Variation in seed size and its relationship to other functional traits in a seasonally dry tropical forest

A Thesis

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by

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IISER Pune

Certificate

This is to certify that this dissertation entitled “Variation in seed size and its relationship to other functional traits in a seasonally dry tropical forest” towards the partial fulfilment of the MS degree at the Indian Institute of Science Education and Research, Pune represents study/work carried out by Dhrubojyoti Patra at Indian Institute of Science Education and Research under the supervision of Dr. Deepak Barua, Associate Professor, Department of Biology, during the academic year 2021-2023.

(Dhrubojyoti Patra)

(Dr. Deepak Barua)

Declaration

I hereby declare that the matter embodied in the report entitled “Variation in seed size and its relationship to other functional traits in a seasonally dry tropical forest” are the results of the work carried out by me at the Department of Biology, Indian Institute of Science Education and Research, Pune, under the supervision of Dr. Deepak Barua and the same has not been submitted elsewhere for any other degree

Dhrubojyoti Patra

14th April 2023

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Figure 7: Relationship of seed size with other traits at Bhimashankar Wildlife Sancturary, weighted by relative dominance of species. Relationship of seed mass (SM) with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) in woody species from Bhimashanker wildlife sanctuary. Each point is the representative mean trait value for an individual species. The fitted line is a standardized major axis regression (SMA) line. In every panel the weighted correlation coefficients (r) and P – values (p) are reported. 36

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Abstract

Seed size is an important plant functional trait related to important axes of plant function like regeneration and stress (shade, drought and herbivory) tolerance. Globally seed size has been found to be related to plant height and independent of leaf economic spectrum (LES) traits making it a part of a size architecture spectrum. However global relationships of seed size with other functional traits do not always show consistency across scales and in different environments. This study tried to understand the relationships of seed size with other functional traits and if these vary with environment. A literature survey showed that the trait relationships of seed size with other functional traits varies with scale and climate, with a lot of variation in the trait relationships of seed size from the tropics. In order to understand the variation in seed size and its relationship with other functional traits, seed size and its trait relationships were quantified for the entire woody plant community in a seasonally dry tropical forest, and across habitats in the forest differing in their light and water environments. Seed size did not vary across habitats. In well-lit habitats with low soil moisture seed size was found to be related to leaf mass per area a chief leaf economic trait whereas in shade habitats with high soil moisture, seed size was related to wood density, leaf dry mass and plant height. A high value of all these traits confer shade tolerance. Hence water availability drives the trait relationships of seed size in well-lit dry environments and shade is the main driver of trait relationships of seed size in shade moist environments. In order to understand if different trait combinations are successful across different habitats, the trait space was examined across habitats, well-lit dry habitats which are heterogeneous harbored a wider trait space particularly along the leaf economic spectrum, whereas shade moist habitat had a much restricted trait space.

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Introduction:

Regenerative traits couple early and late life history stages of plants. For seed plants, particularly in woody species, seed traits comprise most of regenerative traits. For long lived woody species, it is particularly important to understand seed traits because the early and late life history stages often occupy different environmental niches and has different life history strategies and consequently has different evolutionary forces acting on them. Seeds comprise an embryo encased in two layers, the inside covering or the endosperm is the food storage tissue and the endosperm in turn is covered by a seed coat. The seed coat protects the embryo against desiccation giving seed plants an evolutionary advantage over non seed plants (Niklas, 2008, Saatkamp et al. 2019). Understanding seed traits would also help us better understand plant population and community ecology. As plants often experience the highest degree of mortality during the seed and seedling stages, seedling abundance also has a very tight correlation with the distribution of adult plants. The major seed functions; dispersal, persistence in seed bank, germination and seedling establishment represent significant life history transitions for plants.

Seed size happens to be the most studied seed trait and its ecological significance has been unequivocally established. Seed size can be measured in seed mass, seed dimensions or seed volume. Out of these seed mass has been found to be most relevant for understanding trait – trait and trait – performance relationships of plants. The seed mass of a species depends on its resource allocation strategies to seed production in the adult life stage. Seed mass also has important implications for the survival and establishment of juvenile plants. Hence seed mass in a way bridges the regenerative and adult functional strategies of plants. Seed mass has been found to be related to all the major seed functions (Figure 1). Like in seed dispersal (Hawes et al. 2019, Liang et al. 2020), seed mass has been related to seed dispersal distance, it has been found with seed mass decreases with increasing dispersal distance (Thomson et al. 2011). Seed mass is also linked to seed persistence, smaller seeds persist longer in the seed bank and vice versa (Long et al. 2014). Seed mass also relates to germination and establishment, mean time to germination (Norden et al. 2009) and establishment rates (Walters et al 2000; Poorter and Rose, 2005; Baraloto et al. 2007, Wright et al. 2010) increases with increasing seed size.

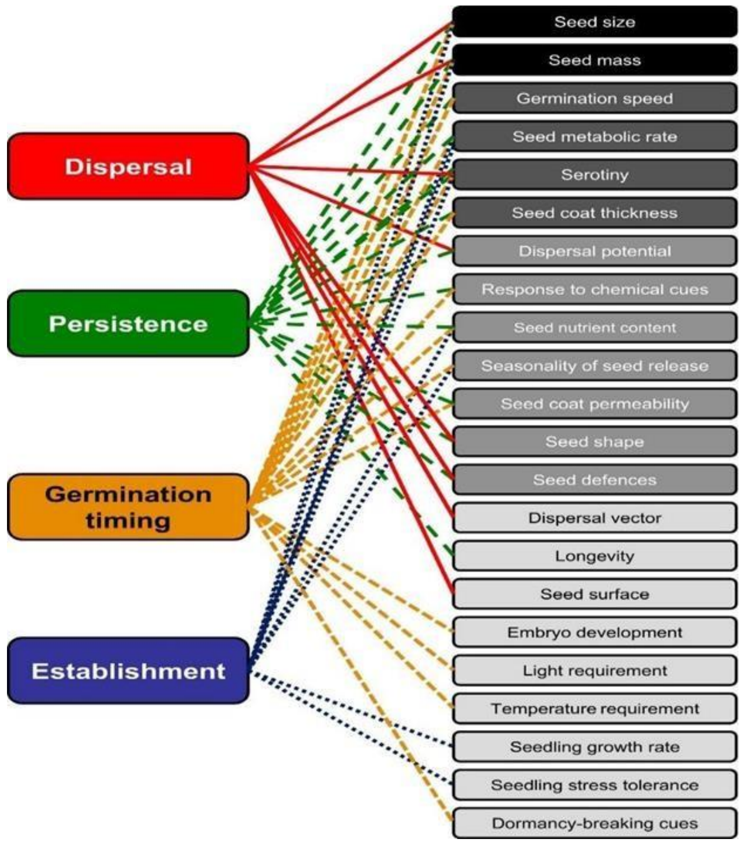

Figure 1: Some established and proposed relationships of four major seed functions (left) with seed traits (right). Shading of trait boxes refer to number of links with seed function. Seed size and seed mass has the highest number of links. (reproduced from Saatkamp et al. 2019).

Seed mass also influences stress tolerance of seeds and seedlings and hence seedling establishment. Seed mass has been shown to be positively related to both shade and drought tolerance, i.e. bigger seeded species are better at surviving shade and drought stress (Kitajima, K. 1996, Krishnan et al. 2019, Hallet et al. 2011). Krishnan et al. 2019 in their study found a positive relationship of drought tolerance with seed mass in an Indian dry tropical forest tree species. The better performance of large seeded species under shade and drought is chiefly attributed to greater storage reserves and bigger initial seedling size. This relationship of seed size to survival and growth is mediated by cotyledon morphology. Bigger seeds usually have reserve type cotyledons from which food reserve is slowly mobilized in a conservative manner for seedling growth whereas smaller seeds have foliar cotyledons in which the stored food gets utilized and the cotyledons turn photosynthetic causing the seedling to grow fast (Kitajima, K 2002). Shade and drought stress are two most important selection pressures during seedling establishment in tropical forests, where seedlings often experience both shade and drought stress combined (Grubb, P.J., 2016). Hence seed mass happens to be an important trait that would affect the distribution of species in the tropics.

Other than seed mass, five other traits, namely – leaf mass per area (LMA), leaf nitrogen content, maximum plant height, leaf area and wood density have been found to capture the expanse of variation in vascular land plants (Diaz et al. 2016) These five traits along with seed mass has also been found to have strong correlations with demographic rates – growth, survival and reproduction (Visser et al. 2016, Ruger et al. 2018). These six traits are referred to as functional traits.

Diaz et al. 2016, using the six major functional traits defined the global spectrum of plant form and function (Figure 2). The variation in extant vascular land plants was found to be captured by two major dimensions, a leaf economic spectrum (LES) reflecting resource acquisition strategies and a size – architecture spectrum related to competition and reproductive strategies. The LES goes from low leaf mass per area (LMA) leaves with high leaf nitrogen, faster photosynthesis to high LMA leaves, with low leaf nitrogen and slower photosynthesis in other words from acquisitive resource use strategies to conservative resource use strategies (Wright et al. 2004, Diaz et al. 2016). The size – architecture spectrum is built of seed mass and maximum plant height, at one end are smaller plants capitalizing on fecundity, on the other end are tall species producing large seeds to compete for light and survive the juvenile period in shade sustaining on a large seed reserve (Wright et al. 2007, Diaz et al. 2016).

Since, seed mass happens to be an integral part of the size – architecture axis, it also reflects a regeneration spectrum - a species can produce many small seeds or it may invest in few big seeds with greater food reserve to increase the survival chances of the seedlings (Moles et al. 2005a, b; Igea et al., 2017).

Though wood density loads poorly on the fast – slow axis contemporary understanding of wood density places it as a part of fast – slow continuum (Reich et al. 2014) Particularly for woody specieswhere wood density axis aligns best with the carbon turnover and survival strategy dimensions (Wright etal. 2007, Ruger et al. 2018).

Hence at the global level vascular land plants can be considered to have two functional modules of trait combinations or syndromes, one related to resource acquisition and the other related to size and architecture (Figure 2).

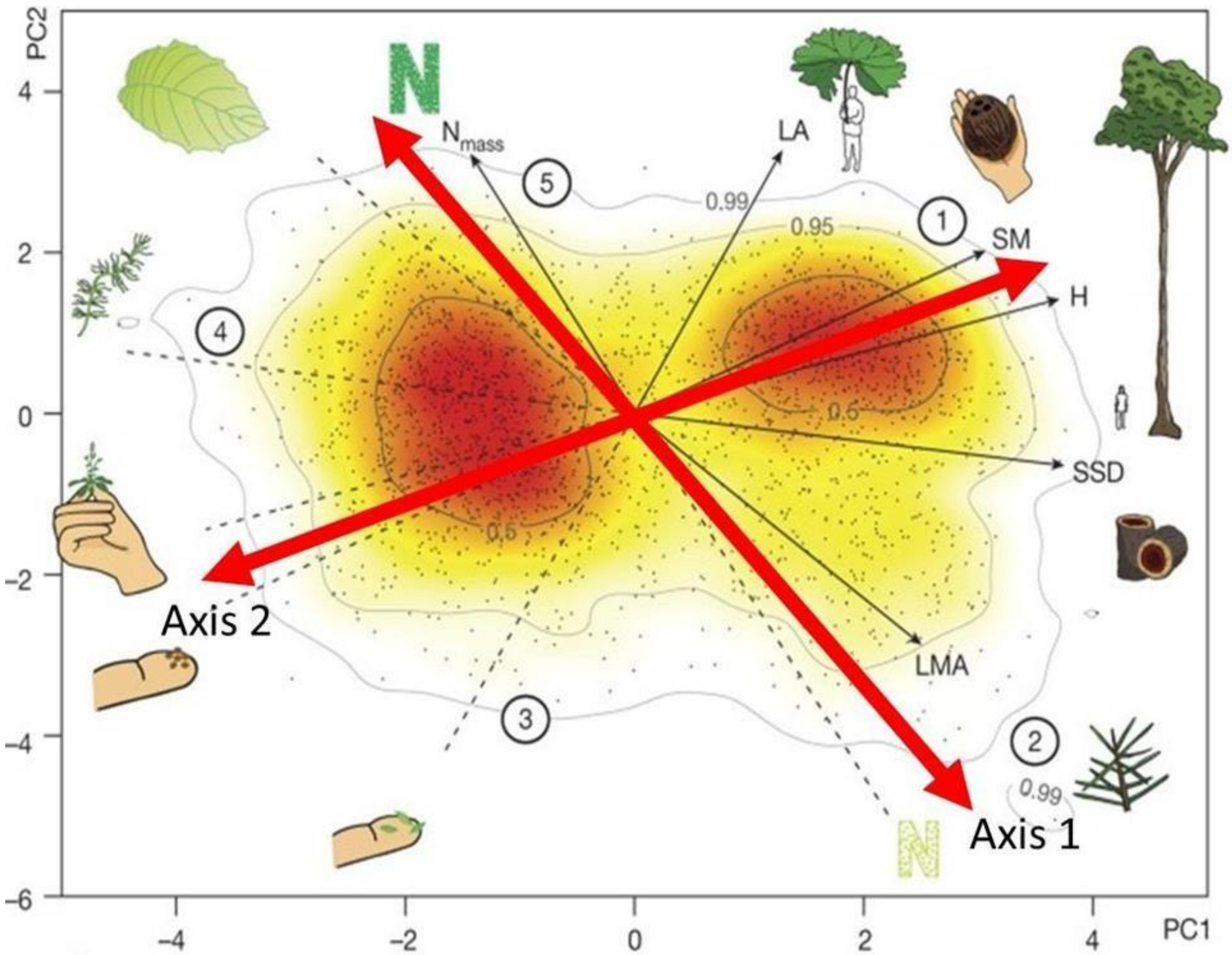

Figure 2: Global vascular plant species on plane defined by principal component axes (PC) 1 and 2. Direction and weighing of the vectors of the six different traits represented by solid arrows. Positions of extreme poles of trait values indicated by circled numbers. Colour gradients represents probability of occurrence of species, red (highest) to white (lowest), contour lines represent 0.5, 0.95 and 0.99 quantiles. Axis 1 represents the leaf economics spectrum and axis 2 represents the size – architecture spectrum. (Modified after Diaz et al. 2016).

While these trait relationships are established at the global scale they always do not hold true for species at smaller scales (Kraft et al. 2015, Messier et al. 2017, Burton et al. 2020), and since it is the local trait distributions and relationships that have implications for community patterns and processes. It becomes important to understand local trait relationships. The Western Ghats biogeographic realm, with its rich endemicity and diversity of woody plants would be an important place to understand trait relationship and networks. Also, given the paucity of such studies in this region it becomes further important to understand plant trait relationship in this region.

The relationship of the regenerative spectrum with the resource acquisition spectrum would be particularly interesting and important to look at. The LES which reflects a fast – slow continuum at the tissue level has been found to be associated with a fast – slow continuum at whole plant level in the form of the growth – mortality tradeoff axis (Sterck et al. 2006, Ruger et al. 2018) and seed mass has been found to be associated with growth rate, with smaller seeded species having faster growth and vice versa (Poorter and Rose, 2005, Baraloto et al. 2007, Wright et al. 2010). Hence an association of LES with the seed mass would imply for a fast – slow continuum across both the regenerative and established phases i.e. throughout life history. Further a link between LES and seed mass would also link community functions like productivity and decomposition to regeneration and community assembly processes (Diaz and Cabido, 2001).

Similarly, it would be important to understand the relationship of seed mass with plant height, leaf area and wood density at the level of communities. Globally and for most communities seed mass has been found to be positively related with plant height (Diaz et al. 2016, Moles et al. 2004, Wright et al. 2007). Seed mass has been found to have a triangular relationship with leaf area in some studies (Cornelissen, 1999) that is smaller seeded species can either have small or big leaves whereas bigger seeded species usually have large leaves. However, there's a lack of consensus about the relationship with seed mass with wood density.

Environmental filters in communities can decouple traits related at the global level or give rise to within community new trait relationships. For instance, one of the most consistent trait relationship the LES has also been found to be absent in certain studies (Kraft et al. 2015, Messier et al. 2017). Similarly, while seed mass is independent of the LES at the global scale, studies involving particular functional groups or at the smaller scales for instance within communities often find seed mass to be associated with LES (e.g. Wright et al. 2010, Simova et al. 2017). Studying trait relationships along environmental factors can help us understand what trait distributions and syndromes are getting filtered along these environmental gradients and what trait syndromes are adaptive in a given environment. It is important to understand trait relationships at the local level because trait dependent processes at the level of communities are determined by what trait relationships and syndromes exist within the community.

Since dominance of species has important role for the patterns and processes of a community, and dominant species also play important role in how communities respond to environmental changes (Ackerly *et al.*, 2002). It makes more ecological sense to understand functional traits and trait relationships in the light of relative dominance – which is the basal area covered by a species relative to the total basal area of the community. Community weighted mean (CWM) is the summation of the species mean trait value weighted by the relative abundance or relative dominance of the species (Garnier *et al.*, 2004; Violle *et al.*, 2007; Siefert *et al.*, 2014).

Seasonally dry tropical forests differ highly in their temporal and spatial heterogeneity in water and light availability (Walsh and Newbery, 1999) and hence provides different environmental contexts under which the trait relationships of seed mass can be enquired, for instance whether resource acquisition (LES) and regeneration (seed mass – seed number) spectra could be related under certain environmental conditions. The Western Ghat's seasonally dry tropical forests with its high plant diversity, high variability in light and water environments both temporally and spatially (Pascal and Pelissier, 1996) provides opportunities to study the effect of environmental filter gradients on trait relationships and also to enquire under what conditions certain relationship might emerge.

Similar to seed mass, leaf mass per area (Kitajima K., 2002) and wood density (O'Brien et al. 2017) are also related to shade and drought tolerance. Both Leaf mass per area and wood density have been found to be increasing with shade or drought stress. Hence the relationship of seed mass with LES traits and wood density can be expected to be effected by the light and water environment of a community.

This study addresses variation in seed size, and the relationship of seed size with other functional traits, for the woody species of Bhimashankar Wildlife Sanctuary (BWS), a seasonally dry tropical forest in Northern Western Ghats. BWS has three habitats which vary in their light and water availability (Jezeera, AM. 2016). The three habitats are referred to as open, edge and closed, the open forest has heterogeneous water and light environment, while the closed forest has a moist and shaded environment, the edge represents intermediate kind of light and moisture environment (Jezeera, AM. 2016; Chakrabarty, S. 2020). Hence, BWS gives an ideal opportunity to enquire into the effect of light and water environments on the trait relationships of seed size.

The first objective of the study was to understand what is known about the relationship of seed size with other functional traits at various scales ranging from global to within community. The next objective of this study was to understand the variation of seed mass in the woody plant community of BWS, to understand it in the context of global range of seed sizes and to see if community weighted mean (CWM) seed mass differs in the three habitat types of BWS. The species level seed mass data were weighted by relative dominance of species in the three habitats. Next the trait relationships of seed mass for the entire community of BWS, as well as across habitats was examined. For the habitat wise comparisons, the trait relationships were weighted by relative dominance of the species. The final objective of the study was to understand the position of seed mass in the entire trait space of BWS and how the position of seed mass varies in trait space across the three habitats.

Since the heterogeneity in light and water availability decreases from the open to closed habitat, the closed habitat being moist and high shade, the community weighted mean seed mass was expected to increase from open to closed habitat. Bigger seeds would confer higher shade tolerance in the closed habitat, whereas in the open habitat it would be beneficial for the species to capitalize on fecundity by producing large number of small seeds.

Based on how seed size, leaf mass per area and wood density relate to light and water availability (summarized in Table 1), the relationships of seed mass with LES traits and wood density were expected to vary from open to closed habitat as summarized in Table 2. The relationship of seed mass with leaf nitrogen and leaf dry matter were expected to show similar patterns to leaf mas per area because, these traits are related to leaf mass per area. The high light, low soil moisture open habitat will have species with drought avoiding strategies with (low seed mass, low leaf mass per area and low wood density), as well drought tolerating (high seed mass, high leaf mass per area and high wood density), strategies coexisting, hence it was expected that leaf mass per area and wood density will be positively related to seed mass in the open habitat. Since the relationship of seed mass to height (Wright et al. 2007, Diaz et al. 2016) and leaf area (Cornelissen, 1999; Hodgson et al. 2017) are thought to be biologically constrained, the relationship of these two traits with seed mass are expected to be consistent across the habitats.

Table 1: Association of seed mass, leaf mass per area (LMA) and wood density with level and availability of light and water

	Closed environments		**Open environments**	
	Moist	**Shade**	**Dry**	**High light**
Seed mass	Large seeds	Large seeds	Small and large seeds	Small seeds
LMA	low LMA (eliminated by low light)	High LMA	Low and High LMA	Low LMA
Wood density	High wood density	High wood density	Low and High Wood density	Low wood density

The relationship of seed mass to a leafing phenology parameter – average canopy loss (ACL) was also checked for the entire community as well for the three habitats. Average canopy loss represents the amount of canopy maintained or lost annually (Chakrabarty et al. 2021). Since Chakrabarty et al. 2021 found average canopy loss to be negatively related to leaf mass per area in BWS, the relationship of seed mass with average canopy loss was expected to be opposite to that with leaf mass per area (Table 2).

Table 2: Expected relationship of seed mass with other traits – leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H_{max}), leaf area (LA) and average canopy loss for open, edge and closed habitats of Bhimashankar Wildlife Sanctuary

Trait	Open	Edge	Closed
LMA	Positive		No relationship
LNC	Negative		No relationship
LDMC	Positive		No relationship
WD	Positive	Intermediate	No relationship
H_{max}	Positive		Positive
LA	Triangular		Triangular
ACL	Negative		No relationship

Materials and Methods

Study area:

The study was based on woody plant species of, Bhimashankar Wildlife Sanctuary (BWS) a seasonally dry tropical forest in Northern Western Ghats mountain range of peninsular India (19.0837° N, 73.5549° E). It is located at an elevation of about 900 m above mean sea level (850-1050 m). The mean annual precipitation experienced by BWS is 2266 mm, most of the rainfall is concentrated from the month of June to the month of October. July is the month of peak rainfall, with an average precipitation of around 880 mm of rainfall. The months from November to May are the months of dry season, rainfall can go to less than 100 mm per month. Average temperature in the site ranges from 36˚C in May to 7˚C in December. Three distinct habitats namely, open, edge (intermediate) and closed can be distinguished in the western part of BWS (Jezeera, AM. 2016; Chakrabarty, S. 2021). The open and closed habitats represent the two extremes in the community (Figure 3). Open habitat had high light intensity; 30%-70% tree cover, low water availability and short statured trees (2-5 m). Closed habitat had low light intensity, high tree cover (90- 100%), high water availability and tall statured trees (10-30m). The edge habitat was in between the open and closed habitat in terms of its characteristics. Edge habitat has around 70% tree cover, intermediate light intensity and water availability and medium statured trees (5-20m). Hence, this community was selected as study system as it suits to address the question studying the variation of plant functional traits in a gradient of light and water.

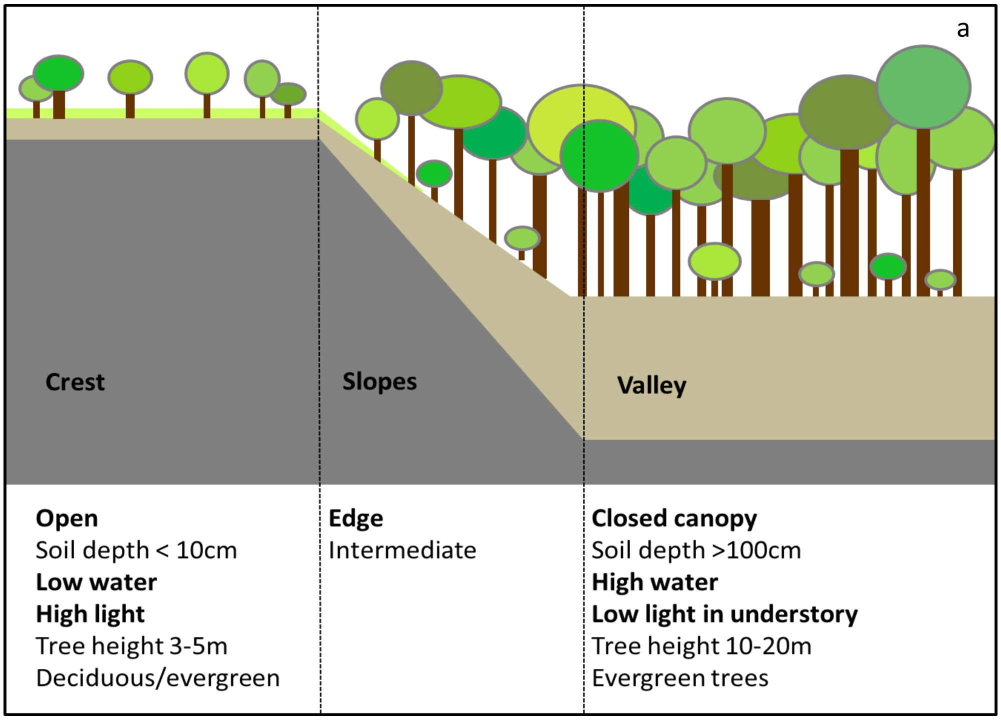

Figure 3: Schematic representation of the three habitats showing differences in soil depth, relative status of soil water, light and canopy (reproduced from Chakrabarty, S. 2021).

Species were sampled for leaf functional traits, by Asmi Jezeera. by laying nine, 20m x 20m plots in each habitat. The open habitat shows significant difference from edge and closed habitat in terms of relative light intensity and soil moisture content, but the edge and closed do not show statistically significant difference (Jezeera, AM. 2016). However, the light intensity is very heterogeneous in the open and edge habitats as compared to closed (Jezeera, AM. 2016).

Literature survey to understand the relationship of seed size with other functional traits: In order to understand the relationship of seed mass with the other plant functional traits, a literature survey was conducted in google scholar using key words “seed mass” OR “seed size” AND “tree”, paired with each of the key words “specific leaf area”, “leaf mass per area”, “leaf nitrogen”, “maximum height”, “wood density” and “leaf area” with the Boolean AND. All the searches were repeated by replacing tree with woody species. This was followed by looking for studies in the references of big global studies on trait relationship. Specific leaf area is the inverse of leaf mass per area, so wherever relationships were with specific leaf area the results were reported opposite in order to compile with the studies that have studied the relationship of seed size with leaf mass per area.

The result of the literature survey was assorted by biome types, where the studies were carried out and whether the studies had trait relationships as their primary objective or not. Studies were classified as global, tropical, subtropical, temperate, Mediterranean and desert. For the tropical biome the studies were subdivided into – dry tropics, seasonally dry tropics and wet tropics. For the studies which did not have understanding trait relationship as their primary objective, some of them presented it as ancillary result, others had the data but did not present the results. The ones which had data but did not test for relationships, the data was extracted and the relationship of available traits with seed size was tested.

Collection and measurement of seed mass:

For estimation of species level seed mass, it was aimed to collect around six individuals of every species, this is based as per the recommendations of Perez-Harguindeguy et al. 2016. Depending on availability and accessibility the number of individuals collected varied. Owing to difficulties in acquiring permits from protected areas, the collections were carried out from unprotected sites having comparable species composition to that of BWS, identified with the help of an expert. The collections were done from Ecogrid (18.5293° N, 73.4408° E), Plus valley (18.4772° N, 73.4085° E), Tahmini Ghat (18.4759° N, 73.4592° E), Mulshi (18.5307° N, 73.5112° E) Andharban (18.5092° N, 73.4265° E) and Vile (19.0968° N, 72.8517° E). A calendar for collection of seeds was prepared according to end fruiting season phenology data from Chakrabarty, S. 2020 and with consultation with an expert. Seed collection trips were scheduled accordingly. Fruits or seeds were collected from the ground or tree depending on availability. Number of seeds or fruits collected from every individual ranged from 50 - 100.

The collected seeds were air dried before measurement. In case where fruits were collected they were depulped and seeds were extracted, cleaned and air dried. Different depulping methods were employed for different fruits. For instance, for *Zizyphus rugosa* and *Elaegnus conferta* the fruits were soaked in water and then depulped. *Aglaia lawii* was depulped fresh without soaking in water, others like *Dysoxylum binectariferum* and *Casearia tomentosa* were depulped after air drying the fruits. For species like *Terminalia tomentosa* where the seed is practically inseparable from the fruit, the fruit mass was used for seed mass, and for winged species like *Ventilago bombaiensis* and *Lagerstroemia microcarpa*, first the wings were removed and then seed mass measured (Perez-Harguindeguy et al. 2016).

Seed mass was measured using a fine balance, of smallest standard displayed division of 0.1mg. The number of seeds of an individual of a species to be measured at a time was decided depending on seed size, in order to avoid measurement error. For instance, for bigger seeds like *Terminalia bellirica*, 5 seeds were measured at a time, likewise for *Mallotus philippensis* 50, and for *Callicarpa tomentosa* a 100 seeds were measured at a time. The seed mass data measured was supplemented by primary seed mass data from Brihaspati Kumar Gaurav and Souparna Chakrabarty. For species in which the number of individuals required for a species was less, it was supplemented with secondary data extracted from databases and primary literature.

The variance in all seed mass data for every species was evaluated using box plots and jitter plots, and outliers were identified. The reason behind the outliers were investigated, if they were because of measurement errors the measurement was repeated. Outliers from secondary data were mostly found due to different methods used for measurement, for example if the seeds were oven dried or fresh seeds were measured. In cases of secondary data where individual level seed mass data was not provided, the species level average was multiplied by the number of individuals, the product was added to primary seed mass data from individuals and the sum was divided by the grand total. For ten species no primary seed mass data could be found hence secondary data was used. For *Celtis tiomrensis* a genus level average was used, determined from secondary seed mass data of other species of the genera. Secondary seed mass of *Piper nigrum* was used for *Piper trichostachyon,* since the two species are phylogenetically related and have similar sized seeds. Even secondary seed mass data could not be acquired for *Dimorphocalyx glabellus var. lawianus, Pavetta indica* and *Strobilanthes callosa,* for these species seed mass was estimated from seed length using a type II regression equation between seed length and seed mass. In total species level seed mass for 74 species of BWS was estimated.

Collection and measurement of wood density:

In order to get an estimate of species level wood density, wood from 5 – 6, individuals of each species were collected, this is based on recommendations of functional trait hand book of Perez – Harguindeguy et al. 2016. For rare species lesser number of individuals were used to estimate wood density owing to difficulty of finding individuals. Due to difficulties in acquiring permits for collection of wood core and for collection from protected areas, branches of species (Perez-Hargundeguy et al. 2016) were collected from unprotected sites having comparable species composition to that of BWS. These sites were identified with the help of an expert. The collections were done from, Plus valley (18.4772° N, 73.4085° E), Mulshi (18.5307° N, 73.5112° E) Andharban (18.5092° N, 73.4265° E) and Rajmachi (17.3197° N, 74.2348° E). Branches of diameter 1 – 2 cm were collected, (Perez-Hargundeguy et al. 2016) around 3 – 4 sections from every individual.

Volume of the branches were determined using both water displacement method and from dimensions. Volume determined from both methods showed strong correlation and since water displacement method is a more accurate way for measuring volume, it was used for calculation of wood density. The woods were oven dried at 75°C for 12 – 14 hours for 5 days, and then measured for mass. Volume from water displacement method and oven dry mass was used for calculating wood density for every branch section, an individual level branch wood density was estimated from this. The branch wood density was multiplied by 1.411 in order to estimate main stem wood density (Perez-Hargundeguy et al. 2016). The wood density data measured was compiled with primary woody density data collected by Ron Sunny. Species level wood density was estimated from the individual level estimates. In total primary wood density data for 62 species were estimated, this was supplemented by secondary data for 11 more species.

Compilation and curation of other functional trait data:

For other functional traits measurements already done in the lab was used. For leaf mass per area (LMA), leaf dry matter content (LDMC), and leaf area, data from Asmi Jezeera, Neha Mohababu and Souparna Chakrabarty were used. Leaf nitrogen concentration (LNC) measurements for 56 species from Neha Mohanbabu were used. Since, LMA and LNC have a strong correlation, LNC for 15 species were estimated using a type II regression model developed. LNC for 4 species were extracted from Borges et al. 1998. All the data sheets with leaf level measures of leaf fresh mass, dry mass, leaf area and leaf nitrogen were compiled and first individual and then species level trait values were estimated. Maximum plant heights data as measured by Asmi Jezeera and Souparna Chakrabarty were used. Average canopy loss (ACL) as estimated for species by Souparna Chakrabarty was used.

Estimation of relative dominance:

Relative dominance of the species in the three habitats were estimated from basal areas of individuals calculated by Asmi Jezeera using girth at breast height, from nine 20 x 20m plots in each habitat in BWS. The total basal area of a species from the plots were scaled up to basal area of the species for the entire habitat, for all three habitats. The whole habitat basal area of every species was summed up to get an estimate of total basal area of the species for whole BWS. The total basal area of all species from the plots were also scaled up to for the entire habitat, for the three habitats. The total basal area from each habitat was then summed up to get an estimate of the total basal area of BWS. Basal area of a species for BWS was divided by total basal area of BWS to get an estimate for the relative dominance of the species in BWS (Appendix 1). The data for the area of the three habitats were gotten from Souparna Chakrabarty.

Understanding the range of seed mass in Bhimashankar wild life sanctuary:

In order to understand the woody species seed mass range of BWS in the context of global and tropical woody species seed mass range, seed mass data for woody species was extracted from Diaz et al. 2016, which is a global data set vascular plant functional traits. No data set for seed mass of all tropical woody species was found, hence seed mass data from different studies from tropics were compared to get an estimate of range of seed mass for tropical woody species. The range of seed mass for tropical woody species was the same as the global range, hence the seed mass range of BWS was compared to that of the global seed mass range.

Data analysis:

All trait data were checked for normality using Shapiro – Wilk test. The traits that were found to be non-normal were log transformed, and again tested for normality, if found still non normal increase in fit for normality was evaluated (Appendix 2).

The community weighted mean (CWM) trait values were calculated by, $\Sigma i^n p_i x_i$, p_i is the relative dominance of the species and x_i is the species level mean trait value for species i. One-way Anova (Analysis of variance) was done to check if the CWM seed mass differs between the three habitat types. CWM values of seed mass were then compared pairwise between all three habitats using Tukey post – hoc test.

In order to understand the relationship of seed mass with other functional traits, Pearson's correlation test was performed. In order to understand community weighted trait relationships, a weighted Pearson's correlation test was performed, with the relative dominance of species as weights using wCorr package (Sikali et al. 2023). A weighted correlation uses a weighted mean and weighted covariance to calculate the correlation coefficient. A standardized major axis regression (SMA) line was fit to the scatter in order to understand the trend using smatr package (Warton et al. 2018). SMA regression is suitable when the dependent and independent variables cannot be determined.

Principal component analysis (PCA) was performed with all eight the traits in order to understand the entire trait space of BWS. To understand the position of seed mass in the trait space for the three habitats, a PCA was performed with all eight traits taking into account the overlap of species using package ggplot2. Hence, every species x habitat combination was an observation. The three habitats were demarcated using 95% confidence interval ellipses. All analysis was done in R version 4.2.1 (R Core Team, 2022).

Results

Literature survey to understand the relationship of seed size with other functional traits: The literature survey found a total of 44 studies in which 6 of them are global studies. Among these 33 studies have directly examined the relationship of seed mass with SLA or LMA and leaf nitrogen, of which 15 studies had understanding this trait relationship as a primary objective. Eleven studies had trait data but didn't report trait relationships. Of these 18 studies found a positive relationship of seed mass with LMA, and 22 had no evidence or a relationship and 2 found positive relationship. Fifteen studies as per expectations found no evidence for relationship of seed mass with leaf nitrogen, while 3 studies found a negative relationship (Figure 4A). This shows that seed mass and leaf nitrogen might be independent of each other.

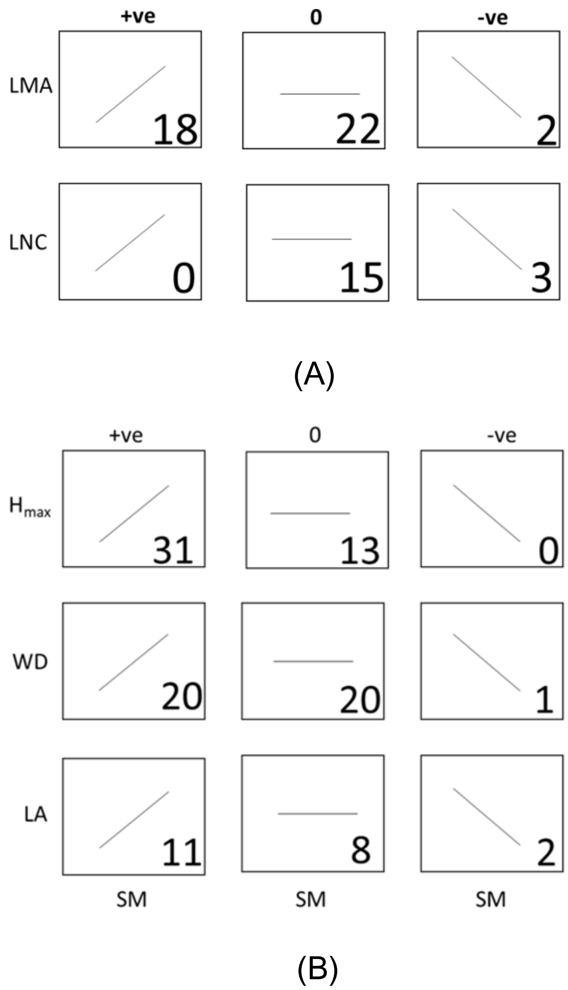

Figure 4: Summary of literature survey for the relationship of seed mass (SM) with (A) leaf economics spectrum (LES) traits – leaf mass per area (LMA) and leaf nitrogen (LNC), and (B) other maximum attainable height (H_{max}), wood density (WD) and leaf area(LA), numbers in parenthesis in lower right corner of each box represents the number of studies that had that relationship.

Table 3: Summary of literature survey with number of studies that found negative (N), no (0) or positive relationship of seed mass with leaf mass per area (LMA) and leaf nitrogen concentration (LNC), leaf dry matter content (LDMC) maximum attainable height (H_{max}), wood density (WD) and leaf area(LA). Studies are assorted biome types.

Biome		LMA	LNC	LDMC	WD	H_{max}	LA
Global	N						
	0	6	4		5	2	1
	P				1	3	1
Tropical	N				1		
	0	10	2		9	7	5
	P	11	4	1	12	12	4
Subtropical	N		1	1			2
	0	2			1	1	
	P	1			1	2	
Temperate	N	1					
	0	6	6	1	7	4	3
	P			2	1	8	3
Mediterranean	N						
	0	1	1	2		2	2
	P	1			1		
Desert	N						
	0						
	P	1				1	

Literature search for the relationship of seed mass with wood density, leaf area and maximum attainable height found, 31 and 11 studies found a positive relationship of maximum attainable height and leaf area with seed mass respectively, 13 and 8 studies found no evidence for relationship of seed mass with maximum attainable height and leaf area respectively. Two study found negative relationship between seed mass and leaf area. For wood density 20 studies found positive, 20 found no evidence and 1 found a negative relationship with seed mass (Figure 5B). In total, '68' studies, for seed mass and other functional trait relationships, with direct and indirect results were evaluated. A lot of variation in relationship of seed size with other functional traits were from the studies in the tropics (Table 3).

Because of global trends the variations in functional trait relationships of seed size are often ignored. LMA, plant height, wood density and leaf area can have no to positive relationship with seed size.

Range of seed mass in Bhimashankar wildlife sanctuary and variation in community weighted mean (CWM) seed mass across habitats:

Figure 5, represents the range of seed mass in BWS in the context of global range of seed sizes. The range of woody species seed mass for the tropics was same as that of the global range. *Woodfordia fruticose* and *Mangifera indica* had the lowest and highest seed mass respectively in BWS.

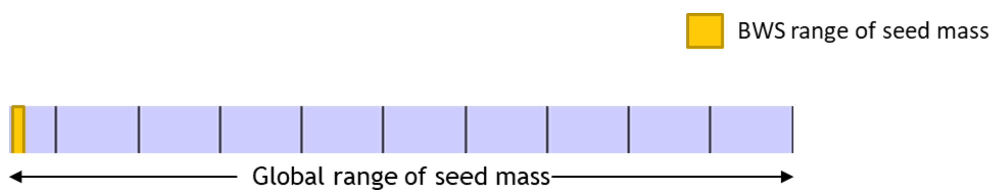

Figure 5: Range of woody species seed mass in Bhimashankar wildlife sanctuary in the context of global range of woody species seed mass seed mass

CWM seed mass, weighted by relative dominance did not show significant difference from open to closed habitat ($F=2.603$, $p>0.05$) (Appendix 3). Hence, contrary to hypothesis community weighted mean seed mass remains same across the three habitats, despite increasing shade (Figure 6).

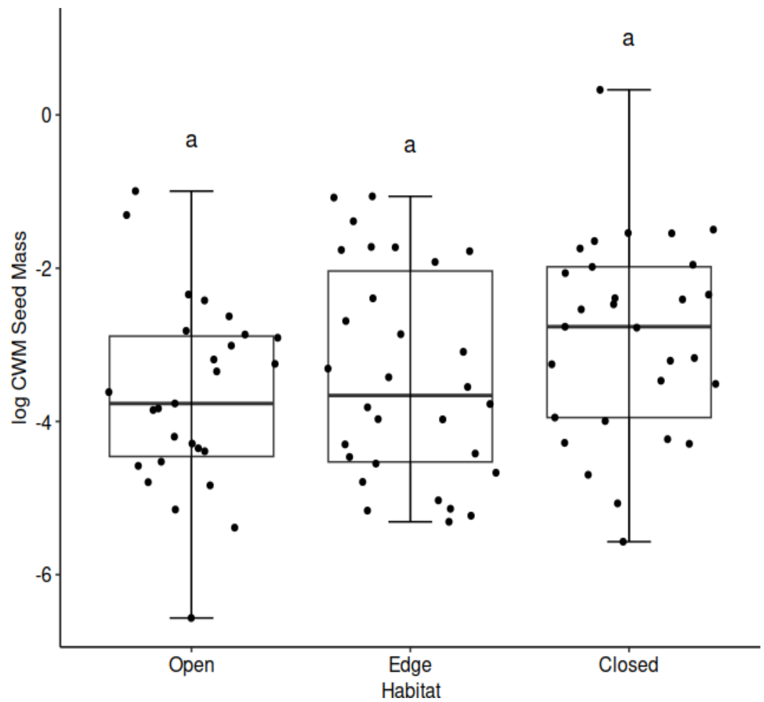

Figure 6: Box plots and strip charts representing distribution of relative dominance weighted seed mass values for the three habitats of Bhimashankar wildlife sanctuary (BWS). Horizontal line inside each box represents median relative dominance weighted seed mass, the lower and the upper edges of the boxes represent 25th and 75th percentiles of the distribution respectively. Similar letter indicates community weighted mean (CWM) seed mass does not show significant difference at $p < 0.05$ (Tukey's post-hoc test), across the three habitats.

Relationship of seed mass with other functional traits and average canopy loss in Bhimashanker wildlife sanctuary, for the entire community and across the three habitats:

The relationship of seed mass with other functional traits for the entire community of BWS was evaluated using Pearson's correlation test. As per the expectations of the study seed mass was found to be positively related to leaf mass per area, LMA (r=0.31, p< 0.05), wood density (r=0.36, p<0.05) and maximum attainable height (r=0.33, p<0.05). Seed mass was found negatively related to ACL (r=0.40, p<0.05), in accordance with expectations. Contrary to expectations seed mass was unrelated to other LES traits, leaf dry matter content (LDMC) and leaf nitrogen concentration (LNC).

Seed mass was also unrelated to leaf area. Contrary to expectations the weighted Pearson's correlation test for BWS species, weighted by relative dominance found seed mass to be related to leaf area (r=0.39, p<0.05), and unrelated to LMA and, wood density and ACL. In accordance to expectations of the study but in contrast to the unweighted correlation test, seed mass was related to leaf nitrogen concentration (LNC) (r=-0.26, p<0.05) and leaf dry matter content (LDMC) (r=0.43, p<0.05) (Figure 7).

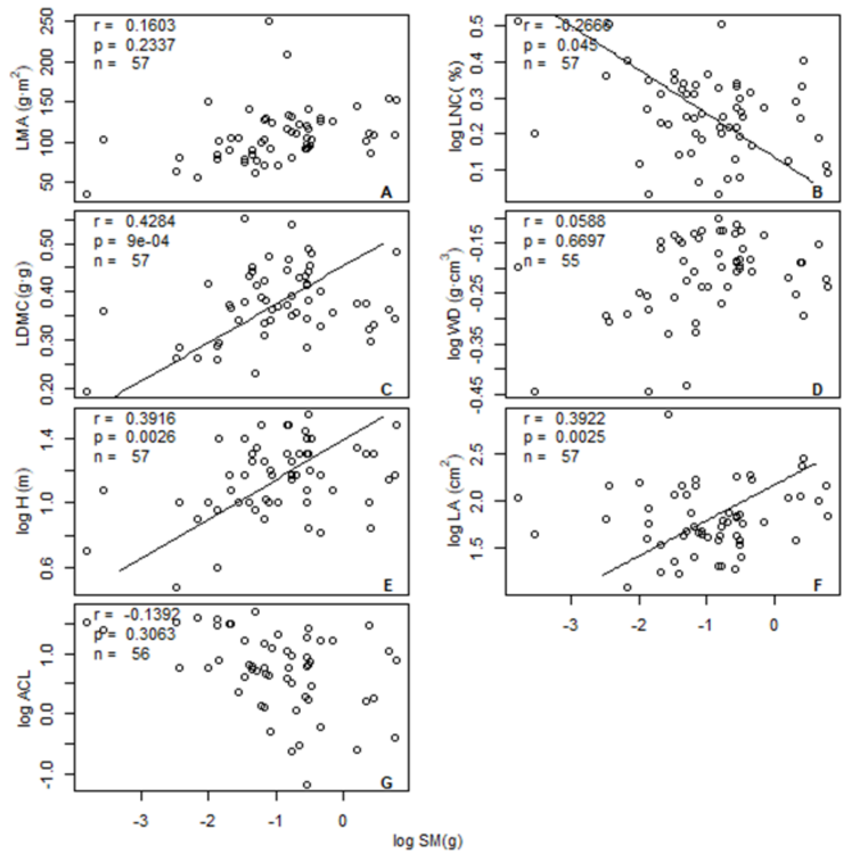

Figure 7: Relationship of seed size with other traits at Bhimashankar Wildlife Sancturary, weighted by relative dominance of species. Relationship of seed mass (SM) with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) in woody species from Bhimashanker wildlife sanctuary. Each point is the representative mean trait value for an individual species. The fitted line is a standardized major axis regression (SMA) line. In every panel the weighted correlation coefficients (r) and P – values (p) are reported.

This was followed by evaluation of the relationship of seed mass with other functional traits for the three habitats – open, edge and closed present in BWS. First the presence of trait relationships was tested using Pearson's correlation, then by weighted Pearson's correlation test, in which the species mean trait values and covariance's were weighted by the relative dominance of the species in the habitat. Table 4 and 5 summarizes the results of unweighted and weighted and Pearson's correlation tests for the relationships of seed mass with other functional traits in the three habitat types respectively. Pearson's correlation test revealed, for the open habitat seed mass was significantly related to LMA ($r=0.31$, $p<0.05$), LNC ($r=-0.43$, $p<0.05$), LDMC ($r=0.46$, $p<0.05$), and maximum plant height ($r=0.47$, $p<0.05$). Contrary to expectations seed mass was unrelated to wood density and ACL. In the edge habitat seed mass was related to LMA ($r=0.50$, $p<0.05$), LDMC ($r=0.50$, $p<0.05$), wood density ($r=0.44$, $p<0.05$), height ($r=0.54$, $p<0.05$) and ACL ($r=-0.37$, $p<0.05$). Seed mass was unrelated to LNC as expected. Seed mass was unrelated to leaf area in both open and edge habitats. Going against expectations in the closed habitat seed mass related to LMA ($r=0.47$, $p<0.05$) and ACL ($r=-0.42$, $p<0.05$) and unrelated to maximum plant height. It was unrelated to all other functional traits in the closed habitat.

Table 4: Summary of relationship of seed mass with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H_{max}), and leaf area (LA) for woody plant species in Bhimashankar wildlife sanctuary and the three habitat types (Open, Edge and Closed) there. Columns with habitat name gives the Pearson's correlation coefficient (r). Significant results are in bold.

Trait	BWS	Open	Edge	Closed
LMA	**0.31**	**0.49**	**0.50**	**0.47**
LNC	-0.19	**-0.43**	-0.30	-0.27
LDMC	0.16	**0.46**	**0.50**	0.32
WD	**0.36**	0.34	**0.44**	0.98
H_{max}	**0.33**	**0.47**	**0.54**	0.33
LA	0.20	0.03	0.06	0.09
ACL	**-0.40**	-0.34	**-0.37**	**-0.42**

Table 5: Summary of weighted relationship of seed mass with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H_{max}), and leaf area (LA) for woody plant species in Bhimashankar Wildlife Sanctuary and the three habitat types (Open, Edge and Closed) there. Columns with habitat name gives the weighted Pearson's correlation coefficient (wt. r), weighted by species relative dominance. Significant results are in bold.

Trait	BWS	Open	Edge	Closed
LMA	0.16	**0.38**	0.20	0.15
LNC	**-0.26**	-0.36	-0.19	-0.31
LDMC	**0.43**	0.29	**0.37**	**0.55**
WD	0.06	0.21	**0.52**	**0.93**
H_{max}	**0.39**	0.29	**0.46**	0.29
LA	**0.39**	**0.60**	0.07	**0.45**
ACL	-0.14	-0.35	-0.33	**-0.49**

Unweighted trait relationships conceal that certain trait syndromes maybe much more abundant in a particular environment, as it weighs every trait combination equally simply on the basis of its presence. When trait relationships are tested using weighted Pearson's correlation, weighted by relative dominance, that gave much more information about what trait syndromes or combinations dominate the community. Seed mass was related to LMA (wt. r=0.38, p<0.5) and leaf area (wt. r=0.60, p<0.5) and unrelated all other traits for the open habitat. (Figure 8). For edge habitat seed mass was related to LDMC (r=0.37, p<0.05), wood density (wt. r=0.52, p<0.5) and maximum plant height (wt. r=0.46, p<0.5), and was unrelated to rest of the functional traits (Figure 9). In the closed habitat seed mass was surprisingly related to LDMC (wt. r=0.55, p<0.5), wood density (wt. r=0.93, p<0.5), leaf area (wt. r=0.45, p<0.5) and ACL (wt. r= -0.49, p<0.5), and surprisingly unrelated to height. As expected for the closed habitat seed mass was unrelated to LMA and LNC (Figure 10). Hence, the relationship of seed mass to other functional traits did not quite follow the expected pattern except for LMA.

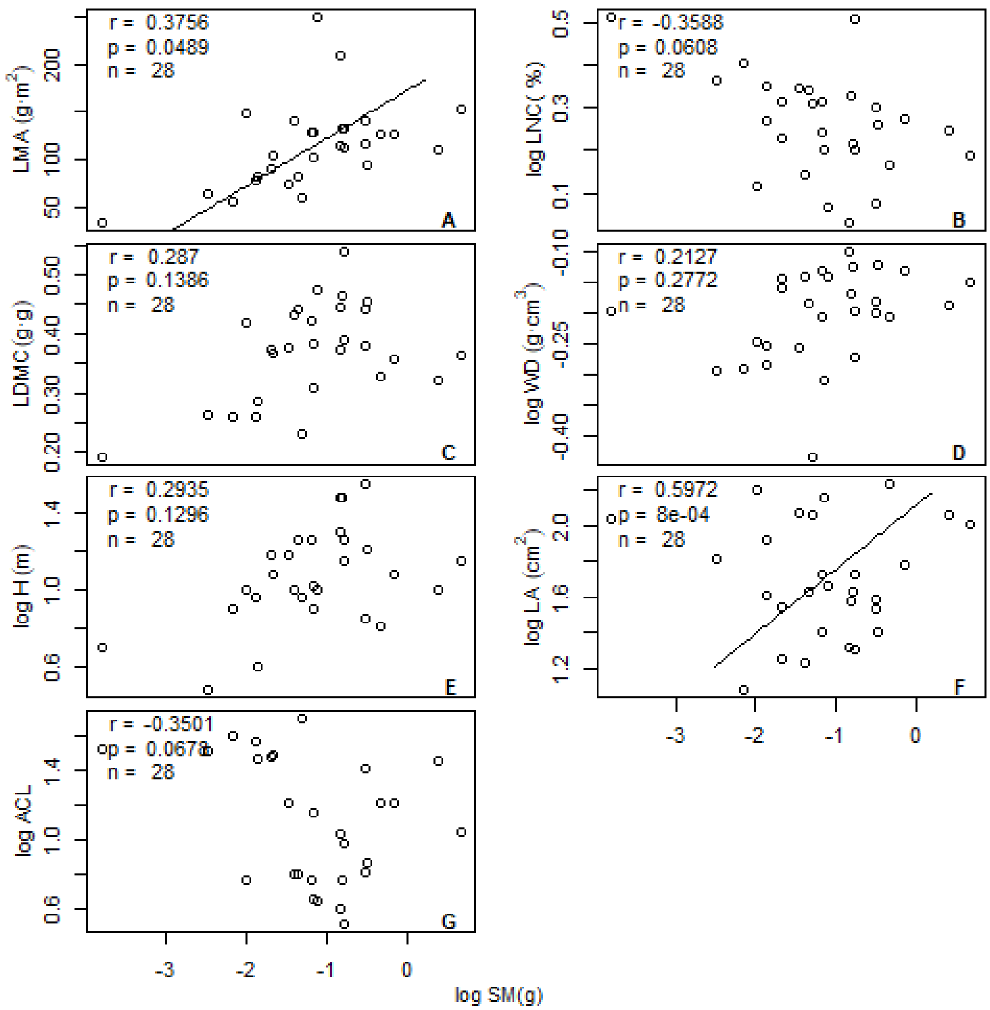

Figure 8: Relationship of seed size with other traits in Open habitat, weighted by relative dominance of species. Relationship of log seed mass (SM) with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) in woody species from open habitat of Bhimashanker wildlife sanctuary. Each point is the representative mean trait value for an individual species. The fitted line is a standardized major axis regression (SMA) line. In every panel the weighted correlation coefficients (r) and P – values (p) are reported.

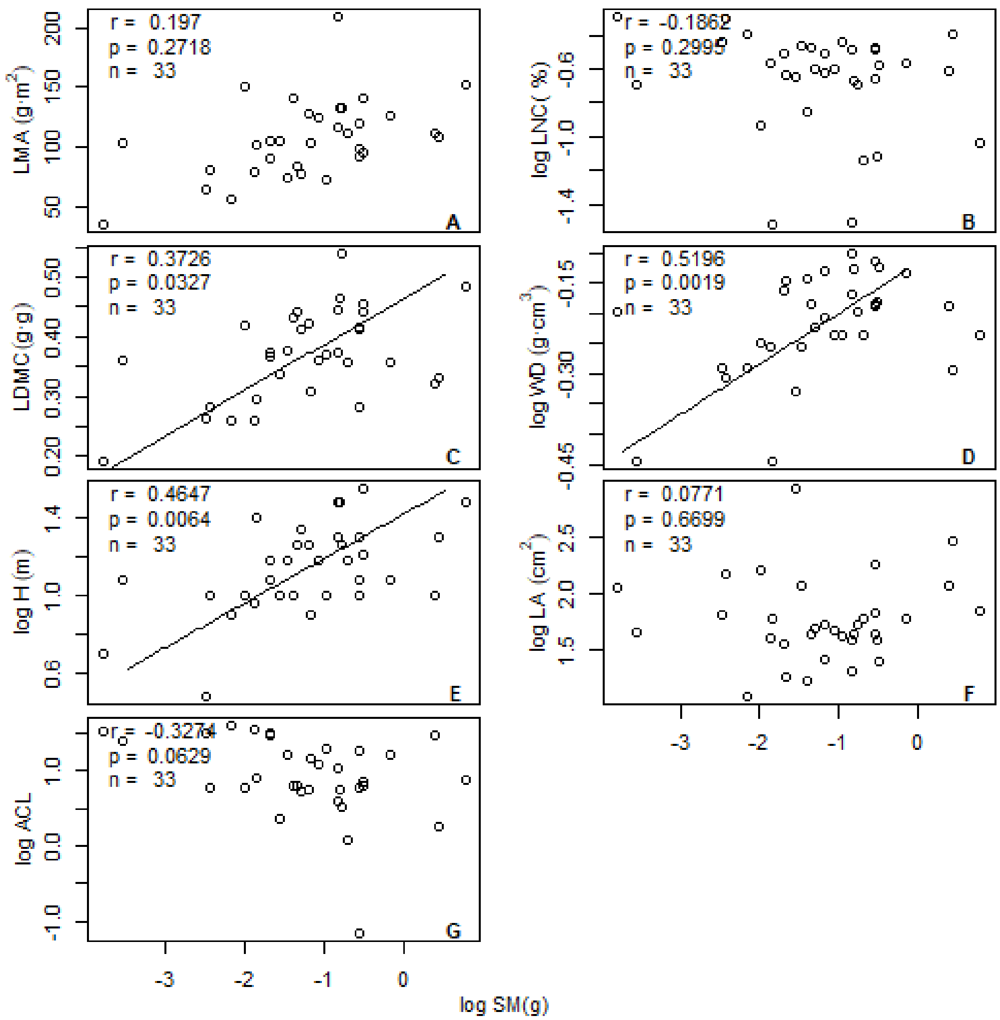

Figure 9: Relationship of seed size with other traits in Edge habitat, weighted by relative dominance of species. Relationship of log seed mass (SM) with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) in woody species from edge habitat of Bhimashanker wildlife sanctuary. Each point is the representative mean trait value for an individual species. The fitted line is a standardized major axis regression (SMA) line. In every panel the weighted correlation coefficients (r) and P – values (p) are reported.

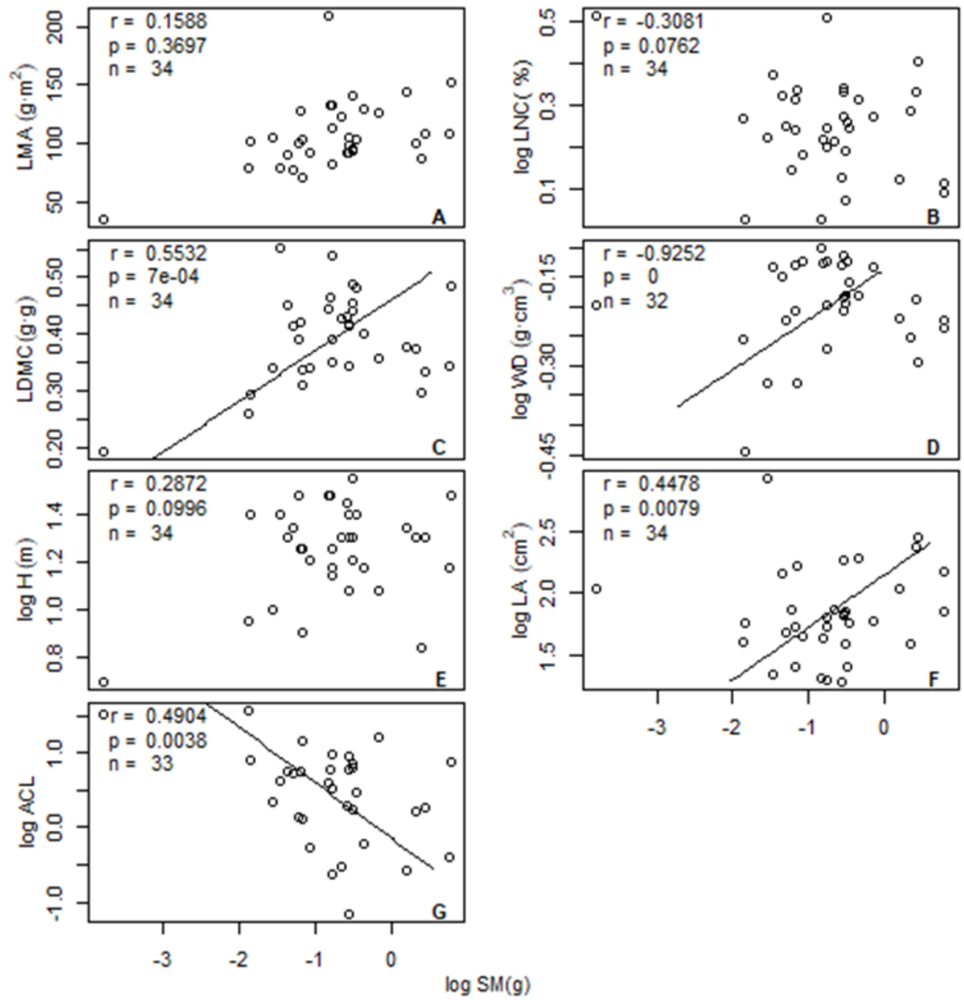

Figure 10: Relationship of seed size with other traits in Closed habitat, weighted by relative dominance of species. Relationship of log seed mass (SM) with leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) in woody species from the closed habitat of Bhimashanker wildlife sanctuary. Each point is the representative mean trait value for an individual species. The fitted line is a standardized major axis regression (SMA) line. In every panel the weighted correlation coefficients (r) and P – values (p) are reported.

Weighted correlation tests can even change the nature of a trait relationship, for instance in the unweighted relationship, relationship of seed mass with LMA do not follow the expected pattern but in the weighted correlation relationship of seed mass with LMA followed the expected pattern. While seed mass was significantly positively related to LMA in edge and closed habitat in the unweighted correlation test, the relationship disappeared in the weighted analysis.

Trait space occupied by the species of Bhimashankar Wildlife Sanctuary and in the three habitats:

Principal component analysis (PCAs) were performed with the functional traits in order to understand the trait space for BWS. First a PCA was done with traits for the entire BWS woody species community, this was followed by a PCA in which the three habitats were demarcated.

In the PCA performed with all traits of BWS (Figure 11), the first three PC axes explained 67.9% of the variation in the eight dimensional trait space (Appendix 4; Figure 1). Hence the PCA biplots with the first three PC axes were used to represent the trait space. PC1 explained 38.1% of the variation LDMC, height, LMA and LNC having the highest loadings on PC1 in that order. Leaf area and seed mass formed P C2 (16.7%). PC3 (13.1%) had highest loadings of LNC, LMA and wood density (Appendix 4; Table 1). Hence, dimension 1 is mostly formed from LES traits and height, whereas dimension 2 is made up of seed size and leaf area.

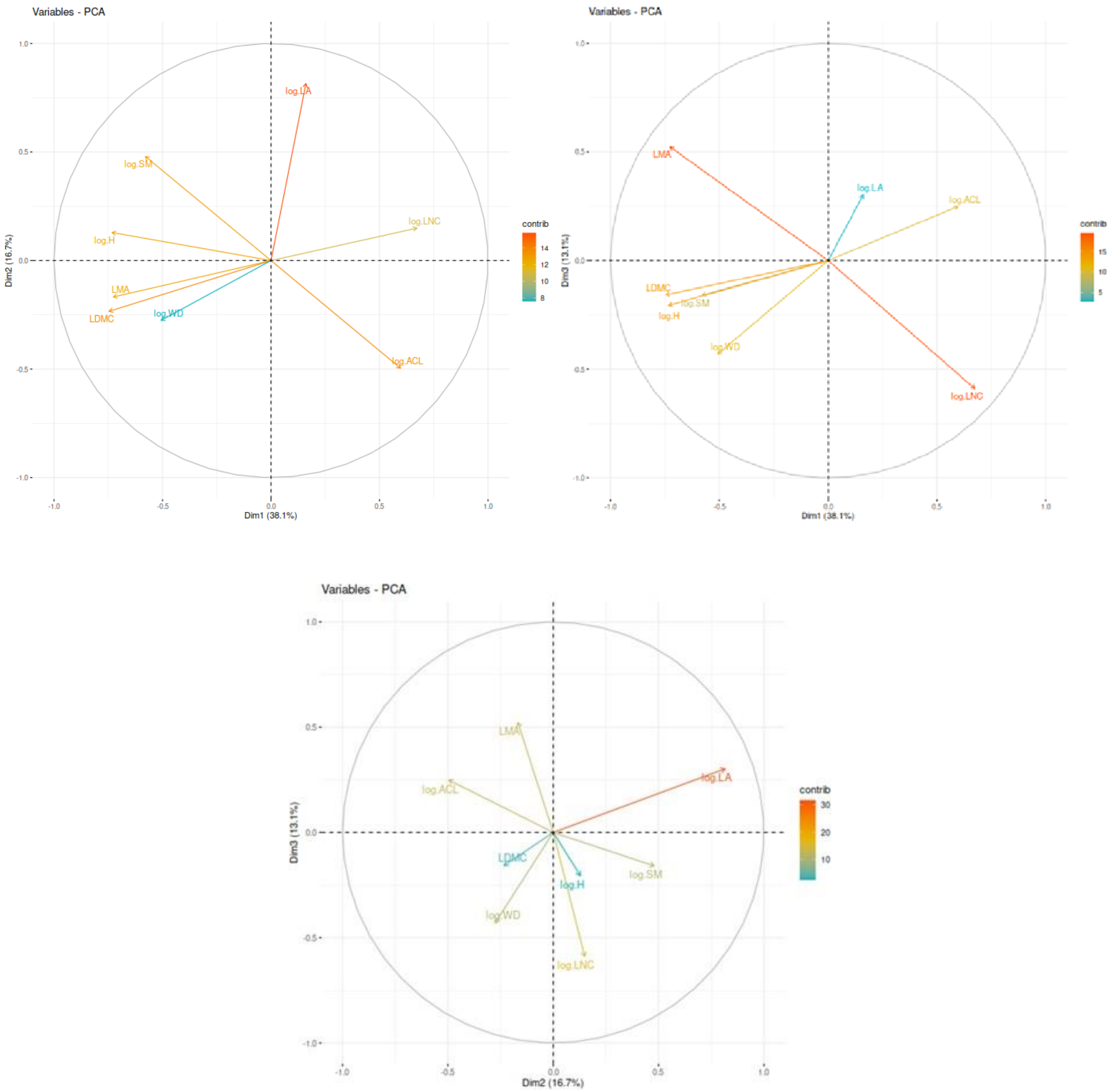

Figure 11: Results for principal component analysis of functional traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL), of woody plants in Bhimashankar wildlife sanctuary a) biplot for components 1 and 2, b) biplot for components 1 and 3, c) biplot for components 2 and 3.

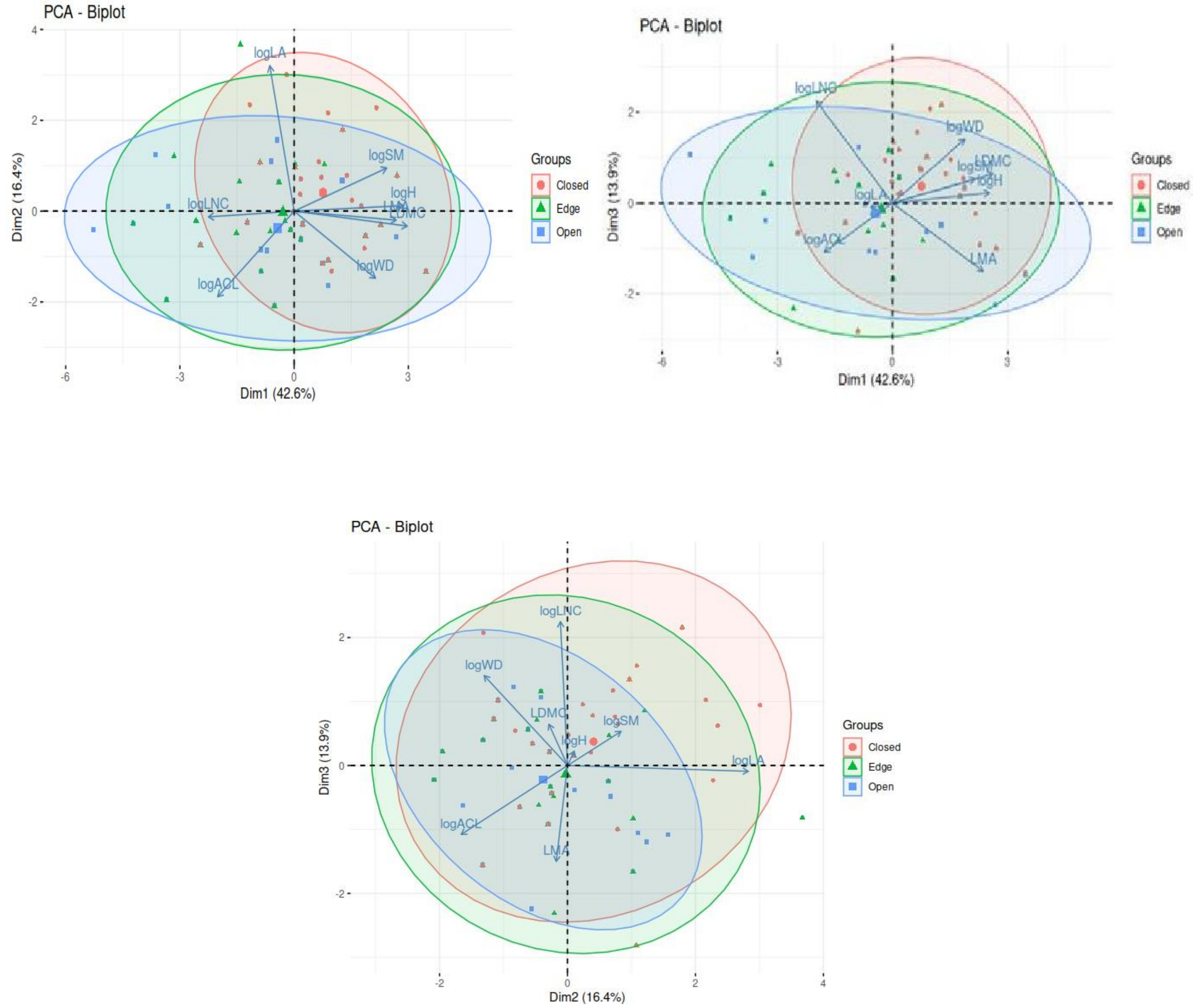

Figure 12: Results for principal component analysis of functional traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL), of woody plants in Bhimashankar wildlife sanctuary with the three habitats demarcated, blue, green and red ellipses represents open, edge and closed habitat respectively. Ellipes represent 95% CI. a) biplot for components 1 and 2, b) biplot for components 2 and 3, c) biplot for components 1 and 3

In the PCA performed with all traits of BWS (Figure 12), the first three PC axes explained 72.9% of the variation in the eight dimensional trait space (Appendix 4; Figure 2, Table 2). Hence the PCA biplots with the first three PC axes were used to represent the trait space. The percentage of variation explained by the PC axes differed from the previous analysis because species instead of species being an observation species x habitat combination was used as an observation, hence species that were not restricted to a particular habitat got counted more than once. PC1 explained 38.1% of the variation LDMC, height, LMA and LNC having the highest loadings on PC1 in that order. Leaf area and seed mass formed PC2 (16.7%). PC3 (13.1%) had highest loadings of LNC, LMA and wood density. Hence, dimension 1 is mostly formed from LES traits and height, whereas dimension 2 is made up of seed size and leaf area. Variation in trait space of the open habitat was mostly captured by PC 1, while PC 2 captured the variation in trait space for the closed habitat.

Discussion

This is one of the first studies to examine whether the trait relationships of seed size vary with environment (light and water). Trait relationships of seed mass were examined in Bhimashankar Wildlife Sanctuary (BWS), a seasonally dry tropical forest and across different habitats in the forest. Seed mass was found to be associated with traits reflecting carbon allocation, leaf dry matter and wood density and with traits of organ size and architecture – height and leaf area, and deciduousness in moist shade habitat and with leaf mass per area (LMA) a chief leaf economic trait and leaf area in dry high light dry habitat. This is also one of the very few studies that tried to understand trait relationships in a community weighted manner. An unweighted trait relationship counts every species equally simply depending on their presence whereas a weighted relationship the relationship is driven by the more dominant or abundant species. Hence, a weighted relationship helps understand what trait combinations or trait syndromes are more successful in a community. A weighted trait relationship also has more implications for community level patterns and processes.

Variation in trait relationships of seed mass across studies:

A survey of the literature found that the relationship of seed mass with other functional traits vary across studies, differing in scale and climate. Contrary to what global studies find, seed mass can be associated with the traits of the leaf economic spectrum (LES) or dissociated from the traits of the size architecture spectrum. Seed mass was found to have either positive or no relationship with LMA, maximum plant height, wood density and leaf area, hence no consensus can be drawn about the relationship of seed mass with these functional traits. However, seed mass was found to be negatively related to leaf nitrogen across most studies. Hence, it is important to enquire the relationship of seed mass with other functional traits across scales and environments.

While most studies from the temperate biome were in consensus with global trait relationships of seed mass which is seed mass is related to height but independent of the leaf economic spectrum, studies from the tropics showed a lot of variation in the relationship of seed mass to other functional traits. Since, tropics have high level of heterogeneity in their light and water environments, light and water might be two resources which affects the relationship of seed mass with other functional traits.

Range of seed mass in Bhimashankar wildlife sanctuary and variation in seed mass across the three habitats:

The range of woody species seed mass in BWS was fairly representative of range of seed mass in most seasonally dry and wet tropical forest woody species seed size range. Contrary to expectations community weighted mean seed mass did not differ across the three habitats in BWS. It was expected that seed mass would increase from the open to the closed habitat with decreasing light availability. In shade the large storage reserves of big seeds help the seedling sustain in light limitation (Kitajima, K 1996) while in the open habitat in absence of shade, plants would capitalize on fecundity producing large number of small seeds. However, in BWS the two environmental filters, drought and shade; that select for bigger seed size, operate in opposite directions. Bigger seeds can confer drought tolerance by producing deeper roots (Hallett et al. 2011) as well as shade tolerance due to greater storage reserve (Kitajima, K 1996; Kitajima, K 2002). While selection for shade tolerance might be selecting for bigger seeds in the closed habitat, but selection for drought tolerance is selecting for bigger seeds in the open habitat. The seed mass is comparable for the edge and closed habitat might be because, the closed and the edge habitats do not differ in their light availability and soil moisture content (Jezeera, AM. 2016). These might be causing the community weighted mean seed mass to be comparable across the three habitats. The open habitat also happens to be very heterogeneous in terms of light and water availability as compared to other habitats (Jezeera, AM. 2016) hence it supports a range of seed masses causing the community weighted mean seed mass to increase.

Relationship of seed mass with other functional traits in Bhimashankar wild life sanctuary for the entire community:

In BWS, seed mass was found to be positively related to LMA, wood density, maximum plant height and deciduousness. When relative dominance of the species was accounted in weighted trait relationship, seed mass was found to be negatively related to leaf nitrogen concentration, and positively related to leaf dry matter, height and leaf area. Thus, height is the only trait to which seed mass was found to be related in both unweighted and weighted analysis of trait relationships. The unweighted trait relationship shows the entire range of trait values and trait syndromes that exists in the community. This in a sense reflects the trait syndromes that can overcome dispersal limitation and reach the community, whereas the community weighted trait relationship reflects what trait syndromes overcame environmental filtering and competitive exclusion and successfully established themselves in the community. The unweighted trait relationships in BWS are probably driven by the trait combinations that exist in the open habitat. Since the open habitat is highly heterogeneous in light and water environment, it harbors a whole range of trait values and syndromes. As even the PCA results show the open habitat has a large variance in the LES traits. Whereas the weighted trait relationships are probably driven by the trait combinations of the closed and the edge habitats since they cover large basal areas and hence are more dominant in the community. The high incongruence between the unweighted and weighted trait relationships for the woody plant community in BWS might also be due to the high heterogeneity of the habitat, in terms of water and light availability, slope and soil depth. While for the unweighted relationship seed mass was related to LMA, for community weighted seed mass was related to leaf nitrogen. This shows LMA and leaf nitrogen though highly related to each other can vary in their relationships to other traits. While LMA is known to be related to a number of plant functions like shade and drought tolerance (Krishnan et al. 2019, Hallet et al. 2011, Lusk and Warton, 2007, O’ Brien et al. 2017), leaf nitrogen reflects the protein content in the tissues, hence more directly related to metabolism (Wright et al. 2001). In the unweighted relationships seed mass’s relationship to deciduousness is probably driven by its relationship in the edge and closed habitats. Since, as can be seen from the trait space the closed habitat harbors a large range of deciduousness.

Relationship of seed mass with other functional traits across the three habitats in Bhimashankar wild life sanctuary:

Seed mass is related to the LES traits (LMA and leaf nitrogen) for the open habitat but is decoupled from the LES traits in the edge and closed habitats. This trend is more apparent in the community weighted relationship of seed mass to LMA across the three habitats. To deal with the low water availability of open habitat, drought avoiding and drought tolerating strategies would co-exist (Givnish 2002, Mendez-Alonzo et al. 2012, Chakrabarty et al. 2021). While the drought avoiding species which are mostly deciduous usually have low LMA and would produce many small seeds to compensate for drought related mortality, the drought tolerating species usually have high LMA (Wright et al. 2005, Markesteijn & Poorter 2009) and produce large seeds which confers drought tolerance (Krishnan et al. 2019, Hallet et al. 2011). Hence, the drought avoiding and drought tolerating strategies couple seed mass (the regeneration spectrum) and LES (the resource acquisition spectrum) in the open habitat.

Relationship of seed mass with leaf dry matter followed the expectations in in the unweighted trait relationship across three habitats. This is probably because the expectations of the studies for these relationships were based on the drought avoiding and drought tolerating strategies coexisting and hence bring the trait axis together in the open habitat. Leaf dry matter has been associated with drought tolerance (Wright et al. 2006, Krishnan). No trend was found in the unweighted relationship of seed mass with wood density across the habitats. The community weighted trait relationships of seed mass with both leaf dry matter and wood density showed the opposite trend in the weighted trait relationship. The positive relationship of seed mass with leaf dry matter and wood density in these habitats might be driven by shade tolerance in the edge and closed habitats, which do not differ in their light availability (Jezeera, AM. 2016). Higher seed mass (Baraloto et al. 2007, Kitajima K., 2002, Poorter and Rose, 2005, Modrzynski et al. 2015), leaf dry matter (Westbrook et al. 2011, Wang et al. 2022) and wood density (Wright et al. 2010, Ruger et al. 2012) all have been found to confer higher shade tolerance. A lot of large seeded species in closed habitat also had large leaves, this would also cause large seeded species to have higher leaf dry matter. Since, large leaves will have proportionately higher leaf dry mass for structural support.

For the entire community of BWS as well as in the edge and closed, seed mass was related to height as was expected, since seed mass has been found to be positively related to height across studies and the two traits might be biologically related (Wright et al. 2007, Diaz et al, 2016). This association of seed mass with height in shade moist habitat, might again be further strengthened by shade tolerance. Since plants in shade will have longer juvenile period due to slower growth rate and taller heights would help them compete better for light (Wright et al. 2007, Wright et al. 2010), and bigger seeds would give higher shade tolerance. In the open habitat where plants do not need to compete for light achieving reproductive maturity faster might be more evolutionarily beneficial for the plant.

In the community weighted trait relationship seed mass was found to be positively related to leaf area in open and closed habitats, the two extremes in light and moisture availability. This might be because the open and closed habitats are dominated by small seeds, small leaves and big seeds, big leaves species respectively. Small leaf area would help lower evaporative water loss in the dry environments, while bigger leaves would help capture more light in environments with low light availability (Wright *et al*., 2005).

Seed mass was found to be mostly negatively related to deciduousness in the BWS woody plant community, hence in this community a deciduousness – reproductive effort axis might be existing as has been found in other dry tropical forests (Lohbeck et al. 2015). Species with more canopy loss that is higher deciduousness producing many small seeds and species with less canopy loss that is low deciduousness producing few bigger seeds.

The functional trait space and position of seed mass in it in, Bhimashankar Wildlife Sanctuary:

In the functional trait space in BWS, the LES traits were found to be associated with seed mass. The LES traits were also associated with height, hence in BWS unlike the global spectrum of plant form and function (Diaz et al. 2016), the LES and size architecture are associated. The two major axis that captured the variation in trait space of BWS are – an LES, seed, height axis and leaf area forming another axis. The open habitat occupied a lot of lot of the trait space of BWS, along the major axis of variance of the trait space. This might be due to the high light and water heterogeneity of the open habitat supporting a wide range of trait syndromes. The edge habitat occupied lesser of the trait space than the open, and the closed occupied the least. The smaller trait space of closed habitat reflects its homogeneous shade and moisture environment and hence only support trait syndromes that are adapted to such environment. Hence, the level of heterogeneity of a habitat, is associated with the expanse of trait space that species of the particular habitat occupies.

The relationships of seed size with other functional traits in the open (dry and well- lit) habitat are driven by strategies to deal with drought stress – drought avoidance and drought tolerance, while in the closed habitat shade tolerance drives the trait relationships of seed size. Hence, in this seasonally dry tropical forest the trait relationships of seed size in different habitats are driven by the major limiting resource in the particular habitat. This study in a sense addresses one of the major question of when drought versus shade acts as the major environmental filter for the formation of species associations (Poorter et al. 2021). The results of this study also points that with forest fragmentation which would increase habitat heterogeneity seed size and leaf mass per area can get associated, and shade adapted syndromes of large seeds, high leaf dry mass and denser wood will find it difficult to survive.

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Appendix 1: Relative dominance of species in Bhimashankar wildlife sanctuary (BWS) and the three habitats

Species name	Relative dominance			
	BWS	OPEN	EDGE	CLOSED
Actinodaphne angustifolia	0.0591	0.0055	0.0923	0.0024
Aglaia lawii	0.0059		0.0017	0.0196
Allophyllus cobbe	0.0012	0.0002	0.0019	
Ancistrocladus heyneanus	0.0006			0.0023
Atalantia racemosa	0.0051	0.0026	0.0050	0.0067
Bridelia retusa	0.0033		0.0052	
Caesalpinia cucullata	0.0002			0.0009
Callicarpa tomentosa	0.0015		0.0024	
Careya arborea	0.0024	0.0197		
Carissa carandas	0.0019	0.0150	0.0001	
Casearia tomentosa	0.0002	0.0013		
Cassine glauca	0.0009			0.0036
Catunaregam Spinosa	0.0381	0.2563	0.0100	
Colebrookea oppositifolia	0.0007	0.0056	0.0000	0.0001
Dimorphocalyx glabellus var. lawianus	0.0097			0.0389
Diospyros montana	0.0231	0.0125	0.0344	
Diospyros sylvatica	0.0031			0.0124
Diploclisia glaucescens	0.0021		0.0031	0.0006
Dysoxylum binectariferum	0.0000		0.0001	0.0080
Dysoxylum gotadhora	0.0021			0.0083
Elaeagnus conferta	0.0002	0.0007		0.0004
Embelia basaal	0.0006	0.0030	0.0004	0.0006
Embelia ribes	0.0014		0.0021	0.0003
Ficus racemosa	0.0204		0.0326	
Flacourtia indica	0.0022	0.0021	0.0030	
Garcinia talbotii	0.0006			0.0023

Glochidion hohenackeri	0.0026	0.0008	0.0040	
Gnetum ula	0.0012			0.0048
Gnidia glauca	0.0053	0.0372	0.0010	
Heynea trijuga	0.0204		0.0010	0.0818
Jasminum malabaricum	0.0026	0.0211		
Leea indica	0.0006		0.0009	0.0001
Lepisanthes tetraphylla	0.0015			0.0059
Litsea josephi	0.0053			0.0210
Macaranga peltata	0.0003	0.0025		
Mallotus philippensis	0.0167	0.0024	0.0262	
Mangifera indica	0.1263		0.0367	0.4141
Maytenus rothiana	0.0014	0.0050	0.0012	0.0002
Memecylon umbellatum	0.2116	0.4338	0.1856	0.1664
Meyna spinosa	0.0039		0.0062	
Myristica dactyloides	0.0007			0.0028
Olea dioica	0.1124	0.0024	0.1463	0.0818
Oxyceros rugulosus	0.0050			0.0201
Pavetta indica	0.0017	0.0094	0.0008	
Premna coriacea	0.0001			0.0005
Psydrax dicoccos	0.0030	0.0242		
Rourea minor	0.0011			0.0045
Smilax ovalifolia	0.0001	0.0012		
Symplocos beddomei	0.0062		0.0100	
Syzygium cumini	0.1937	0.0224	0.3042	0.0013
Syzygium gardneri	0.0299			0.1199
Terminalia bellerica	0.0004	0.0029		
Terminalia chebula	0.0173	0.0142	0.0237	0.0028
Terminalia tomentosa	0.0103	0.0779	0.0011	
Ventilago bombaiensis	0.0008			0.0031
Xantolis tomentosa	0.0397	0.0170	0.0557	0.0111
Ziziphus rugosa	0.0002		0.0003	

Appendix 2: Result of Shapiro-Wilk test of normality on functional traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) of Bhimashankar wildlife sanctuary A p-value < 0.05 rejects the null hypothesis that the data are from a normally distributed population.

Trait	Shapiro-Wilk W	p value	Normality
SM	0.4780	0.0000	Not normal
LMA	0.9131	0.0771	Normal
LNC	0.9694	0.0663	Not normal
LDMC	0.9859	0.5746	Normal
WD	0.9441	0.0028	Not normal
H	0.9466	0.0032	Not normal
LA	0.5352	0.0000	Not normal
ACL	0.8558	0.0000	Not normal

Appendix 3: Anova table for Community Weighted Mean (CWM) of seed mass weighted by relative dominance in the three habitats.

Variables	SS	Degrees of freedom	MS	F	p
Habitat	**2**	**8.82**	**4.408**	**2.603**	**0.0801**
CWM SM	**83**	**140.53**	**1.693**		

Appendix 4:

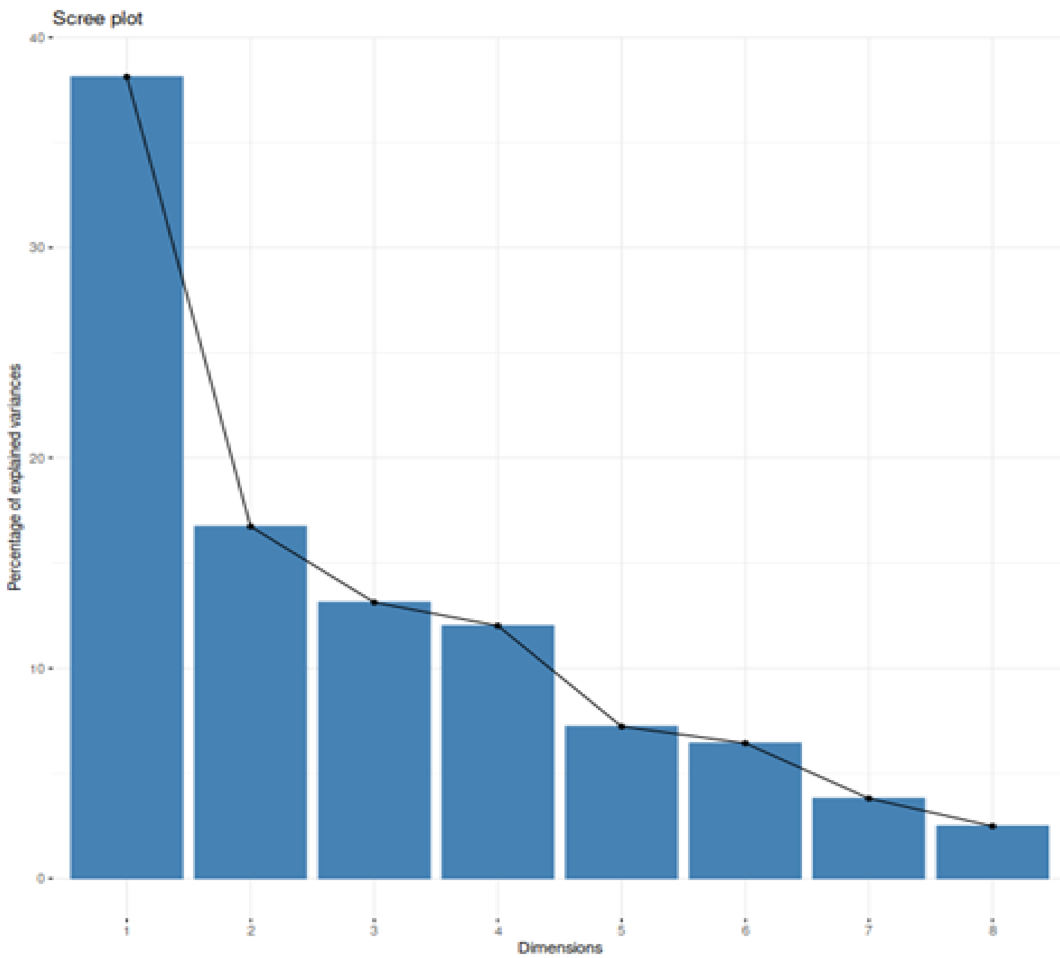

Figure 1: Scree plot for principal component analysis of functional traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL), of woody plants in Bhimashankar wildlife sanctuary

Table 1: PC loadings for PCA with traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) from Bhimashankar Wildlife Sanctuary for the first three PC axes

Traits	Dim.1	Dim.2	Dim.3
log.SM	10.9935	17.1681	2.4085
LMA	17.3170	2.1035	25.9997
log.LNC	14.8394	1.6699	32.9952
LDMC	18.2787	4.0876	2.3673
log.WD	8.4258	5.6709	17.5831
log.H	17.6154	1.2427	4.0312
log.LA	0.8491	49.6870	8.7110
log.ACL	11.6807	18.3700	5.9036

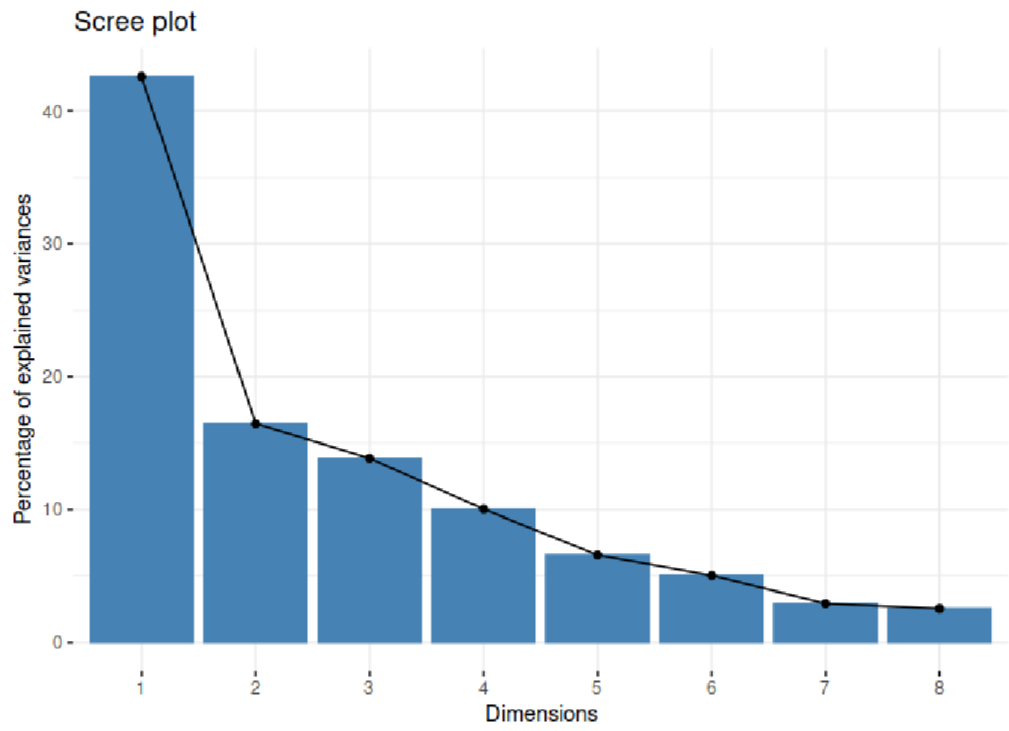

Figure 2: Scree plot for principal component analysis of functional traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL), of woody plants in Bhimashankar wildlife sanctuary with the three habitats demarcated

Table 2: PC loadings for PCA with traits - seed mass (SM), leaf mass per area (LMA), leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), wood density (WD), height (H), leaf area (LA) and average canopy loss (ACL) from Bhimashankar Wildlife Sanctuary, with habitats taken into account for the first three PC axes

Traits	Dim.1	Dim.2	Dim.3
log.SM	13.3751	5.2767	2.5360
LMA	16.2457	0.2337	20.0939
log.LNC	11.4546	0.0933	45.1346
LDMC	19.9412	0.6381	3.7121
log.WD	10.3231	12.7794	17.6214
log.H	18.6145	0.0853	0.4520
log.LA	0.9269	60.0985	0.0743
log.ACL	9.1189	20.7951	10.3757

Appendix 5:

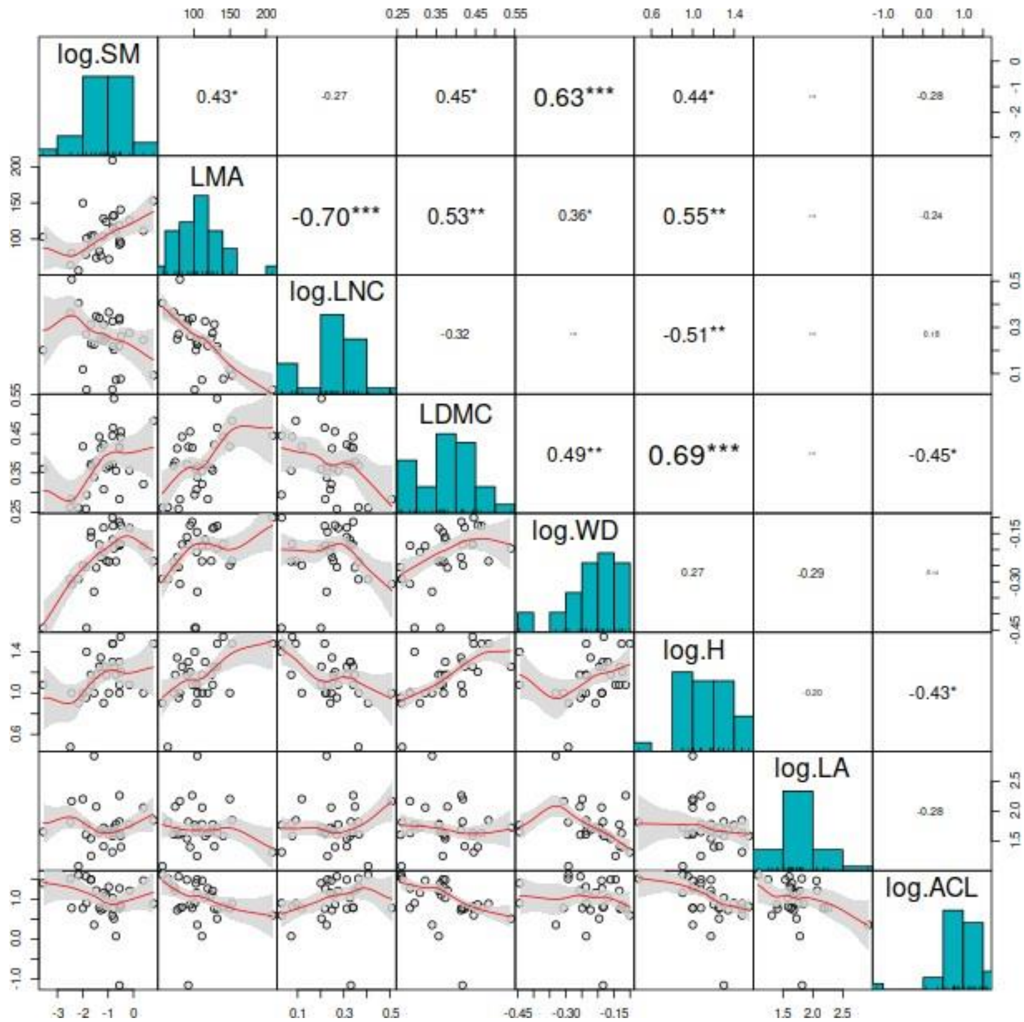

Figure 1: Relationships between the functional traits of Bhimashankar wildlife sanctuary. The rows represent the following parameters: log seed mass (SM), leaf mass per area (LMA), log leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), log wood density (WD), log maximum attainable height (H), log leaf area (LA) and log average canopy loss (ACL). The histogram in the diagonal represents the frequency distribution of each parameter. The bivariate scatter plots along with the fitted line are displayed on the bottom of the diagonal. The values are Pearson's correlation between each set of parameters and the significance level as stars are on the top of the diagonal. Each significance level is associated to a symbol: *** = 0.001, ** = 0.01, * = 0.05, and = 0.1.

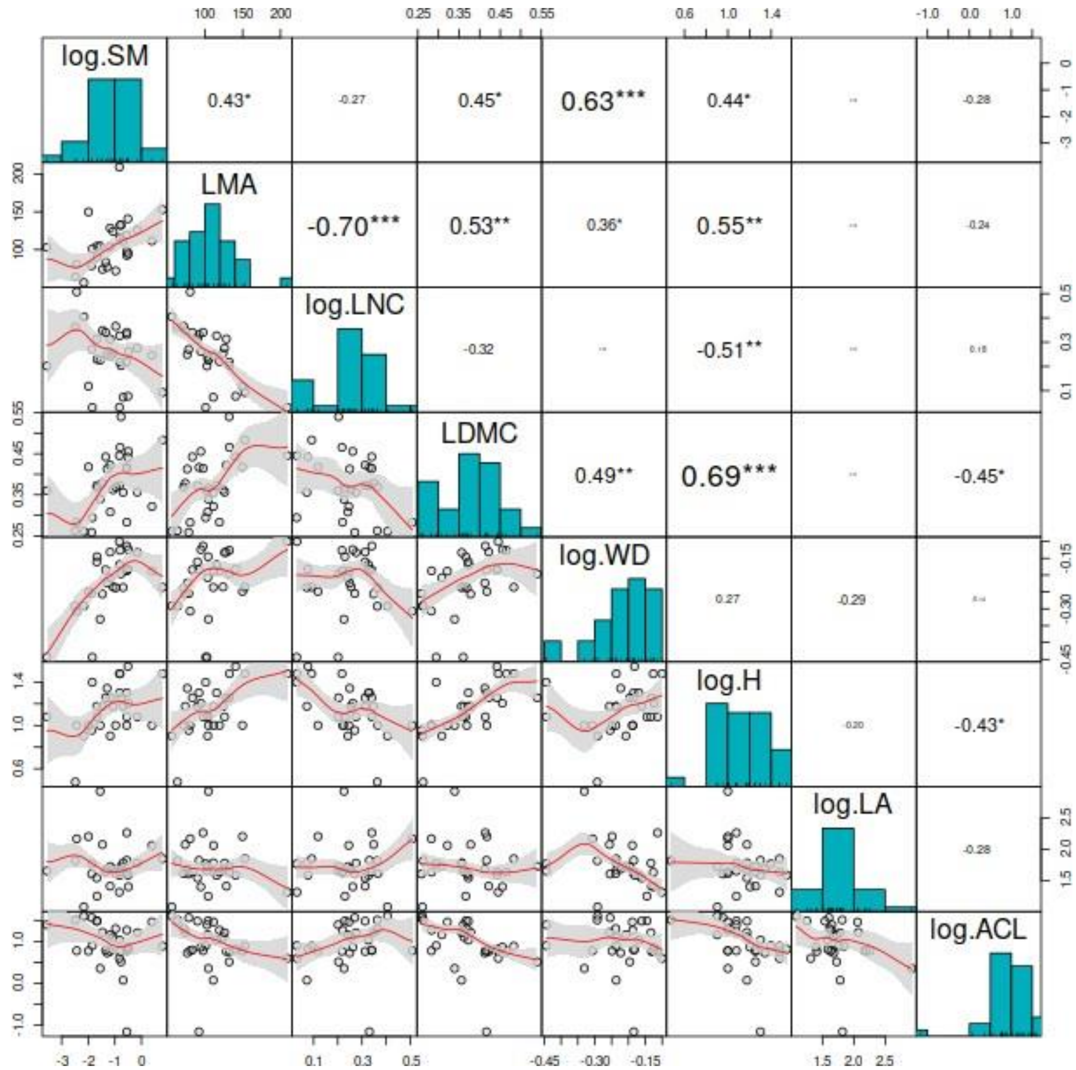

Figure 2: Relationships between the functional traits of open habitat in Bhimashankar wildlife sanctuary. The rows represent the following parameters: log seed mass (SM), leaf mass per area (LMA), log leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), log wood density (WD), log maximum attainable height (H), log leaf area (LA) and log average canopy loss (ACL). The histogram in the diagonal represents the frequency distribution of each parameter. The bivariate scatter plots along with the fitted line are displayed on the bottom of the diagonal. The values are Pearson's correlation between each set of parameters and the significance level as stars are on the top of the diagonal. Each significance level is associated to a symbol: *** = 0.001, ** = 0.01, * = 0.05, and = 0.1.

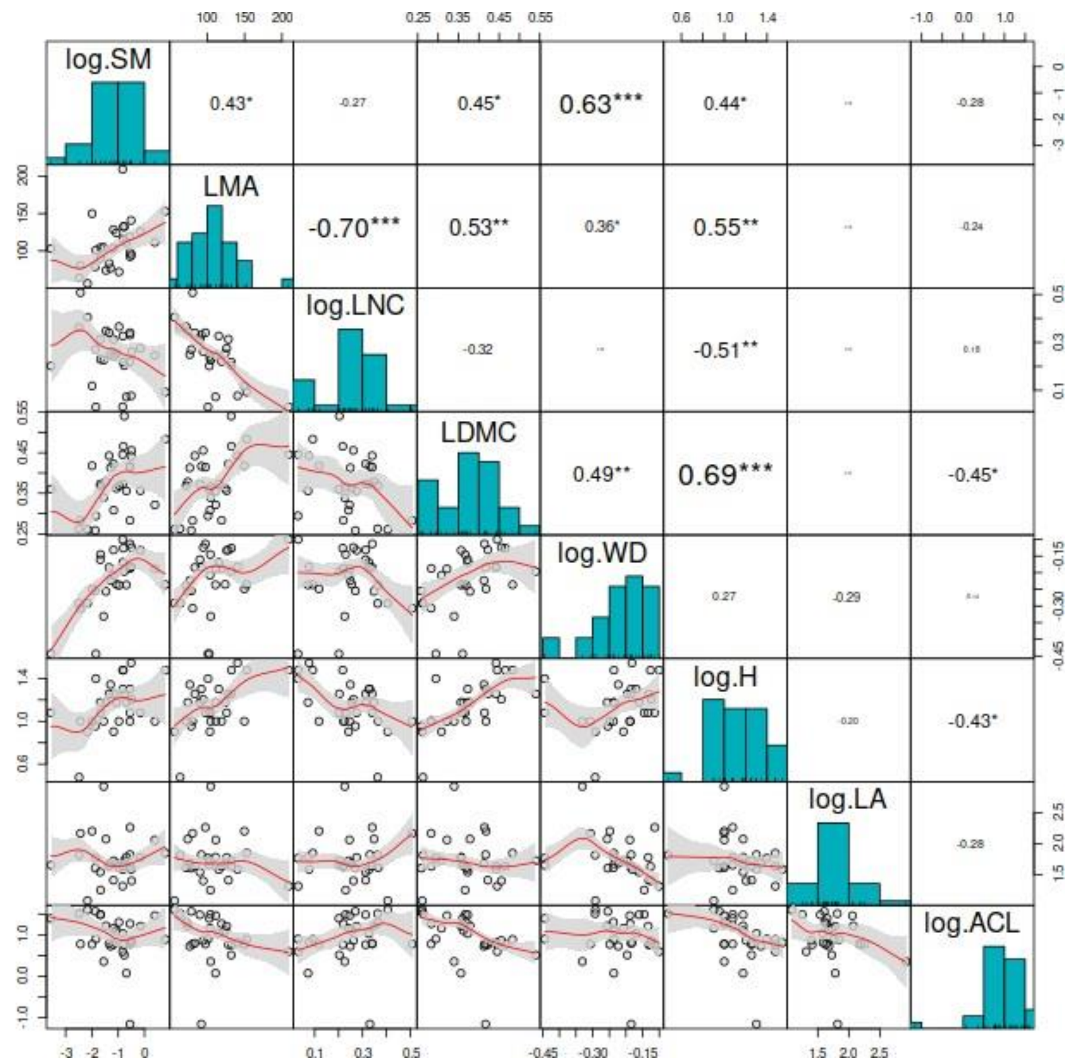

Figure 3: Relationships between the functional traits of edge habitat in Bhimashankar wildlife sanctuary. The rows represent the following parameters: log seed mass (SM), leaf mass per area (LMA), log leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), log wood density (WD), log maximum attainable height (H), log leaf area (LA) and log average canopy loss (ACL). The histogram in the diagonal represents the frequency distribution of each parameter. The bivariate scatter plots along with the fitted line are displayed on the bottom of the diagonal. The values are Pearson's correlation between each set of parameters and the significance level as stars are on the top of the diagonal. Each significance level is associated to a symbol: *** = 0.001, ** = 0.01, * = 0.05, and = 0.1.

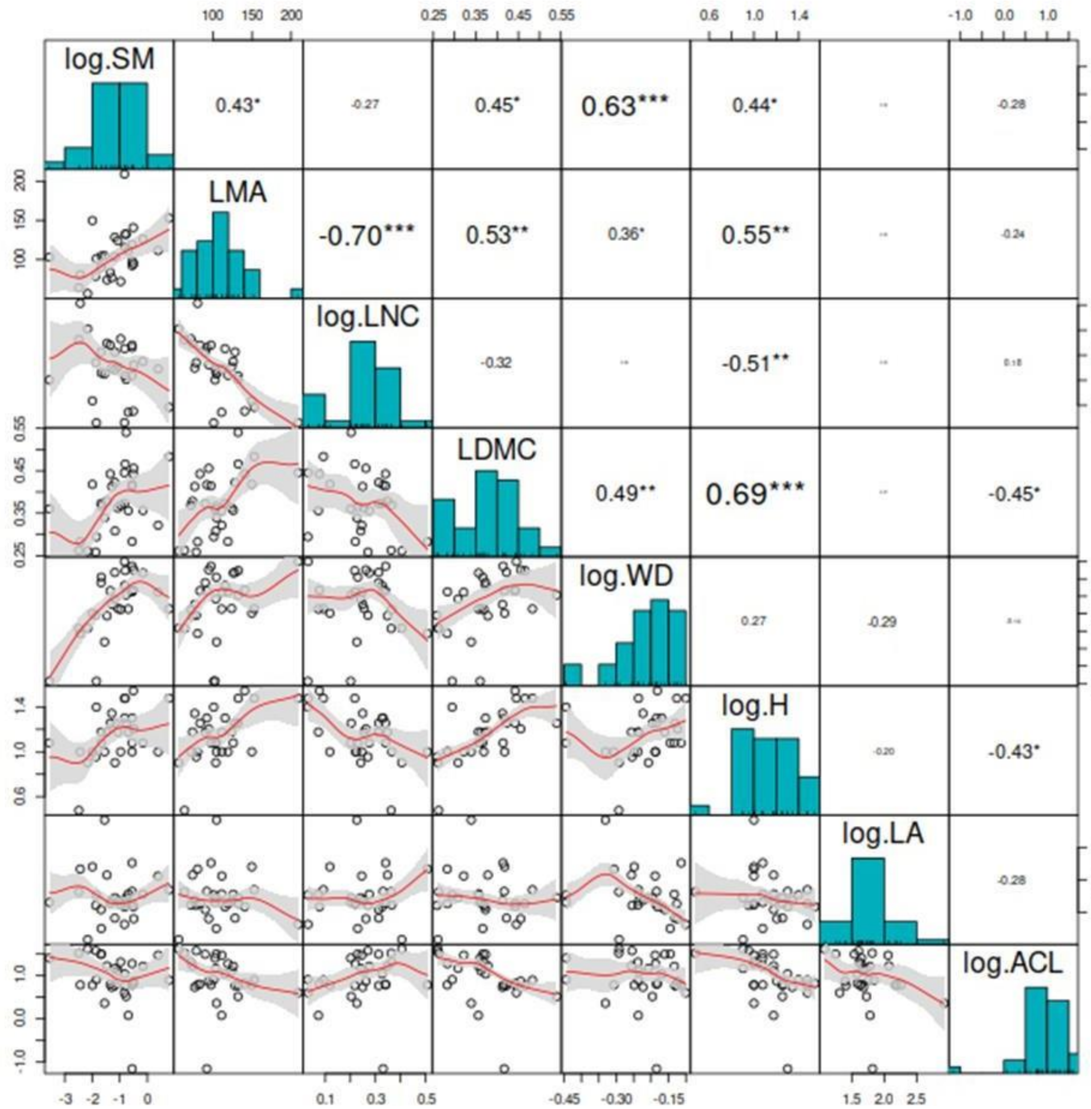

Figure 4: Relationships between the functional traits of closed habitat in Bhimashankar wildlife sanctuary. The rows represent the following parameters: log seed mass (SM), leaf mass per area (LMA), log leaf nitrogen concentration (LNC), leaf dry matter content (LDMC), log wood density (WD), log maximum attainable height (H), log leaf area (LA) and log average canopy loss (ACL). The histogram in the diagonal represents the frequency distribution of each parameter. The bivariate scatter plots along with the fitted line are displayed on the bottom of the diagonal. The values are Pearson’s correlation between each set of parameters and the significance level as stars are on the top of the diagonal. Each significance level is associated to a symbol: *** = 0.001, ** = 0.01, * = 0.05, and = 0.1.

Appendix 6: Table showing functional trait data for wood species from Bhimashankar wildlife sanctuary, SM – seed mass, LMA – leaf mass per area, LDMC – leaf dry matter content, LNC – leaf nitrogen content, LA – leaf area, H – plant height, WD – wood density, ACL is average canopy loss

Species Name	SM	LMA	LDMC	LNC	LA	H	WD	ACL
Acacia concinna	0.02078	59.84500	0.42450	2.55233	76.80000	11.00000	0.62155	13.58333
Actinodaphne angustifolia	0.16978	132.17000	0.53987	1.59640	53.20000	18.00000	0.63660	3.23560
Aglaia lawii	0.28167	92.32300	0.41668	2.14050	66.20000	20.00000	0.65439	0.06944
Allophylus cobbe	0.03430	74.07300	0.37830	2.22840	118.30000	15.00000	0.55431	16.42677
Ancistrocladus heyneanus	0.06862	71.24000	0.33600	2.16710	169.00000	18.00000	0.47000	1.31313
Artocarpus heterophyllus	5.00000	109.45800	0.32364	1.80813	94.40000	12.00000	0.62824	1.23016
Atalantia racemosa	0.06627	128.46000	0.42224	2.05620	25.70000	18.00000	0.73866	5.75000
Bridelia retusa	0.08564	124.10600	0.36218	1.79590	47.30000	15.00000	0.58192	12.53241
Caesalpinia cucullata	0.04383	89.83500	0.45184	2.10390	146.10000	20.00000	0.70832	5.59524
Callicarpa tomentosa	0.00369	80.60800	0.28288	3.21580	146.60000	10.00000	0.49337	5.94494
Carallia brachiata	0.09990	126.71915	0.34240	1.46600	48.00000	15.00000	0.70085	11.80556
Careya arborea	0.46000	125.94800	0.32775	1.46400	169.90000	6.50000	0.62241	16.06902

Carissa carandas	0.04021	140.64000	0.43171	1.38720	16.90000	10.00000	0.72017	6.31987
Casearia tomentosa	0.01368	83.51600	0.28667	2.23570	82.90000	4.00000	0.52131	29.43287
Cassine glauca	0.08370	92.20200	0.34103	1.52110	44.90000	16.00000	0.75126	0.52579
Catunaregam spinosa	0.02128	104.33100	0.36625	1.69640	17.80000	12.00000	0.71587	30.75926
Celtis timorensis	0.12000	172.15900	0.41285	0.86762	28.00000	10.00000	0.76610	8.70370
Colebrookea oppositifolia	0.00016	34.83100	0.19327	3.25550	110.50000	5.00000	0.63292	33.11728
Dimorphocalyx glabellus var. lawianus	0.17203	81.52500	0.34943	1.77300	63.10000	15.00000	0.74993	0.24306
Diospyros montana	0.14971	115.53500	0.37295	2.12030	38.20000	20.00000	0.67728	10.67424
Diospyros sylvatica	0.34439	102.51200	0.48094	1.76100	56.90000	25.00000	0.69214	2.87616
Diploclisia glaucescens	0.05100	76.82500	0.41266	1.77494	48.00000	22.00000	0.59817	5.29630
Dysoxylum binectariferum	2.81508	108.84400	0.33154	2.52950	288.00000	20.00000	0.50796	1.83372
Dysoxylum gotadhora	2.54500	86.59432	0.29554	2.15109	233.92661	7.00000	0.65000	
Elaeagnus conferta	0.16954	112.66100	0.39113	3.21050	20.20000	14.00000	0.53632	9.36756
Embelia basaal	0.01343	78.75100	0.25872	1.86320	40.20000	9.00000	0.55637	36.61806
Embelia ribes	0.01423	101.17700	0.29440	1.07230	58.30000	25.00000	0.36000	7.88462

Ficus nervosa	0.00008	116.86114	0.44658	1.55691	47.69102	17.00000	0.28000	3.38889
Ficus racemosa	0.00028	102.89300	0.36022	1.59000	44.90000	12.00000	0.36000	24.79630
Ficus tsjahela	0.00030	107.24400	0.36955	1.84134	55.20000	12.00000	0.57000	22.43687
Flacourtia indica	0.02088	90.25200	0.37279	2.05490	34.70000	15.00000	0.69063	30.30000
Garcinia indica	0.29059	76.54500	0.23692	2.30183	25.30000	14.00000	0.61261	0.99074
Garcinia talbotii	1.60000	144.49100	0.37594	1.33220	110.70000	22.00000	0.60270	0.25849
Glochidion hohenakeri	0.01017	149.80200	0.41770	1.31290	159.00000	10.00000	0.56440	5.87191
Gnetum ula	2.15675	100.37843	0.37458	1.94432	38.43761	20.00000	0.56000	1.63194
Gnidia glauca	0.00685	56.36800	0.26099	2.54070	12.00000	8.00000	0.51079	39.89303
Grewia tiliifolia	0.15888	112.85300	0.37834	2.34000	86.00000	8.00000	0.55983	18.19444
Heterophragma quadriloculare	0.12602	103.48100	0.34356	1.89779	197.10000	14.00000	0.44601	46.51852
Heynea trijuga	0.28086	97.65600	0.41416	2.19040	182.10000	12.00000	0.77000	5.96296
Ixora nigricans	0.03954	107.28800	0.37526	1.84068	46.10000	4.50000	0.72206	16.32407
Jasminum malabaricum	0.30768	116.75700	0.38108	1.99480	34.60000	7.00000	0.63244	26.02778
Lagerstroemia parviflora	0.00334	101.62500	0.35561	1.65200	44.60000	14.00000	0.57451	30.50347

Leea indica	0.02795	104.74900	0.33929	1.68140	836.20000	10.00000	0.46667	2.25168
Lepisanthes tetraphylla	0.45079	129.14900	0.40043	2.07140	192.80000	15.00000	0.65841	0.59259
Litsea josephi	0.21730	122.85200	0.42866	1.64800	73.70000	20.00000		0.30423
Macaranga peltata	0.07037	129.19900	0.38254	1.58680	145.00000	10.50000	0.49000	4.52381
Mallotus philippensis	0.04502	83.51300	0.44229	2.18750	43.30000	18.00000	0.65409	6.20885
Mangifera indica	6.17625	152.81000	0.48322	1.23760	70.10000	30.00000	0.58070	7.70337
Maytenus rothiana	0.06701	103.75600	0.30831	1.74500	52.90000	8.00000	0.62000	14.32383
Memecylon umbellatum	0.14717	209.09500	0.44534	1.07450	20.60000	30.00000	0.79341	3.92765
Meyna spinosa	0.28075	119.36300	0.28339	1.65956	42.90000	10.00000	0.65000	18.38889
Murraya paniculata	0.80000	82.23500	0.38663	2.21648	86.70000	10.00000	0.72000	6.50253
Myristica dactyloides	5.94395	108.73400	0.34496	1.30100	148.10000	15.00000	0.60000	0.40404
Olea dioica	0.15848	132.44900	0.46557	1.64950	42.80000	30.00000	0.74775	5.79365
Oxyceros rugulosus	0.06050	100.04900	0.38926	1.40430	74.30000	30.00000		1.35185
Pavetta indica	0.00327	63.93700	0.26275	2.30590	65.40000	3.00000	0.51000	32.30556
Piper trichostachyon	0.03200	63.74700	0.20963	2.70000	62.20000	7.00000	0.34000	19.35096

Pittosporum wightii		109.66200	0.48327	1.80507	32.50000	8.00000	0.66000	0.96154
Premna coriacea	0.28090	104.85700	0.34486	1.87715	68.70000	25.00000	0.62000	8.89815
Psydrax dicoccos	0.07815	249.04100	0.47304	1.16300	46.60000	10.00000	0.72289	4.33333
Rourea minor	0.30937	94.06600	0.48915	1.55610	71.10000	20.00000	0.64000	1.72222
Smilax ovalifolia	0.04976	61.23100	0.22959	2.04770	116.10000	9.00000	0.37000	50.21825
Sterculia guttata	1.07996	100.23285	0.36161	2.91200	82.00000	13.00000	0.44000	21.73765
Strobilanthes callosa	0.07269	61.96700	0.22903	2.03455	133.30000	3.00000	0.71000	45.52642
Symplocos beddomei	0.20350	111.20200	0.35601	1.18150	60.50000	15.00000	0.58000	1.17845
Syzygium cumini	0.30894	140.73200	0.44205	1.19400	38.50000	35.00000	0.65748	6.45337
Syzygium gardneri	0.26650	91.55600	0.43121	1.35160	19.10000	28.00000	0.74000	1.97222
Terminalia bellerica	4.70173	153.50200	0.36268	1.54940	101.10000	14.00000	0.70652	11.18056
Terminalia chebula	0.69677	126.15000	0.35662	1.88430	59.90000	12.00000	0.73592	16.06481
Terminalia tomentosa	2.46907	111.49500	0.32168	1.75970	114.70000	10.00000	0.64808	28.91605
Ventilago bombaiensis	0.03378	79.49400	0.55278	2.35190	22.50000	25.00000	0.73372	4.20556
Woodfordia fruticosa	0.00004	66.17300	0.35976	2.45741	16.60000	5.00000	0.63259	28.08007

Xantolis	0.32	94.736	0.4554	1.8275	25.100	16.000	0.7513	7.2407
tomentosa	131	00	9	0	00	00	7	4
Zanthoxylum	0.01	99.682	0.3649	1.9547	211.60	10.000	0.6349	37.361
rhetsa	040	00	0	7	000	00	5	11
Ziziphus	0.10	71.923	0.3689	2.3195	41.000	10.000	0.5785	20.085
rugosa	734	00	4	0	00	00	1	98

Appendix 7: List of species for which primary seed data was collected, number individuals from which data was collected. Number of individuals collected are divided according to collector – DP – Dhrubojyoti Patra, BKG – Brihaspati Kumar Gaurav, SC – Souparna Chakrabarty. Bulk indicates that the collection was not separated individual wise

Species Name	Family	No. of individuals collected		
		DP	BKG	SC
Acacia concinna	Leguminosae			1
Actinodaphne angustifolia	Lauraceae		3	
Aglaia lawii	Meliaceae	2		
Allophylus cobbe	Sapindaceae			1
Atalantia racemosa	Rutaceae			5
Bridelia retusa	Phyllanthaceae	11	3	
Caesalpinia cucullata	Leguminosae	4		
Callicarpa tomentosa	Lamiaceae	5	3	
Carallia brachiata	Rhizophoraceae	2		
Careya arborea	Lecythidaceae		1	
Carissa carandas	Apocyanaceae		4	
Casearia tomentosa	Salicaceae	10	Bulk	
Cassine glauca	Celastraceae			1
Catunaregam spinosa	Rubiaceae	3	3	
Colebrookea oppositifolia	Lamiaceae	5	3	
Diospyros montana	Ebenaceae			1

Diospyros sylvatica	Ebenaceae		1	
Diploclisia glaucescens	Menispermaceae	2		
Dysoxylum binectariferum	Meliaceae	1		
Dysoxylum gotadhora	Meliaceae		1	
Elaeagnus conferta	Eleagnaceae	5	3	
Embelia basaal	Primulaceae	1		1
Embelia ribes	Primulaceae	2		
Ficus tsjahela	Moraceae		1	
Flacourtia indica	Salicaceae		2	
Garcinia indica	Clusiaceae	4		
Garcinia talbotii	Clusiaceae		1	
Glochidion hohenakeri	Phyllanthaceae	4	3	
Gnetum ula	Gnetaceae	2	3	
Gnidia glauca	Rutaceae	7	3	
Grewia tiliifolia	Malvaceae	1		
Heterophragma quadriloculare	Bignoniaceae	1	3	
Heynea trijuga	Meliaceae			1
Ixora nigricans	Rubiaceae	3		
Jasminum malabaricum	Oleaceae		6	
Lagerstroemia parviflora	Lythraceae	3		
Leea indica	Vitaceae	7	6	
Lepisanthes tetraphylla	Sapindaceae		Bulk	
Macaranga peltata	Euphorbiaceae	4	3	
Mallotus philippensis	Euphorbiaceae	2	3	
Mangifera indica	Anacardiaceae		3	
Maytenus rothiana	Celastraceae		3	
Memecylon umbellatum	Melastomataceae		1	
Meyna spinosa	Rubiaceae	1	3	
Murraya koenigii	Rutaceae	1		
Myristica dactyloides	Myristaceae		2	1
Olea dioica	Oleaceae	9	3	

Oxyceros rugulosus	Rubiaceae			1
Psydrax dicoccos	Rubiaceae	2	3	
Smilax ovalifolia	Smilacaceae		3	
Sterculia guttata	Sterculiaceae		1	1
Syzygium cumini	Myrtaceae		1	
Terminalia bellerica	Combretaceae	5		
Terminalia chebula	Combretaceae	1	6	
Terminalia tomentosa	Combretaceae	2	3	
Ventilago bombaiensis	Rhamnaceae	2		
Woodfordia fruticosa	Lythraceae	6	3	
Xantolis tomentosa	Sapotaceae	3		
Ziziphus rugosa	Rhamnaceae	4	3	

List of sources of secondary seed data:

Primary literature:

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Appendix 8: List of species for which primary wood density data was collected and number individuals from which data was collected. Number of individuals collected are divided according to collector – DP – Dhrubojyoti Patra, OK – Omkar Khache, RS – Ron Sunny

Species	**No. of individuals collected**	
	DP & OK	**RS**
Acacia concina	3	
Actinodaphne angustifolia	4	
Aglaia lawii	5	
Allophyllus cobbe	5	3
Ancistrocladus heyneanus	5	
Artocarpus heterophyllus	1	
Atlantia racemosa	1	3
Bridelia retusa	5	3
Caesalpinia cuculatum	5	
Callicarpa tomentosa	5	
Carallia brachiata	5	
careya arborea	5	3
Carissa carandas	5	
Casearea tomentosa	5	
Cassine glauca	1	
Catunaregam spinosa	5	
Celtis timorensis	5	
Coolebrokea oppositifolia	4	
Dimorphocalyx lawianus	5	
Diospyros montana	5	
Diospyros sylvatica	5	

Diplocasia glaucesens	6	
Dysoxylum binectiferum	5	
Eleagnus conferta	5	
Embelia basaal	5	
Ficus racemosa	5	
Flacourtia indica	5	4
Garcinia indica	5	
Garcinia talbotii	5	
Glochidion hohenackeri	5	
Gnetum ula	5	
Gnidia glauca	5	
Grewia tiliaefolia	5	
Heterophragma quadriloculare	5	
Ixora nigricans	5	
Jasminum malabaricum	4	
Lagerstromia microcarpa	5	
Leea indica	5	
Lepisanthes tetraphylla	4	
Macaranga peltata	5	
Mallotus phillipensis	1	
Mangifera indica	3	4
Maytenus rothiana	3	3
Memecylon umbellatum	5	
Meyna spinosa	5	4
Murraya paniculata	4	
Olea dioca	5	
Pavetta indica	4	4
Premna coriacea	3	
Psydrax dicoccos	3	
Sterculia guttata	4	3

Strobilanthus callosa	5	
Symplocos beddomei		
Syzygium cumini	5	3
Terminalia bellerica		4
Terminalia chebula	2	4
Terminalia tomentosa	5	3
Ventilago bombaiensis	5	
Woodfordia fruticosa	5	
Xantolis tomentosa	2	
Zanthoxylum rhetsa	5	3
Zizyphus rugosa	5	