RESEARCH PAPER

Plant functional composition as an effective surrogate for biodiversity conservation

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ABSTRACT

In biodiversity conservation frameworks, determining surrogates for biodiversity is crucial for improving the effectiveness of biodiversity conservation and management. As plant functional composition can indicate variations in ecosystem functions and services, it could be used as an effective surrogate in biodiversity conservation planning. However, to the best of our knowledge, this metric has been rarely used in biodiversity conservation planning. To explore whether plant functional composition can be used as an effective surrogate for biodiversity conservation, we used a linear mixed regression model to investigate the relationships between plant functional composition (i.e., community-weighted means (CWMs) from the sPlot database) and the species richness of birds, mammals, and amphibians, and between plant functional composition and terrestrial conservation priority ranks (considering biodiversity conservation alone, or biodiversity, carbon, and water conservation together). Thereafter, we quantified the changing trends in these relationships across biomes using the least square method. We found that CWMs significantly affected species richness and terrestrial conservation priority ranks, based on the marginal R^2 and conditional R^2 values from the linear mixed regression model. Further, CWMs significantly affected species richness and terrestrial conservation priority ranks across different biomes of forests and shrublands. However, the nature of these effects (i.e., positive or negative) was dependent on biome type. These results suggest that functional composition can be considered as a biodiversity surrogate for conservation planning, and that biome-specific relationships should be considered.

Introduction

In biodiversity conservation frameworks, determining surrogates for biodiversity is important because biodiversity is too complex to measure directly; additionally, prioritizing sites should be based on multiple criteria (Lewandowski, Noss, & Parsons, 2010; Margules & Pressey, 2000; Rapacciuolo et al., 2019; Wiens, Hayward, Holthausen, & Wisdom, 2008). The effectiveness of biodiversity conservation planning can be examined using environmental variables that are closely associated with biological assemblages or communities (Sarkar et al., 2005; Wisz et al., 2013). For instance, geodiversity, the variety of Earth's surface materials, forms and processes that constitute and shape the Earth, is a good predictor of biodiversity and can therefore be used as a surrogate (Crisp, Ellison, & Fischer, 2021; Read et al., 2020). However, various surrogates (e.g., species richness, ecosystem services, and land cover) are available, and they represent biodiversity differently (Jung et al., 2021; Lewandowski et al., 2010; Mac Nally et al., 2002; Xue et al., 2022). Thus, evaluating effective surrogates for biodiversity conservation is necessary.

Most conservation priorities have been established for vertebrates because data on these taxa are generally more available than data on other groups (Brum et al., 2017; Jarzyna & Jetz, 2016; Jung et al., 2021;

Pollock, Thuiller, & Jetz, 2017). Plants structure ecosystems and properties of plant assemblages are thus better indicators of the quality of ecosystems and their important role for biodiversity (Lamanna et al., 2014)Blonder et al., 2018; Boonman et al., 2020; Butler et al., 2017; Violle, Reich, Pacala, Enquist, & Kattge, 2014). As the coverage of plant distribution data has been increasing, it is now possible to set spatial conservation priorities for plant species diversity. However, as biodiversity and ecosystems are highly complex, conservation planning and managements should not rely solely on surrogates such as species subsets, species assemblages, and habitat types (Rapacciuolo et al., 2019; Wiens et al., 2008). Hence, it is difficult to obtain a comprehensive understanding of the effectiveness of different surrogates that are required to cover all the possible biodiversity features in a conservation planning framework.

Facets of biodiversity other than species diversity (i.e., species richness) are considered increasingly critical for maintaining ecosystem functions and services (Jarzyna & Jetz, 2016; Pollock et al., 2017; Conti et al., 2023). For example, the functional diversity and phylogenetic diversity of vertebrates have been considered in efforts to improve the effectiveness of biodiversity conservation within the framework of systematic conservation planning (Brum et al., 2017; Jarzyna & Jetz, 2016; Margules & Pressey, 2000; Pollock et al., 2017; Wiens et al., 2008). Biodiversity protection can be improved by considering various biodiversity facets, instead of species diversity alone, because functional diversity and phylogenetic diversity may contribute substantially to ecosystem functions and services (Díaz & Cabido, 2001; Pollock et al., 2017). Specifically, high species diversity and phylogenetic diversity stabilize biomass production via enhanced asynchrony in the performance of co-occurring species, suggesting that species and phylogenetic diversities are effective indicators for ecological restoration and biodiversity conservation (Craven et al., 2018; Mazzochini et al., 2019). Functional composition is the key facet of biodiversity that influences multifunctionality (Le Bagousse-Pinguet et al., 2021). Plant functional composition in particular affects the functions and services of ecosystems across spatial scales (Díaz & Cabido, 2001). Plant functional composition affects ecosystem processes carbon sequestration and water conservation (Chan, Shaw, Cameron, Underwood, & Daily, 2006; Jung et al., 2021; Ma, Wang, Chen, Yu, & Wan, 2023). Plant functional traits and functional composition should, therefore, be integrated into conservation planning as surrogates for functional diversity.

Plant functional traits can predict community assembly and ecosystem functioning, and they are widely used in global models of vegetation dynamics and land–climate feedbacks (Anderegg, Trugman, Bowling, Salvucci, & Tuttle, 2019; Blonder et al., 2018; Boonman et al., 2020; Butler et al., 2017). Plant functional composition has been considered for biodiversity conservation and ecological restoration in several experimental and field studies (Carlucci, Brancalion, Rodrigues, Loyola, & Cianciaruso, 2020; Lavorel, 2013). Further, in recent studies (e.g., Lamanna et al., 2014; Blonder et al., 2018; Boonman et al., 2020; Butler et al., 2017; Violle et al., 2014), plant functional composition has been mapped at the regional (e.g., ecoregion and biome) and global scale using environment–trait relationships. This provides guidance for ecosystem management under changing environmental conditions. Additionally, as datasets increase and technologies advance, the concept of plant functional composition could be used in a wide range of studies on macroecology and functional biogeography (Sabatini et al., 2021; Taugourdeau, Villerd, Plantureux, Huguenin-Elie, & Amiaud, 2014; Violle et al., 2014). These studies could provide opportunities for systematic conservation planning using plant functional variation as the input for feature maps.

Plant functional composition could serve as an effective surrogate for biodiversity across different animal groups (e.g., mammals, birds, and amphibians), thus contributing to biodiversity conservation from local to global scales. Additionally, plant functional composition is closely related to ecosystem functions, such as nutrient levels, nutrient turnover, and productivity, and to the resistance, resilience, and stability of the ecosystems for animals and their life cycles (Díaz & Cabido, 2001; McCauley et al., 2018). The biomass, nutrient content, stability, and productivity of resident communities that are functionally rich can support trophic pyramids in mammals, birds, and amphibians (McCauley et al., 2018; Welti et al., 2020). Further, ecological processes such as herbivory and predation depend on energy flow, food webs, topology and stability, trophic cascades, and the structure of metacommunities (Bauer & Hoye, 2014). In addition, animal migration can influence ecological networks of animal diversity worldwide, whilst community dynamics and ecosystem functioning may affect this migration and the interactions between migrants and multiple resident communities (Bauer & Hoye, 2014). For example, plant functional traits (e.g., height, leaf area, and wood density) and plant community dynamics are closely related to variations in the canopy characteristics, such as leaf area index, canopy type, plant physiognomy, and canopy architecture; further, canopies provide habitats, structure, energy, and ecosystem services (e.g., food) that promote rich bird diversity (Coops, Waring, Wulder, Pidgeon, & Radeloff, 2009; Ibanez et al., 2013). Hence, plant characteristics should be a good proxy for animal biodiversity because plants provide habitats for animal species. Finally, Jung et al. (2021) stated that systematic conservation planning should consider maximizing ecosystem services closely related to plant functional composition, such as carbon retention and water quality regulation, to improve the effectiveness of biodiversity conservation strategies. Integrating large-scale data on species richness and ecosystem services can support biodiversity conservation and enhance nature's contributions to human welfare and well-being more effectively (Díaz et al., 2007; Jung et al., 2021; Lavorel, 2013).

Different facets of biodiversity are considered critical for conservation targets and human survival (Brum et al., 2017; Díaz & Cabido, 2001; Jarzyna & Jetz, 2016; Margules & Pressey, 2000; Pollock et al., 2017). Pollock et al. (2017) and Brum et al. (2017) used systematic conservation planning to assess the conservation ability of global protected areas for vertebrates based on three facets: species, phylogenetics, and functional composition. Conservation planning should consider multiple biodiversity facets to maximize animal biodiversity conservation (Díaz & Cabido, 2001; Pollock et al., 2017). However, recent studies have focused on plant conservation planning based on only two facets, species diversity and phylogenetic diversity (Li, Kraft, Yu, & Li, 2015; Tucker & Cadotte, 2013; Brown et al., 2020). To our knowledge, plant functional composition has not yet been integrated into conservation planning as a general biodiversity facet. Here, we investigated whether plant functional composition can be used as an effective surrogate for biodiversity. We quantified biodiversity based on the species richness of mammals, birds, and amphibians, and we used the conservation maps provided by Jung et al. (2021) to assess biodiversity conservation separately, as well as biodiversity and ecosystem services together. More specifically, we aimed to determine: (1) whether plant functional composition affects animal biodiversity, and (2) whether plant functional composition is related to the priority ranks of biodiversity conservation.

Materials and methods

Plant functional trait data

Plant functional composition data were obtained from the sPlot database v2.1 (Sabatini et al., 2021). The analysis considered 18 plant functional traits (all concentrations based on dry weight of sampling materials) that were closely associated with ecosystem functions (Table S1), as suggested by Sabatini et al. (2021). The 18 plant functional traits were: (a) leaf area (mm^2), (b) stem specific density (g/cm^3), (c) specific leaf area (m^2/kg), (d) leaf carbon concentration (mg/g), (e) leaf nitrogen (N) concentration (mg/g), (f) leaf phosphorus (P) concentration (mg/g), (g) mean plant height (m), (h) seed mass (mg), (i) seed length (mm), (j) leaf dry matter content (g/g), (k) leaf N per area (g/m^2), (l) leaf N:P ratio

(g/g), (m) leaf δ15N (‰), (n) seed number per reproductive unit, (o) leaf fresh mass (g), (p) stem conduit density (per mm^2), (q) dispersal unit length (mm), and (r) wood vessel element length (µm). Community-weighted mean (CWM) data were obtained for 94,422 unique vegetation plots from 105 constitutive datasets, which were a part of the sPlot dataset at the global scale (Fig. 1). The metadata of the individual vegetation-plot datasets stored in sPlot are managed through the Global Index of Vegetation-Plot Databases (Dengler et al., 2011). CWMs (i.e., plot-level trait values weighted by species abundances) coupled with environmental conditions can reflect the selection of locally optimal phenotypes, which include the substantial interspecific trait variation typically found within ecological communities (Sabatini et al., 2021).

For this study, we assigned each vegetation plot to a biome type, which is a large area characterized by its vegetation (Dinerstein et al., 2017). The biome types of the plots were determined using the extraction function of QGIS 3.30 (https://www.qgis.org/en/site/) and referring to the global map provided by Dinerstein et al. (2017) (Fig. S1). Different biomes were considered to test whether plant functional composition can be used in conservation planning due to the variation in conservation goals of different organism groups. The vegetation plots belonged to 14 biomes (Fig. S1; Dinerstein et al., 2017; Sabatini et al., 2021). The values for the 18 functional traits were natural log-transformed and then used in a principal component analysis (PCA) to quantify the dimensions of the plant functional trait economics spectrum based on the CWM values of the functional traits across all 94,422 vegetation plots. The two-dimensional spectrum of global plant trait variation can occur because of: (1) size variation at the organ and plant level and (2) leaf economics balancing leaf persistence against plant growth potential (Díaz et al., 2016; Joswig et al., 2022). Hence, this spectrum has the potential to capture the essence of plant function at the plot level. Here, PCA was used here to quantify the dimensions of the plant functional trait economics spectrum based on the CWM values of the functional traits across all 94,422 vegetation plots.

The significant contributors to the primary PCA axis of plant functional composition were quantified using CWMs, i.e., by feeding PCA with plot-level means per trait as the input data, as suggested by Joswig et al. (2021). The driving traits were identified for each dimension based on all vegetation plots. The respective loadings on the first three principal components (PCs) were extracted to explain 63.4% of the variance in CWMs, which was considered significant based on the number of axes using a sequential Bonferroni procedure. The values of the first three PCs of CWMs were assigned to each plot, thus linking them to the corresponding biome types. The plant functional trait economics spectrum was then mapped based on the first three CWM-PCs (i.e., three dimensions), as shown in Table S1. The PC scores for the vegetation plots are shown in Fig. S2. The spatially explicit CWM values of the plots were then linked to the spatially explicit biodiversity richness values of grid cells (10 × 10 km and 50 × 50 km), which were consistent with data on biodiversity and terrestrial conservation priority ranks (see below).

Data on biodiversity and terrestrial conservation priority ranks

Maps of birds, mammals, and amphibians at two spatial resolutions, 10 × 10 and 50 × 50 km, were used for our analysis. Existing biodiversity maps at 10 × 10 km resolution based on Jenkins, Pimm, and Joppa (2013) and Pimm et al. (2014), which included birds, mammals, and amphibians, were first downloaded (https://biodiversitymapping.org/). The 50 × 50 km maps were generated by applying the resampling function in QGIS 3.30 (https://www.qgis.org/en/site/) to the 10 × 10 km maps. The biodiversity values of these maps were assessed by calculating the total species richness based on distribution data from the International Union for Conservation of Nature (https://www.iucn.org/) and BirdLife International (https://www.birdlife.org/). The biodiversity maps were updated based on grid cell values.

Data on terrestrial conservation priority ranks were obtained at two
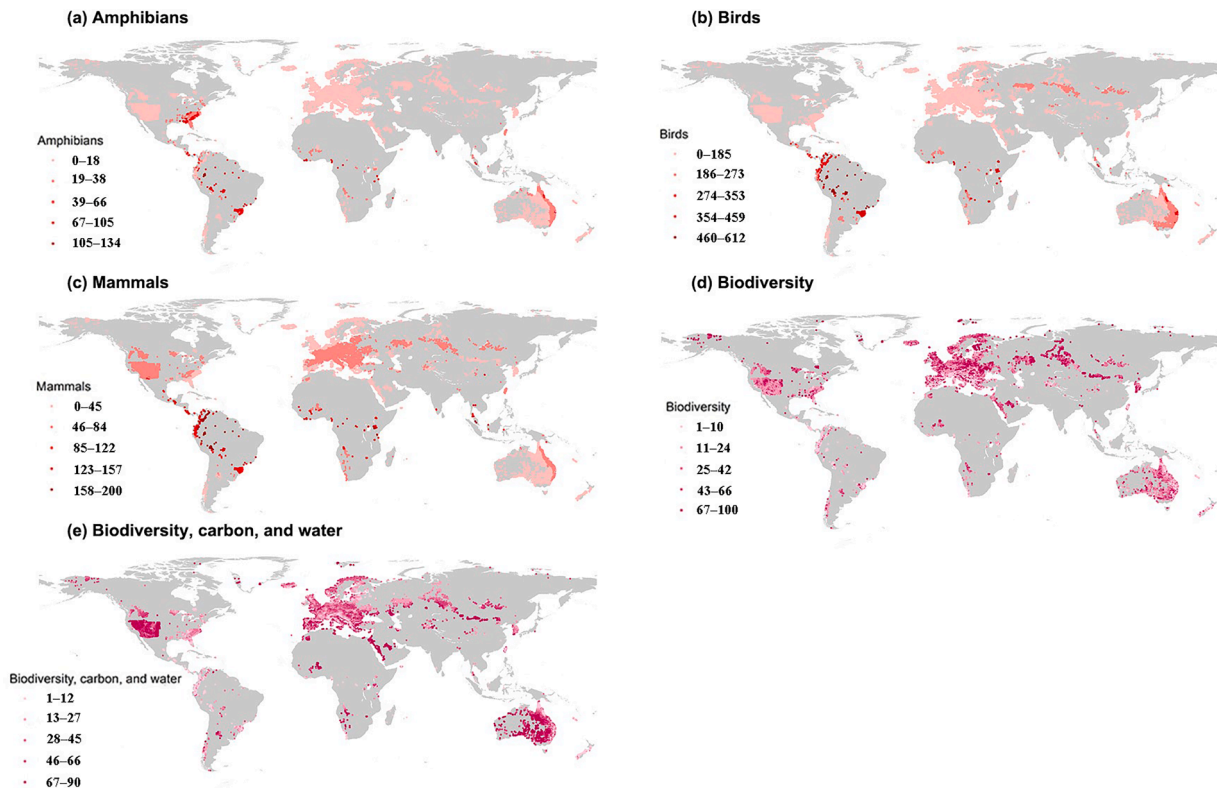
Fig. 1. Species richness (birds, mammals, and amphibians) and terrestrial conservation priority ranks (biodiversity conservation only, and biodiversity, carbon, and water combined) of vegetation plots. The gradient from light to dark red represents increasing values of species richness and terrestrial conservation priority ranks. The gray areas indicate regions where no data were available for our study.

spatial resolutions, 10 × 10 km and 50 × 50 km, from Jung et al. (2021) (https://doi.org/10.5281/zenodo.5006332). These data were generated for a global assessment for the optimal management of land for conservation. Terrestrial conservation priority ranks were assessed by solving a budget-limited formulation of the reserve selection problem that aims to maximize conservation benefits (Jung et al., 2021). In the present study, two maps of conservation priority ranks were used; one was based on biodiversity only, and the other one based on biodiversity, carbon, and water combined. The global terrestrial conservation priority ranks were quantified as the maximum value in the present state to be managed for conserving biodiversity, carbon, and water (Jung et al., 2021). All vertebrate range maps were pre-processed following common practice by selecting only those parts of a species' range where (1) it is extant or possibly extinct, (2) it is native or reintroduced, and (3) it is seasonally resident, breeding, non-breeding, or migratory, or the seasonal occurrence is uncertain (Jung et al., 2021). The density of aboveground and belowground biomass carbon and vulnerable soil carbon was assessed for quantifying carbon conservation (Jung et al., 2021). Potential clean water provision was calculated by WaterWorld75 and Co$ting Nature (Jung et al., 2021). The rank aims to maximize improvements in species conservation status, carbon retention, and water provisioning, and terrestrial conservation priorities are ranked globally (Jung et al., 2021). Species richness (birds, mammals, and amphibians) and terrestrial conservation priority ranks (biodiversity conservation only, and biodiversity, carbon, and water conservation combined) of the vegetation plots are shown in Fig. 1.

Analysis

A linear mixed regression model was used to explore the relationships between plant functional composition (three CWM-PCs) with species richness (birds, mammals, and amphibians) and terrestrial conservation priority ranks (biodiversity conservation only, and biodiversity, carbon, and water conservation combined) at the same grid cell sizes as used previously under the *rdacca.hp* package (Lai, Zou, Zhang, & Peres-Neto, 2022) in R (version 4.2.1, R Core Team, 2022; https://www.

r-project.org/) based on Lai et al. (2022). Here, CWM-PCs were used as fixed factors, and biome types as random factors. Based on Lai et al. (2022), the individual contribution of CWM-PCs to species richness and terrestrial conservation priority ranks was determined by generalizing hierarchical and variation partitioning.

An ordinary least square regression model was used to explore the relationship between the three CWM-PCs and species richness and between the CWM-PCs and terrestrial conservation priority ranks across the 14 biomes at the two grid cell sizes. Finally, Spearman correlation coefficients were used to explore the associations of plant functional composition with species richness and with terrestrial conservation priority ranks for each biome across both spatial scales. The correlations were conducted using the *GGally* package in R (Emerson et al., 2013).

Results

CWMs of plant functional traits had a significant relationship with species richness and terrestrial conservation priority ranks, according to marginal R^2 and conditional R^2 values ($P < 0.05$; Fig. 2). CWMs had the largest effect on mammalian species diversity (Fig. 2). However, while the marginal R^2 was low, the conditional R^2 was high when biome type was included as a random factor, indicating that effects were highly biome-specific (Fig. 2).

Trait-specific effects of CWMs on species richness and conservation priority rank

The effects of CWMs on species richness and conservation priority rank depended on changes in PC. PC1 (plant height, seed mass, and seed length) made the largest contribution to species richness of amphibians and birds and to biodiversity conservation priority rank; PC2 (specific leaf area and leaf nitrogen (N) content per leaf dry mass) made the largest contribution to mammal species richness; PC3 (leaf carbon content per leaf dry mass, leaf N content per leaf area, and stem conduit density) made the largest contribution to conservation rank of biodiversity, carbon, and water combined (Fig. 2).
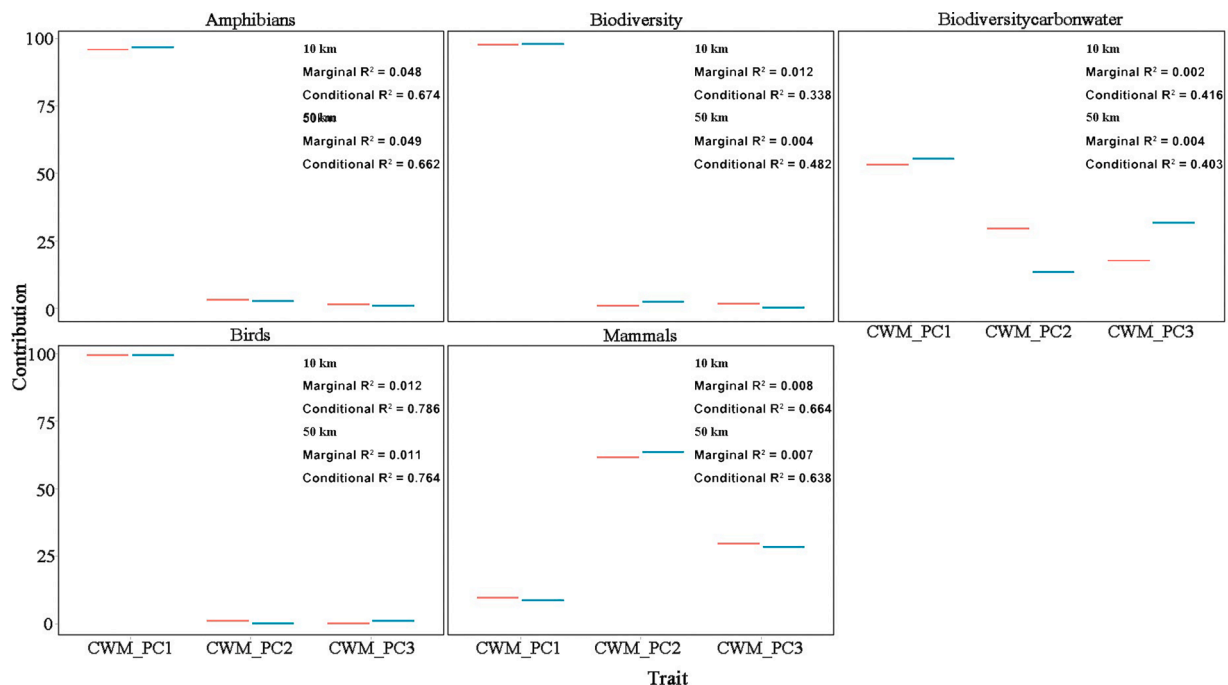
Fig. 2. Contribution of plant functional composition to species richness, for birds, mammals, and amphibians, and to terrestrial conservation priority ranks, for biodiversity only and for biodiversity, carbon, and water combined. The displayed values are based on variation partitioning in linear mixed models, with grid cell sizes of 10 × 10 km (red lines) and 50 × 50 km (green lines). Community-weighted means (CWMs) of plant functional traits had significant correlations with species richness and with terrestrial conservation priority ranks, based on marginal R² and conditional R² values (all significant, $P < 0.05$).

Biome-dependent effects of CWMs on species richness and conservation priority rank

Significant effects of CWMs on species richness and terrestrial conservation priority ranks were widespread in the forest and shrubland biomes (Table 1). CWMs had the largest effect on species richness and on terrestrial conservation priority ranks in flooded grasslands and savannas and in mangrove forests (Table 1). Conversely, the effects of CWMs were weak in deserts and xeric shrublands. The effects of CWMs on species richness were relatively large for amphibians and birds in temperate broadleaf and mixed forests, temperate conifer forests, temperate grasslands, savannas, and shrublands, tropical and subtropical coniferous forests, and tropical and subtropical grasslands, savannas, and shrublands (Table 1). Further, CWMs contributed to biodiversity, carbon, and water conservation, largely in flooded grasslands and savannas, mangrove forests, and temperate conifer forests (Table 1).

However, the relationships of CWMs with species richness and terrestrial conservation priority ranks were biome-specific and stable (Figs 3 and S3). The trends across the biomes were similar for the two grid cell sizes (Figs 3 and S3). However, grid cell sizes influenced the correlations of CWMs with biodiversity in flooded grasslands and savannas and in tropical and subtropical moist broadleaf forests, and with biodiversity, carbon, and water conservation in deserts, xeric shrublands, and tropical and subtropical moist broadleaf forests (Figs 3 and S3). Increasing CWMs were associated with higher amphibian species richness in temperate grasslands, savannas and shrublands, and promoted bird and mammal species richness in tropical and subtropical grasslands, savannas, and shrublands (Fig. 3). Conversely, increasing CWMs were associated with lower species richness of all three animal groups in flooded grasslands and savannas, and lower mammal species richness in Mediterranean forests, woodlands, and scrub (Fig. 3). CWMs were positively related to conservation priority ranks for biodiversity in boreal forests/taiga and in tropical and subtropical grasslands, savannas and shrublands. Moreover, CWMs were negatively related to conservation priority ranks for biodiversity, carbon, and water in flooded grasslands and savannas, temperate conifer forests, and tropical and subtropical dry broadleaf forests (Fig. 3). However, the relationships of CWMs with species richness and terrestrial conservation priority ranks were not consistently positive or negative, with stability for most biomes (Figs 3 and S3).

Discussion

Our analysis demonstrates that CWMs of plant functional traits have

significant effects on species richness, indicating that plant functional composition could be used as an effective surrogate for species richness. Further, this metric can be used to assess priority ranks of terrestrial conservation, and it is a relevant biodiversity feature for systematic conservation planning. This stems from the ecological indicator roles of plant functional composition on species richness and conservation priority ranks (Chillo, Anand, & Ojeda, 2011). However, attention should be paid to the biome regulation of the effects of plant functional composition on species richness and conservation priority ranks, and plant functional composition should be regarded as a biodiversity feature that is dependent on biome type.

Our findings support the use of plant functional composition as a potential biodiversity facet for conservation planning, which contributes to efforts to conserve terrestrial biodiversity, carbon, and water. Further, the application of plant functional composition can contribute to conservation and management of both plants and animals. Several effective approaches have been previously developed to map the distribution pattern of plant functional composition, and these maps have been used as the input layers of conservation planning frameworks (Lamanna et al., 2014; Violle et al., 2014; Butler et al., 2017; Blonder et al., 2018; Boonman et al., 2020). Hence, plant functional composition can likely be used as a general facet for plant and animal diversities in conservation planning.

Trait-dependent effects of CWMs on species richness and conservation priority rank

CWMs of different plant functional traits jointly contributed to species richness and terrestrial conservation priority ranks. Moreover, different functional trait diversities contributed to species richness. Together, plant height, seed mass, and seed length made the largest contribution to amphibian and bird species richness, and leaf traits made the largest contribution to mammal species richness. Tall plants are of particular importance for amphibian and avian habitats, and these animal groups benefit from high plant species richness (Bradbury et al., 2005). Additionally, plant seeds are a food resource for amphibians and birds (Evans, Pocock, Brooks, & Memmott, 2011; Hargreaves et al., 2019). The influence of seed shading on seed germination and seedling establishment provides a template for the spatial distribution of adult plants (Walck, Hidayati, Dixon, Thompson, & Poschlod, 2011). Finally, leaf traits influence multiple components of plant fitness, including the responses of growth, reproduction, and survival to the environment, thereby contributing mechanistically to the environmental distributions of plant species richness, which are closely associated with mammal

Table 1

Linear relationships of plant functional composition (three principal components of plant functional composition quantified using CWMs of vegetation plots combined) with species richness of birds, mammals, and amphibians, and with terrestrial conservation priority ranks, including biodiversity only and biodiversity, carbon, and water combined, across different biomes. Relationships were assessed using ordinary least square regression and were based on a grid cell size of 10 × 10 km.

Biome	Amphibian		Bird		Mammal		Biodiversity		Biodiversity, carbon, and water combined	
	R^2	P	R^2	P	R^2	P	R^2	P	R^2	P
Boreal forests/taiga	0.0199	<0.0001	0.1759	<0.0001	0.1710	<0.0001	0.0571	<0.0001	0.0324	<0.0001
Deserts and xeric shrublands	0.0725	<0.0001	0.0018	<0.0001	0.0161	<0.0001	0.0137	<0.0001	0.0354	<0.0001
Flooded grasslands and savannas	0.7725	<0.0001	0.6917	<0.0001	0.7356	<0.0001	0.6337	<0.0001	0.6232	<0.0001
Mangroves	0.8584	<0.0001	0.4046	0.0225	0.6736	0.0001	0.4878	0.0063	0.5261	0.0032
Mediterranean forests, woodlands, and scrub	0.0470	<0.0001	0.0162	<0.0001	0.0276	<0.0001	0.0012	0.0476	0.0409	<0.0001
Montane grasslands and shrublands	0.0065	0.0011	0.0734	<0.0001	0.0928	<0.0001	0.0096	<0.0001	0.0439	<0.0001
Temperate broadleaf and mixed forests	0.2461	<0.0001	0.1280	<0.0001	0.0230	<0.0001	0.0078	<0.0001	0.0138	<0.0001
Temperate conifer forests	0.1324	<0.0001	0.1150	<0.0001	0.0557	<0.0001	0.0075	<0.0001	0.2583	<0.0001
Temperate grasslands, savannas, and shrublands	0.3664	<0.0001	0.1667	<0.0001	0.0564	<0.0001	0.0403	<0.0001	0.1911	<0.0001
Tropical and subtropical conifer forests	0.1997	<0.0001	0.1423	<0.0001	0.0574	0.0001	0.0035	0.7428	0.0374	0.0039
Tropical and subtropical dry broadleaf forests	0.1459	<0.0001	0.0863	0.0002	0.0950	<0.0001	0.0361	0.0482	0.0333	0.0637
Tropical and subtropical grasslands, savannas, and shrublands	0.0975	<0.0001	0.1348	<0.0001	0.2384	<0.0001	0.0551	<0.0001	0.0739	<0.0001
Tropical and subtropical moist broadleaf forests	0.1528	<0.0001	0.0319	<0.0001	0.0175	<0.0001	0.0230	<0.0001	0.0105	<0.0001
Tundra	0.1307	<0.0001	0.0339	<0.0001	0.0399	<0.0001	0.0450	<0.0001	0.0445	<0.0001
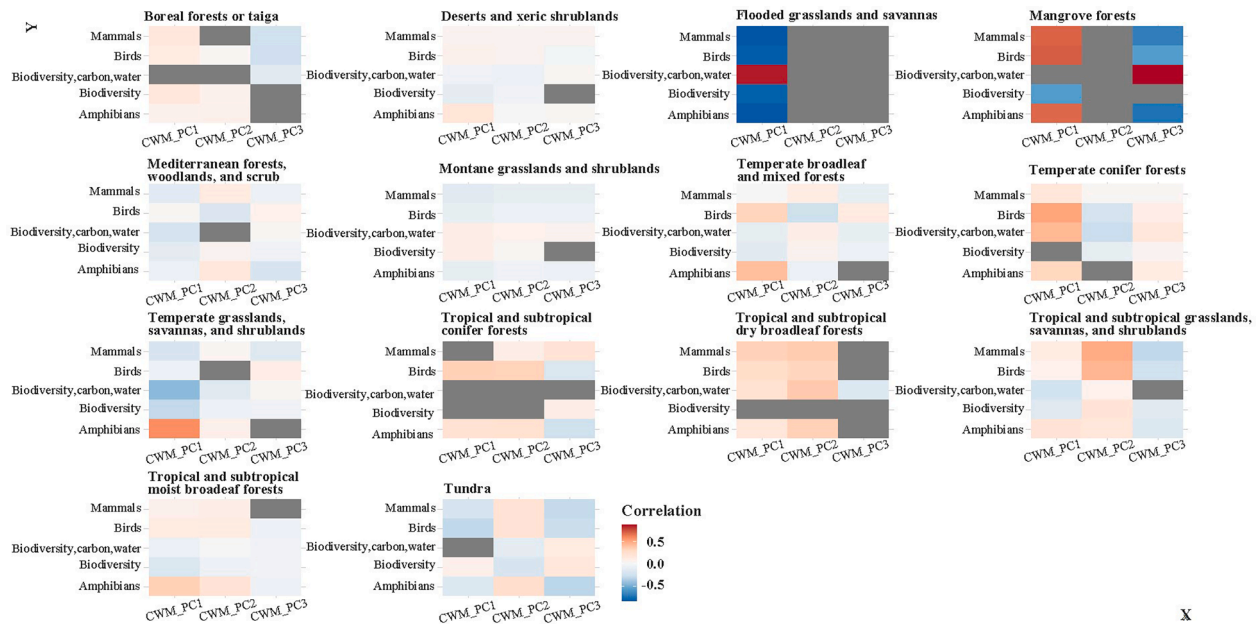
Fig. 3. Biome-specific correlations between plant functional composition and species richness, for birds, mammals, and amphibians, and between plant functional composition and terrestrial conservation priority ranks, for biodiversity only and for biodiversity, carbon, and water combined. Values are based on Spearman correlation coefficients at a grid cell size of 10×10 km. Red represents positive relationships, blue represents negative relationships, and gray represents no data for the relationships. The relationships were significant based on partial ordinary least squares with colours (i.e., red and blue) ($P < 0.05$).

species richness (Wright et al., 2004; Qian, 2007; Donovan, Maherali, Caruso, Huber, & de Kroon, 2011). Hence, plant height, seed mass, and seed length should be developed as conservation indicators for amphibians and birds, and leaf traits should be used to assess mammal species richness.

CWMs of plant height, seed mass, seed length, and leaf carbon content per leaf dry mass were an effective surrogate for conservation priority ranks based on terrestrial biodiversity, carbon, and water. Plant functional composition can be closely linked to many ecosystem services, such as food and fodder provision, carbon storage, regulation of climate and water quality, pollination, and aesthetic and recreational value (Lavorel, 2013; Gross et al., 2017; Carlucci et al., 2020). Overall, our findings demonstrate that plant functional composition can help guide the conservation of biodiversity, carbon, and water, but planners should bear in mind that the situation differs across biomes. The significant effects of CWMs on species richness and terrestrial conservation priority ranks exist mainly in the forest and shrubland biomes. Plant functional composition can help predict the productivity and stability of forest ecosystems on a global scale, using biodiversity–ecosystem functioning relationships (Bongers et al., 2021). Further, aboveground biomass of forests and shrublands can be predicted effectively from plant functional composition (Lavorel, 2013; Gross et al., 2017). CWMs can contribute to predictions of biodiversity, carbon, and water conservation, in flooded grasslands and savannas, mangrove forests, and temperate conifer forests. The leaf economics spectrum describes consistent correlations between various leaf traits that reflect a gradient from conservative to constitutive plant strategies (Donovan et al., 2011). Leaf traits are good predictors of biomass increment of recruits, which can provide animal habitats, promote carbon storage, and improve water quality in flooded grasslands and savannas and in mangrove forests (Pan et al., 2020). Additionally, leaf traits can contribute to the productivity and stability of temperate conifer forest communities (Wang et al., 2015). Hence, plant functional composition has a strong ability to predict species richness and conservation priority in forests and shrublands.

Biome-specific effects of CWMs on species richness and conservation priority rank

The relationships of plant functional composition with species richness and with conservation priority ranks varied across the biome types. The trends in species richness and terrestrial conservation priority ranks along the gradient of CWM differed across the biomes. Previous studies (Jarzyna & Jetz, 2016; Brum et al., 2017; Pollock et al., 2017) have incorporated conservation planning modeling for animals based on the positive relationships between animal functional composition and conservation priority ranks. Our results suggest that the application of plant functional composition may not differ from that of animals based on diversity–rank relationships (positive or negative, based on our results), depending on the specific biome. In summary, plant functional composition could be applied as an effective surrogate for biodiversity, depending on the global biome considered.

Conclusions

Plant functional composition is closely related to ecosystem functioning and services, from local to global scales. This study provides evidence that plant functional composition can be an effective surrogate for biodiversity in conservation applications. Further, the surrogate roles may be biome-specific. Further research is needed to quantify the changing trends in species richness and conservation priority ranks (positive or negative) along the gradient of plant functional composition. This study provides insights into conservation from different perspectives of biodiversity and demonstrates that plant functional composition should be integrated as a biodiversity feature in conservation planning.

Data accessibility statement

No new data were used in this study.

Declaration of Competing Interest

All the authors have approved the manuscript and agree with

submission to your esteemed journal. There are no conflicts of interest to declare.

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Supplementary materials

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