogenetic relationships among species on the correlations between seed size and seed number [71]. To perform this analysis, a phylogenetic tree that included the 11 species was constructed (Figure S1). We downloaded 11 ITS sequences representing each species from NCBI. All sequences were aligned using MEGA 5, and a maximum likelihood (ML) tree was constructed on the basis of the aligned ITS sequence variations using MEGA version 5.0, with default parameters [72].

Finally, the reproductive allocation of each species was calculated as the reproductive biomass divided by the individual biomass, and the reproductive biomass and reproductive allocation of the three functional groups were subsequently analysed via ANOVA and the HSD test. To detect the reproductive strategies of the three functional groups, eight seed traits (number, size, length, width, height, carbon content, nitrogen content and phosphorus content) were subjected to principal components analysis (PCA).

All analyses were carried out in R version 4.2.2 (R Development Core Team, 2019). The PICs analysis was conducted via the “ape” and “ade4” packages, the HSD test was performed via the “agricolae” package, and the data were cleaned and plotted via the “tidyverse” and “ggplot2” packages, respectively.

Author Contributions: Conceptualization: XZ, ZR. Methodology: XZ, JL, RD. Formal analysis: XZ, ZR, HB. Data curation: XZ, RD, HB. Writing-original draft: XZ. Writing-review and editing: JL. Visualization: JL.

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Data Availability Statement: All the required data are uploaded as supplementary material.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PICs	phylogenetically independent contrasts
PCA	principal components analysis

Appendix A

Table A1. The results of linear regression and linear regression based on PICs (phylogenetically independent contrasts) between mean value of species' seed size and seed number in community.

year	linear regression			linear regression based on PICs		
	slope	R^2	p	slope	R^2	p
2018	-0.88	0.47	**0.02**	-0.67	0.34	**0.04**
2019	-0.74	0.60	**0.02**	-0.64	0.45	0.06

Table A2. The raw data of eight seed traits for article analysis. (C: seed carbon content, N: seed nitrogen content, P: seed phosphorus content).

Species	seed number	seed size (mg)	length (mm)	width (mm)	height (mm)	C (%)	N (%)	P (%)
Oxytropis_glabra	22.63	1.13	1.99	1.56	0.77	54.55	6.45	0.50
Astragalus_alpinus	54.1	1.13	1.829	1.49	0.66	46.53	6.86	0.67
Stipa_purpurea	22	2.64	5.459	1.08	1.02	54.87	2.78	0.42
Poa_crymophila	272.64	0.2	1.16	0.69	0.22	52.09	2.70	0.47
Festuca_ovina	1772	0.28	2.92	0.72	0.38	53.00	3.96	0.50
Koeleria_cristata	538.55	0.13	3.40	0.78	0.06	47.44	4.10	0.99
Agropyron_cristatum	34	1.05	1.41	0.59	0.54	60.19	5.79	0.81
Potentilla_bifurca	35.63	0.34	1.44	1.15	0.92	54.68	1.42	0.34
Leontopodium_ leontopodioides	308	0.05	1.31	0.56	0.33	61.88	6.60	0.93
Potentilla_multifida	91.09	0.13	1.61	1.14	0.76	54.74	2.57	0.39
Potentilla_fragarioides	653.9	0.24	1.32	0.94	0.60	55.74	5.26	0.52

Table A3. The raw data of reproductive biomass, seed number and seed mass for article analysis.

Species	Reproductive Biomass (g)	Seed number	Seed Size (mg)	Functional Group
Oxytrois_glabra	0.1307	23	1.382609	Legum
Oxytrois_glabra	0.3706	63	1.350794	Legum
Oxytrois_glabra	0.0564	12	0.816667	Legum
Oxytrois_glabra	0.1233	16	1.0375	Legum
Oxytrois_glabra	0.1128	13	0.984615	Legum
Oxytrois_glabra	0.0799	16	1.46875	Legum

Oxytrois_glabra	0.0718	9	1.1	Legum
Oxytrois_glabra	0.0425	12	1.125	Legum
Oxytrois_glabra	0.0565	5	0.88	Legum
Oxytrois_glabra	0.1422	7	0.814286	Legum
Oxytrois_glabra	0.7849	73	1.469863	Legum
Astragalus_multicaulis	0.0382	28	1.053571	Legum
Astragalus_multicaulis	0.0767	14	1.335714	Legum
Astragalus_multicaulis	0.5019	94	1.380851	Legum
Astragalus_multicaulis	0.1016	35	1.011429	Legum
Astragalus_multicaulis	0.215	45	1.286667	Legum
Astragalus_multicaulis	0.1508	46	1.295652	Legum
Astragalus_multicaulis	0.079	17	0.876471	Legum
Astragalus_multicaulis	0.1719	64	1.176563	Legum
Astragalus_multicaulis	0.235	114	0.734211	Legum
Astragalus_multicaulis	0.215	84	1.153571	Legum
Potentilla_multifida	0.0233	93	0.097849	Forb
Potentilla_multifida	0.0186	32	0.09375	Forb
Potentilla_multifida	0.0192	50	0.126	Forb
Potentilla_multifida	0.0465	112	0.129464	Forb
Potentilla_multifida	0.0124	9	0.188889	Forb
Potentilla_multifida	0.0329	142	0.116197	Forb
Potentilla_multifida	0.0213	48	0.133333	Forb
Potentilla_multifida	0.0748	300	0.125667	Forb
Potentilla_multifida	0.039	113	0.199115	Forb
Potentilla_multifida	0.0115	100	0.131	Forb
Potentilla_multifida	0.014	3	0.1	Forb
Poa_crymophila	0.0397	74	0.17973	Graminoid
Poa_crymophila	0.0754	115	0.231304	Graminoid
Poa_crymophila	0.2717	1428	0.173109	Graminoid
Poa_crymophila	0.0673	177	0.158757	Graminoid
Poa_crymophila	0.1137	346	0.154046	Graminoid
Poa_crymophila	0.0858	201	0.235323	Graminoid
Poa_crymophila	0.0349	83	0.206024	Graminoid
Poa_crymophila	0.0293	79	0.187342	Graminoid
Poa_crymophila	0.039	109	0.202752	Graminoid
Poa_crymophila	0.028	43	0.251163	Graminoid
Poa_crymophila	0.226	344	0.22064	Graminoid
Festuca_ovina	0.2495	3234	0.265121	Graminoid
Festuca_ovina	0.0572	522	0.332184	Graminoid
Festuca_ovina	0.0422	636	0.227358	Graminoid
Festuca_ovina	0.0928	1272	0.286321	Graminoid
Festuca_ovina	0.092	1956	0.238957	Graminoid

Festuca_ovina	0.2663	2610	0.345057	Graminoid
Festuca_ovina	0.3495	3858	0.316952	Graminoid
Festuca_ovina	0.0216	342	0.236842	Graminoid
Festuca_ovina	0.2798	1518	0.253755	Graminoid
Potentilla_fragarioides	0.4291	894	0.237136	Forb
Potentilla_fragarioides	0.4694	976	0.25584	Forb
Potentilla_fragarioides	0.2449	518	0.251544	Forb
Potentilla_fragarioides	0.2815	392	0.316327	Forb
Potentilla_fragarioides	0.1571	423	0.201182	Forb
Potentilla_fragarioides	0.1629	322	0.229503	Forb
Potentilla_fragarioides	0.219	258	0.288372	Forb
Potentilla_fragarioides	0.33	777	0.237066	Forb
Potentilla_fragarioides	0.1664	367	0.233515	Forb
Potentilla_fragarioides	0.4743	1089	0.196143	Forb
Potentilla_fragarioides	0.3533	755	0.260795	Forb
Potentilla_fragarioides	0.5403	1076	0.216357	Forb
Koeleria_cristata	0.0264	1024	0.100391	Graminoid
Koeleria_cristata	0.0829	1424	0.133708	Graminoid
Koeleria_cristata	0.0356	832	0.145673	Graminoid
Koeleria_cristata	0.0472	584	0.128767	Graminoid
Koeleria_cristata	0.0177	276	0.162319	Graminoid
Koeleria_cristata	0.0223	288	0.126389	Graminoid
Koeleria_cristata	0.0282	252	0.11746	Graminoid
Koeleria_cristata	0.0516	384	0.146875	Graminoid
Koeleria_cristata	0.0191	140	0.165714	Graminoid
Koeleria_cristata	0.0627	524	0.135878	Graminoid
Koeleria_cristata	0.0364	196	0.112245	Graminoid
Stipa_purpurea	0.1452	69	2.886957	Graminoid
Stipa_purpurea	0.0528	15	2.88	Graminoid
Stipa_purpurea	0.3012	171	2.722807	Graminoid
Stipa_purpurea	0.092	36	2.666667	Graminoid
Stipa_purpurea	0.1299	45	2.62	Graminoid
Stipa_purpurea	0.1225	60	2.765	Graminoid
Stipa_purpurea	0.0412	24	2.5875	Graminoid
Stipa_purpurea	0.2816	216	2.1	Graminoid
Stipa_purpurea	0.1076	99	2.390909	Graminoid
Stipa_purpurea	0.1947	99	2.769697	Graminoid
Agropyron_cristatum	0.0831	45	1.048889	Graminoid
Agropyron_cristatum	0.1029	55	1.378182	Graminoid
Agropyron_cristatum	0.0646	47	1.002128	Graminoid
Agropyron_cristatum	0.0348	25	1.112	Graminoid
Agropyron_cristatum	0.0243	8	0.825	Graminoid

Agropyron_cristatum	0.0586	46	0.865217	Graminoid
Agropyron_cristatum	0.0564	6	1.2	Graminoid
Agropyron_cristatum	0.0358	25	1.08	Graminoid
Agropyron_cristatum	0.0465	20	1.04	Graminoid
Agropyron_cristatum	0.0909	63	0.939683	Graminoid
Leontopodium_leontopodioides	0.2242	13	0.053846	Forb
Leontopodium_leontopodioides	0.0638	174	0.035057	Forb
Leontopodium_leontopodioides	0.8468	71	0.076056	Forb
Leontopodium_leontopodioides	0.0672	6	0.066667	Forb
Leontopodium_leontopodioides	0.4459	59	0.052542	Forb
Leontopodium_leontopodioides	0.1065	86	0.053488	Forb
Leontopodium_leontopodioides	0.3173	53	0.060377	Forb
Leontopodium_leontopodioides	0.1509	109	0.055046	Forb
Leontopodium_leontopodioides	0.0871	6	0.016667	Forb
Potentilla_bifurca	0.0341	63	0.304762	Forb
Potentilla_bifurca	0.027	49	0.312245	Forb
Potentilla_bifurca	0.0129	13	0.476923	Forb
Potentilla_bifurca	0.0192	41	0.302439	Forb
Potentilla_bifurca	0.0197	40	0.31	Forb
Potentilla_bifurca	0.0215	20	0.32	Forb
Potentilla_bifurca	0.0168	23	0.413043	Forb
Potentilla_bifurca	0.0178	36	0.305556	Forb

Appendix B

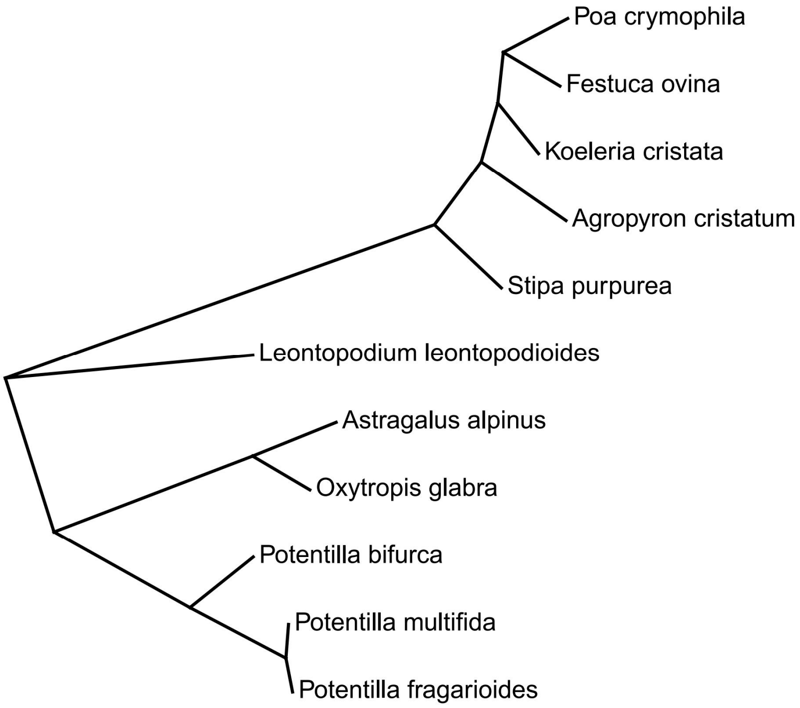

Figure A1. The phylogenetic tree based on nuclear ITS sequences of species.

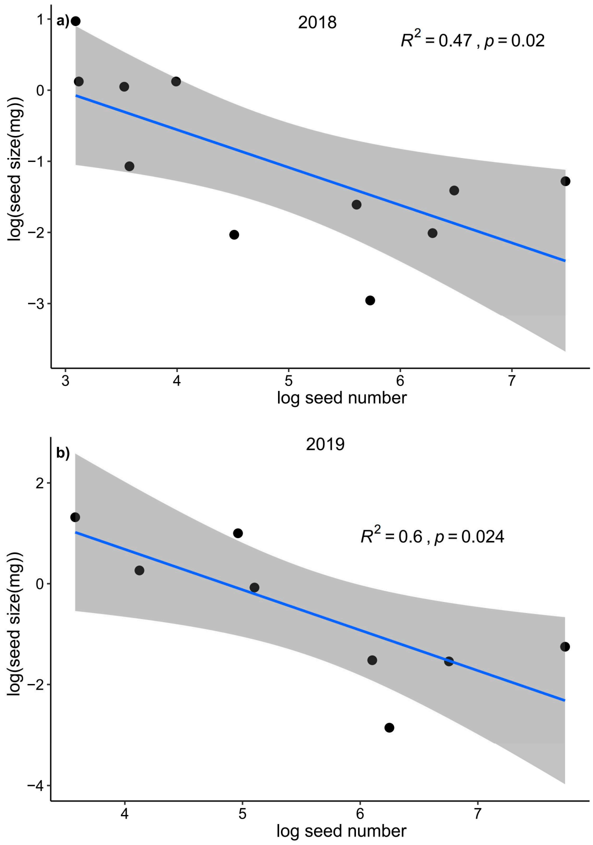

Figure A2. The relationship between seed size and seed number of different species in community. Each points represent a species' mean value.

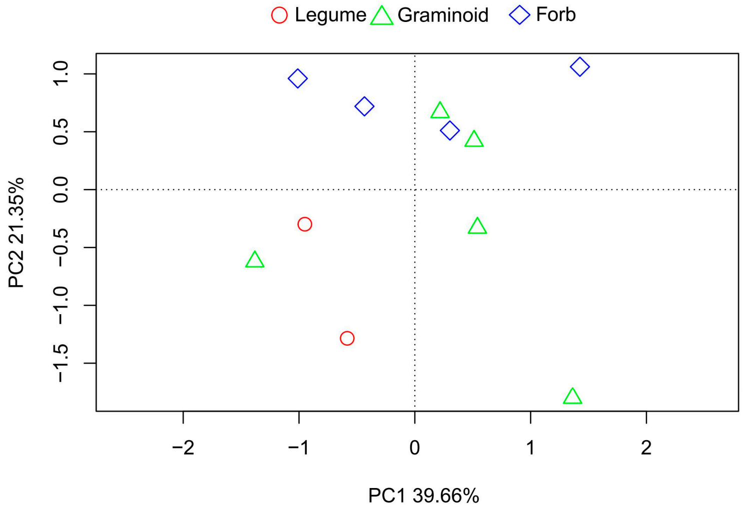

Figure A3. The principal components analysis (PCA) of common species based on eight seed traits.

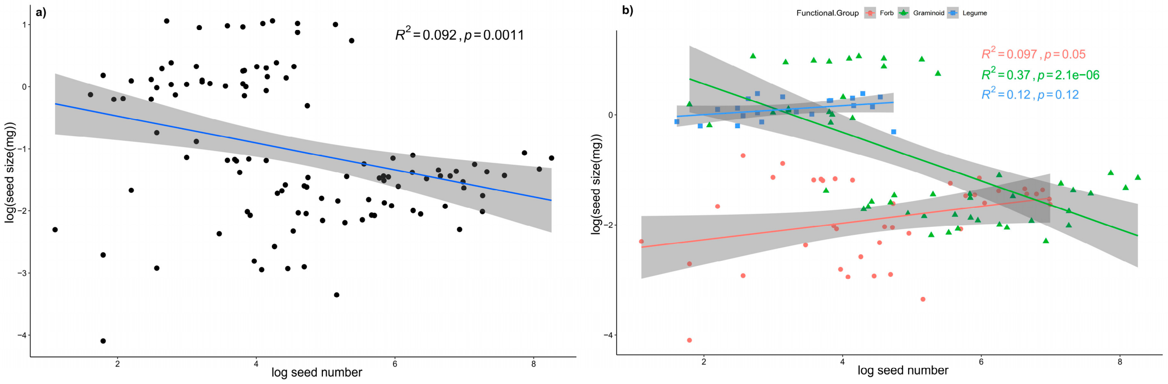

Figure A4. Relationships between seed size and seed number at the community level a) and c) and at the functional group level b) and d) after two years data pooled. The seed size and seed number data were log transformed.

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