Research Progress Postprint of the Subtropical Forest Biodiversity and Ecosystem Function Experimental Platform (BEF-China)

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Abstract

The relationship between biodiversity and ecosystem functioning (BEF) and its underlying mechanisms constitute a focal issue in current biodiversity research. While BEF studies in grassland ecosystems have accumulated substantial research outcomes over the long term, corresponding research in forest ecosystems remains relatively limited. The Biodiversity and Ecosystem Functioning Experiment in Subtropical Forests (BEF-China) represents the largest forest controlled experimental plot to date, encompassing the greatest number of tree species and the highest diversity levels. This article synthesizes research advances based on the BEF-China platform, particularly concentrating on the impacts of biodiversity on ecosystem productivity, nutrient cycling, and multi-trophic interactions. Furthermore, it proposes that future BEF-China research should emphasize the application of emerging technologies such as high-throughput sequencing and remote sensing, and continue to pursue in-depth investigations along interdisciplinary directions encompassing multiple dimensions of biodiversity, multiple components and functions of ecosystems, and multiple scales of BEF research. Systematic review of BEF-China research findings facilitates understanding of the intrinsic mechanisms driving biodiversity-ecosystem functioning relationships in subtropical forests, and provides scientific foundations for biodiversity conservation and ecological restoration.

Full Text

Preamble

Research progress of Biodiversity–Ecosystem Functioning Experiment China Platform (BEF-China)

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Abstract

The relationship between biodiversity and ecosystem functioning (BEF) and its underlying mechanisms represent a central focus in current biodiversity research. While BEF studies have predominantly focused on grassland ecosystems, accumulating substantial knowledge, research based on forest ecosystems remains relatively limited. The Biodiversity–Ecosystem Functioning Experiment China Platform (BEF-China) represents the largest forest control experiment to date in terms of both tree species number and diversity levels. This review synthesizes research progress from the BEF-China platform, particularly concentrating on biodiversity's impacts on ecosystem productivity, nutrient cycling, and multi-trophic interactions. We propose that future BEF-China research should emphasize emerging technologies such as high-throughput sequencing and remote sensing, continuing in-depth investigations across interdisciplinary directions including multi-dimensional biodiversity, multiple ecosystem components and functions, and multiple scales of BEF research. This synthesis of BEF-China findings will enhance understanding of the intrinsic mechanisms driving biodiversity–ecosystem functioning relationships in subtropical forests and provide scientific foundations for biodiversity conservation and ecological restoration.

Keywords: biodiversity, ecosystem functioning, BEF-China, research review

1. Research Background

Globally, forests provide habitats for diverse plants, animals, and microorganisms while delivering multiple essential ecosystem services for human well-being. Biodiversity and ecosystem functioning (BEF) research based on grassland ecosystems has demonstrated that plant species diversity promotes productivity (Cardinale et al., 2012). Species diversity influences ecosystem productivity and stability by regulating nutrient cycling and multi-trophic interactions (Ma et al., 2017). Forest ecosystems, with their complex structure and long individual growth cycles, present greater challenges for BEF research. However, forest BEF experiments offer distinct advantages over grassland systems: they facilitate individual-level experimental studies, allow control of density and evenness, and enable more comprehensive observation of temporal changes in species interactions and their relationships with the environment (Ma 2013).

Forest BEF research began relatively late. Around 2000, 29 forest BEF experiments were established globally, forming the TreeDivNet network (www.treedivnet.ugent.be). These studies span boreal, temperate, subtropical, and Mediterranean regions, with tree diversity levels ranging from 0 to 24 species, involving 230 tree species and over one million individual trees (Paquette et al., 2018). While experimental designs vary, all quantify relationships between tree diversity and ecosystem functions by controlling woody plant species diversity. Among these experiments, the Biodiversity–Ecosystem Functioning Experiment China Platform (BEF-China) represents the first artificial biodiversity control experiment in subtropical forests, conducting long-term systematic research to explore how biodiversity across multiple trophic levels—including plants, animals, and microorganisms—influences ecosystem functioning and stability and their underlying mechanisms.

2. Experimental Plots

The BEF-China experimental site comprises two components: an artificial control experiment plot in Xingangshan Town, Dexing City, Jiangxi Province, and a natural forest comparative plot within Qianjiangyuan National Park [Figure 1: see original paper].

Artificial Control Experiment Plot: This includes Plot A (established in 2009, elevation 105–275 m) and Plot B (established in 2010, elevation 105–190 m). The species pool encompasses 42 tree species and 18 shrub species, with diversity designed using both random broken-stick and direct species loss approaches. Both plots use 1-mu plots (25.82 m × 25.82 m) as basic units for seedling planting, totaling 566 plots. Within each 1-mu plot, tree species richness levels are set at 1, 2, 4, 8, 16, and 24 species. Shrubs are planted in 4-mu super-plots at diversity levels of 0, 2, 4, and 8 species. Each mu plot contains 400 tree seedlings spaced at 1.29 m intervals, with shrubs planted at the same density among the trees. The total number of woody plants planted across both plots exceeds 300,000 individuals (Ma 2013; Bruelheide et al., 2014).

Natural Forest Comparative Plot: Established in 2008, this plot includes 27 subplots of 30 m × 30 m, covering five successional stages with community ages of <20 years, 20–40 years, 40–60 years, 60–80 years, and >80 years. The first census recorded 148 woody plant species (>1 m height) belonging to 46 families (Bruelheide et al., 2011).

3. Research Progress from the Xingangshan Main Experiment

As of March 2023, 229 papers have been published based on the BEF-China platform, addressing biodiversity's effects on multiple ecosystem functions including productivity, nutrient cycling, and multi-trophic interactions [Figure 2: see original paper].

3.1 Effects of Tree Species Diversity on Tree Growth and Productivity

During the early experimental stage, studies on sapling growth rates (Lang et al., 2012; Li et al., 2014; Hahn et al., 2017b), canopy structure (Lang et al., 2012), and water uptake characteristics (Trogisch et al., 2016) indicated that biodiversity's positive effects on productivity had not yet emerged due to insufficient time. Sapling growth exhibited strong species specificity, influenced by functional traits and environmental conditions. The relationship between tree growth and traits varied with tree species diversity, with trait effects on growth becoming more pronounced in higher-diversity communities (Li et al., 2014; Kröber et al., 2015; Bongers et al., 2020b).

Over time, studies documenting biodiversity's positive effects on productivity and underlying mechanisms have emerged. After eight years of growth, 16-species mixed forests stored approximately 32 t C ha^{-1}, while monocultures stored only about 12 t C ha^{-1}—less than half the mixed-forest value. Biodiversity effects increased over time across all diversity levels, driven primarily by complementarity effects (Huang et al., 2018a). Simulating random and non-random extinction scenarios, Chen et al. (2020) found that species loss reduced productivity under all scenarios, with impacts intensifying as stand age increased.

Certain soil fungi form symbioses with plant roots, known as mycorrhizae. Arbuscular mycorrhizal (AM) and ectomycorrhizal (ECM) fungi are common types in forests, and mycorrhizal association type strongly influences how tree diversity affects productivity (Ma et al., 2021). As tree diversity increased, net primary productivity of AM trees increased while that of ECM trees decreased, primarily because AM trees enhanced nutrient uptake and accelerated litter decomposition, whereas ECM trees exhibited a trade-off between litter decomposition and nutrient uptake. These results confirm that AM trees dominate in subtropical forests through nutrient acquisition strategies distinct from ECM trees (Deng et al., 2023).

Neighborhood interactions explained over 50% of variation in community productivity along diversity gradients, with the importance of local-scale neighbor effects increasing significantly as community tree diversity rose (Fichtner et al., 2018). Canopy complementarity and plasticity increased with tree diversity, further promoting light absorption and tree growth (Forrester et al., 2019; Perles-Garcia et al., 2021). Over time, neighbor tree diversity altered wood volume allocation, favoring branches and particularly species with flexible morphologies. Tree diversity-mediated spatial allocation patterns and canopy morphological changes represent fundamental mechanisms of canopy complementarity and important drivers of community overyielding (Kunz et al., 2019).

Furthermore, tree species diversity significantly promoted stability of community productivity through a key mechanism: diversity enhanced functional diversity related to water conduction and stomatal control, leading to asynchronous growth among species that ultimately determined community stability (Schnabel et al., 2021).

Tree diversity significantly affected tree growth by influencing species-level functional traits, including canopy (Perles-Garcia et al., 2022), leaf, and root traits

(Weinhold et al., 2022). But do these species-level effects accumulate to the community level, and how are they regulated by tree diversity? Analysis of ten years of continuous monitoring data from BEF-China revealed that as forests developed, the influence of both functional diversity and functional identity strengthened, but functional diversity's importance increased while that of functional identity decreased. This suggests that over time, having more diverse species in communities becomes increasingly important for productivity enhancement (Bongers et al., 2021).

Forests consist of individual trees, yet individual-level interactions are often overlooked in forest BEF research. How does genetic diversity from different mother trees affect productivity? Bongers et al. (2020b) tracked growth of individuals from known mother trees for eight years and measured key leaf and branch traits. They found that individual-level functional traits had stronger effects on growth in high-diversity communities, with this difference intensifying over time between monocultures and mixtures. Incorporating genetic information revealed that genetic diversity promoted intraspecific functional trait differentiation, creating functional spatial differences in resource use that ultimately affected community productivity (Bongers et al., 2020a). Tree species diversity and genetic diversity can indirectly promote forest community productivity by increasing functional diversity and suppressing herbivore damage and resource competition with soil fungi. Genetic diversity's effect on productivity varied with tree species diversity: in monocultures, intraspecific genetic diversity did not reduce soil fungal diversity or herbivore resource competition pressure, while in mixed forests, genetic diversity enhanced productivity by reducing resource competition with soil fungi (Tang et al., 2022).

Regarding belowground productivity, Sun et al. (2017) showed that fine-root production increased with tree species diversity, an effect explained by belowground niche complementarity among species and representing one mechanism underlying aboveground biodiversity overyielding. Another study found that tree diversity significantly affected specific root length of five tree species, indicating that resource allocation and species interactions are potential mechanisms through which tree diversity influences tree growth in subtropical forests (Bu et al., 2017).

3.2 Effects of Tree Species Diversity on Survival Rates

Tree Survival: Based on two surveys in November 2009 and June 2010 of 26 tree species in Plot A, seedling survival after 14 months was 87% (84% for evergreen species, 93% for deciduous species). Seedling survival was significantly affected by tree species diversity, leaf characteristics (deciduous vs. evergreen), species functional traits, planting time, and elevation (Yang et al., 2013). Analyzing individual survival data from years 3–12, Liu et al. (2022b) found that while overall tree survival increased with plot species richness, the effect of tree diversity on survival varied significantly among species and years. These variations were closely related to species functional traits and annual climate conditions. Conservative species showed increased survival with higher tree diversity, stand age, and annual precipitation, while acquisitive species showed the opposite pattern, indicating that interactions among tree diversity, functional traits, and climate can balance survival rates of different forest species.

Shrub Survival: During the early experimental stage, neither tree nor shrub diversity affected shrub survival, with abiotic environmental factors having the greatest impact. Drought was the primary cause of shrub mortality. Among biotic factors, only herbaceous layer species richness and dominance of the fern *Dryopteris sp.* affected shrub survival (Yang et al., 2017). Based on shrub survival data from 2012 and 2019, Xue et al. (2023) found significant interspecific differences in shrub survival rates. Topography and soil C:N ratio strongly influenced shrub survival, while tree and shrub diversity had limited direct effects. However, increased tree diversity enhanced shrub survival by creating denser canopies. Shrub functional traits significantly affected survival, with conservative life-strategy shrubs showing higher survival rates.

3.3 Effects of Tree Species Diversity on Litter Decomposition and Nutrient Cycling

BEF-China research demonstrates that tree species diversity accelerates litter decomposition through effects on compositional changes during decomposition (Ristok et al., 2017), extracellular enzyme activity (Pan and Zhang 2021), and soil microbial community composition and activity (Pei et al., 2017). The effect of litter species diversity depends heavily on the composition of mixed litter (Huang et al., 2018b). Genetic diversity also significantly influences decomposition rates, which increase with individual genetic diversity (Li et al., 2017a). Soil macrofauna and leaf functional traits drive decomposition of secondary metabolites in leaf litter (Ristok et al., 2019). Beyond biodiversity, abiotic factors such as topography and microclimate are crucial for decomposition rates (Seidelmann et al., 2016). For wood decomposition, arthropod decomposer communities (particularly termites) are the primary influencing factor, while tree diversity itself has no direct effect (Eichenberg et al., 2017). Increased canopy density slows fine wood decomposition by promoting predatory ant abundance and creating cooler, moister microclimates that suppress termite foraging intensity (Wu et al., 2021a, 2021b).

Tree species diversity promotes soil organic carbon accumulation across soil depths, with litter input being an important factor (Li et al., 2019). Soil carbon content increases with tree productivity and root diameter but decreases with litter C:N ratio. Tree productivity and functional traits (e.g., mycorrhizal type and litter C:N ratio) regulate microenvironmental conditions, strongly affecting soil microbial biomass and consequently soil carbon content (Beugnon et al., 2023).

Tree diversity enhances nitrogen acquisition and retention, with effects strengthening over time. Niche complementarity in nitrogen uptake promotes resource utilization among coexisting species (Lang et al., 2014). A pot experiment similarly demonstrated that increased ecosystem biomass with tree diversity could largely be explained by niche complementarity in nitrogen uptake among tree species (Liu et al., 2022a).

3.4 Effects of Tree Species Diversity on Multi-Trophic Interactions

Tree diversity effects on multi-trophic interactions have been reported for extrafloral nectary visitation, herbivory, regulation of high-trophic-level relationships, and microbial communities. Nectary visitor abundance and species diversity decreased with tree diversity, reflecting a resource dilution effect—higher tree diversity reduced the proportion of nectary plant individuals and thus nectar availability (Staab et al., 2017). Regarding herbivory, multiple studies indicate that tree diversity increases herbivore damage (Schuldt et al., 2017c; Yang et al., 2018), caused by generalist herbivores (particularly adults) that can feed on more tree species (Zhang et al., 2018).

Tree diversity positively affected hemipteran and ant species diversity, strengthening plant-ant mutualisms (Staab et al., 2015) and weakening correlations between mutualistic ant-hemipteran interactions and leaf chewers (Schuldt et al., 2017b). Tree phylogenetic diversity, rather than species diversity, determined arthropod community composition across trophic levels, increasing predatory arthropod diversity while decreasing herbivorous arthropod diversity (Staab et al., 2021). Overall, tree diversity promotes higher trophic-level species richness, enhancing interactions (antagonistic and mutualistic) among high-trophic-level species by increasing plant community structural and functional diversity, thereby strengthening forest ecosystem stability in response to environmental changes (Cao et al., 2018; Fornoff et al., 2019; Schuldt et al., 2019; Albert et al., 2022).

Some BEF-China studies report non-significant effects of tree diversity on high trophic levels. For example, tree diversity effects on Lepidopteran diversity were largely indirect, mediated through changes in Lepidopteran diversity, with evolutionary dependencies determining herbivore community responses to tree diversity changes (Wang et al., 2020). Herbivorous Lepidopteran larval co-occurrence indices showed significant negative correlations with phylogenetic distance between trees and Lepidoptera (mean pairwise phylogenetic distance, MPD) and positive correlations with nutritional functional traits (C:N ratio), but negative correlations with defensive traits (e.g., leaf toughness) and tree diversity (including species richness and MPD). These results indicate that in subtropical forests, multiple drivers dominated by environmental filtering significantly affect herbivore community co-occurrence through species interactions (Wang et al., 2022).

Regarding microorganisms, tree mycorrhizal type, tree diversity, and their interactions significantly affect microbial community composition (Yang et al., 2022). Tree mycorrhizal type is a key factor determining soil microbial diversity and community composition, with higher tree diversity promoting convergence in soil microbial community composition (Singavarapu et al., 2022). Tree diversity increases soil microbial respiration by increasing microbial biomass rather than altering microbial taxonomic or functional diversity (Beugnon et al., 2021). Fungal co-occurrence network structure is influenced by tree diversity, community composition, and soil C:N ratio, whereas bacterial network structure is affected by soil pH and spatial distance (Gan et al., 2022). Increased tree diversity promotes foliar fungal pathogen diversity (Rutten et al., 2021) but suppresses foliar fungal infection (Saadani et al., 2021), primarily through host dilution effects. In more diverse plant communities, individual susceptibility decreases and increased host spatial distance may reduce pathogen transmission, thereby diminishing pathogen impacts. Pathogen damage reduction was most significant for tree species with soft leaf texture and narrow climatic niches (Schuldt et al., 2017c).

3.5 Effects of Tree Species Diversity on Other Ecosystem Functions

Tree diversity effects on ecosystem functions also include drought stress resistance (Salmon et al., 2018; Fichtner et al., 2020), canopy throughfall (Geißler et al., 2012; Goebes et al., 2015b), soil erosion resistance (Song et al., 2019), and phenological changes (Du et al., 2019). Tree diversity can alleviate drought stress on sapling growth, with facilitative effects strongest during drought and increasing with tree diversity. Soil water partitioning during drought favored the most vulnerable individuals (Fichtner et al., 2020). Early throughfall studies showed that neighbor tree diversity rather than community-level diversity strongly affected throughfall, indicating that tree diversity in young forests only influenced small spatial scales (Goebes et al., 2015a). As forests developed, tree diversity effects strengthened, with higher canopy cover and leaf area index in high-diversity plots reducing interrill erosion (Seitz et al., 2016; Song et al., 2018). Stone cover, biological soil crusts, and litter also controlled soil erosion (Seitz et al., 2015; Seitz et al., 2016; Song et al., 2019), with litter protection diminishing as decomposition progressed, influenced by soil macrofauna presence (Seitz et al., 2015). Phenologically, tree diversity fluctuations altered leaf-out timing in subtropical forests, with abiotic variables more important than biotic ones. Overall, declining tree diversity may exacerbate phenological changes induced by global warming (Du et al., 2019).

4. Effects of Tree Species Diversity Across Successional Stages

4.1 Effects on Productivity

Tree growth rates varied significantly between seasons and years, decreasing with stand age but showing no significant correlation with topography or neighbor tree diversity/density (Chi et al., 2017). In natural forests, species diversity promoted community carbon accumulation, with higher-diversity stands showing greater carbon storage and flux. Stand age effects showed old-growth forests had higher carbon storage than middle-aged and young forests. Each additional tree species increased total forest community carbon storage by 6.4% in the study region (Liu et al., 2018). For the herbaceous layer, productivity was unaffected by either tree or herb diversity. Although herb layer species diversity decreased significantly during succession, tree diversity contributed substantially to herb diversity across all successional stages, with environmental factors having minimal influence (Both et al., 2011).

4.2 Effects on Litter Decomposition and Nutrient Cycling

Total litter quantity increased with tree diversity, with old-growth forests producing more litter. Increased tree diversity improved litter quality (lower C:N ratio), while stand age had no effect. Higher nitrogen content in litter accelerated nutrient cycling, further promoting forest growth (Huang et al., 2017). Eichenberg et al. (2015) found that litter decomposition did not change significantly with stand age, being primarily influenced by leaf functional traits. For wood decomposition, Pietsch et al. (2019) reported that wood decomposition in subtropical forests was mainly controlled by temperature, with relatively weak effects from tree diversity, fungal OTU diversity, and macroinvertebrate diversity.

Tree diversity affects soil organic carbon storage, but what mechanisms drive this relationship? The pathways differ between topsoil and subsoil. In surface soils (0–10 cm), tree diversity influenced soil organic carbon content by regulating plant-derived components (lignin phenols, light fraction organic carbon, and particulate organic matter) (Jia et al., 2021). In deeper soils (30–40 cm), tree diversity promoted accumulation of microbial-derived components (amino sugars and mineral-associated organic matter), dominating soil organic carbon content changes (Jia et al., 2021). Further research examined rhizosphere soil organic carbon sources and their regulation mechanisms. Compared to bulk soil, lignin phenols were more concentrated in rhizosphere soil organic carbon, and amino sugars were also more concentrated in ECM tree rhizospheres due to ECM fungal contributions, but not in AM tree rhizospheres, which showed reduced fungal necromass accumulation. These results highlight novel mechanisms of rhizosphere soil organic carbon source differences associated with different mycorrhizal tree types, with important implications for enhancing soil organic carbon sequestration through plant-mycorrhizal symbioses (Jia et al., 2022).

4.3 Effects on Multi-Trophic Interactions

As tree diversity and phylogenetic diversity increased, herbivorous arthropod abundance and leaf damage increased. Tree species with lower proportions of leaf biomass in the canopy suffered higher herbivory. Generalist herbivores benefited most from high tree diversity (Brezzi et al., 2017; Schuldt et al., 2010). Woody plant functional diversity (leaf chemical composition) and phylogenetic diversity drove herbivory patterns in high-diversity forests (Schuldt et al., 2014a).

Ant community composition differed significantly between young and old-growth forests, with higher species diversity in young forests and a unique ant community in old-growth forests (Staab et al., 2014a). Omnivorous ant evenness decreased with increasing tree evenness but increased with stand age (Staab et al., 2014b). Predatory ant species diversity increased with tree diversity but decreased with leaf functional diversity and shrub cover. Elevation negatively affected ant species diversity (Staab et al., 2014a).

Spider community functional differences increased with tree diversity and stand age. Spider evenness and differentiation increased with tree diversity and stand age. Although spider species diversity decreased with tree diversity (Schuldt et al., 2011), functional diversity remained constant, indicating reduced functional redundancy with increasing tree diversity (Schuldt et al., 2013b). Environmental heterogeneity (Schuldt et al., 2012) and scale differences (Schuldt et al., 2013a) also significantly influenced spider communities.

Overall, belowground communities in subtropical forest perennial stands were structured by top-down control effects of tree diversity, while aboveground arthropod communities were structured by bottom-up control (Schuldt et al., 2017a). In highly diverse forests, tree diversity strengthened relationships between ant and spider community composition and function: ant presence increased spider family diversity, shifting biomass ratios between web-building and hunting spiders toward more web-building-dominated assemblages (Schuldt & Staab 2015). Beyond tree diversity, plant phylogenetic diversity, functional diversity, and multi-trophic diversity also played important roles: plant phylogenetic diversity had stronger bottom-up control on herbivore communities than species diversity (Schuldt et al., 2014b). Tree phylogenetic diversity promoted host-parasitoid interactions more strongly than species diversity (Staab et al., 2016). Plant functional trait diversity and composition had greater effects on individual functions and multifunctionality than species diversity, with multi-trophic diversity being key to understanding multifunctionality drivers (Schuldt et al., 2018). Elevation also had strong direct effects on animal community species diversity even across relatively small gradients, though its influence depended on local resource availability and high-trophic-level organism characteristics (Binkenstein et al., 2018).

Regarding microorganisms, Gao et al. (2015) used 454 high-throughput sequencing to study ECM fungal communities in young, middle-aged, and old-growth forests. ECM fungal communities comprised 393 OTUs belonging to 21 lineages, with three lineages and 11 OTUs showing distinct preferences across successional stages. Significant correlations existed between host plants and fungal communities. Plant community composition was the main driver of soil fungal diversity and community composition in Chinese subtropical forests (Wu et al., 2012). At the genus level, subtropical forest plant diversity was the most important factor affecting ECM fungal diversity (Gao et al., 2013), with symbiotic plant composition determining how ECM fungal traits and diversity influenced competition among subtropical trees (Shi et al., 2017). Additionally, Wu et al. (2013) found that elevation, soil organic carbon, and soil pH were the most important factors influencing fungal community composition.

5. Future Perspectives for BEF-China Research

Based on this synthesis of BEF-China research progress, we propose that future studies should integrate multiple biodiversity dimensions, ecosystem components, functions, and spatiotemporal scales [Figure 3: see original paper].

Biodiversity Dimensions: Current BEF-China research has focused extensively on tree species and functional diversity, but genetic diversity has received limited attention due to disciplinary, technical, and funding constraints. Existing work has addressed tree genetic diversity (Schuldt et al., 2014a; Schuldt et al., 2014b; Staab et al., 2016; Hahn et al., 2017a; Purschke et al., 2017; Tang et al., 2022) and herbivore genetic diversity (Wang et al., 2020). Genetic diversity represents intraspecific genetic variation—the sum of genetic material and resources within species—primarily at molecular levels, particularly gene and genome-level diversity, including morphological and adaptive trait variation determined by genetic material. Some regions may not have high species diversity but include isolated relict lineages that contain unique and rare evolutionary history information preserved in their genes and genomes (Forest et al., 2007). Future BEF-China research should combine multiple diversity dimensions—species, functional, and genetic diversity—to achieve deeper understanding of BEF relationships.

Ecosystem Components: Current BEF-China research has extensively addressed plants and animals but relatively few studies have examined microbial communities, for similar reasons as the limited genetic diversity research. Aboveground-belowground ecological process research has mainly focused on litter decomposition and root uptake, yet soil microorganisms (fungi and pathogens) play crucial roles in these processes through litter decomposition, mycorrhizal symbiosis formation, and pathogenic damage, thereby influencing aboveground multi-trophic interactions (Delgado-Baquerizo et al., 2016; Chen et al., 2019).

High-throughput sequencing technology can facilitate research on genetic diversity and microbial communities. As sequencing costs decrease and DNA sequence length and quality improve, work previously limited to large research institutions can now be conducted in ordinary laboratories (Schneider et al., 2010). Technological advances will provide more methods to drive BEF-China research forward in microbial community and phylogenetic studies.

Ecosystem Functions: Most current BEF-China studies have considered biodiversity effects on single ecological processes. Establishing multifunctionality indicators that can reasonably explain comprehensive ecosystem functional responses remains a challenge for BEF researchers. Satellite remote sensing can estimate land cover types and extent across entire study areas, providing long-term biophysical and habitat condition data for large regions. Combining remote sensing data with field resources and land cover classification can identify specific habitats for habitat modeling, species distribution prediction, and detecting changes in habitat loss and model extinction rates (Parmesan & Yohe 2003). While field-based ecosystem function measurements are difficult to scale up, remote sensing can simultaneously estimate whole-ecosystem functioning (Rocchini et al., 2004).

Spatiotemporal Scales: Generally, biodiversity's relative importance is substantial at small-to-medium spatial scales. For example, at the neighbor-tree scale, neighbor diversity affects trait variation, influencing interactions between neighbor and target species (Lankau 2011). Neighbor diversity alters relative competition intensity and can increase population competition intensity through niche complementarity (Dostal 2011). However, at regional scales with high environmental heterogeneity, the importance of biotic factors as predictors of ecosystem processes weakens, with abiotic factors becoming the main drivers of ecosystem responses to environmental gradients. Therefore, correctly understanding and predicting biodiversity and ecosystem process changes at large scales—such as when synthesizing BEF-China results with other global forest BEF studies—requires emphasizing feedback effects among biodiversity changes, ecosystem functions, and environmental factors (Loreau et al., 2001). Temporally, a major BEF-China finding is that plant productivity increases with tree species diversity, with this effect strengthening annually (Huang et al., 2018a). When will this increase stabilize? How do ecosystem components, processes, and functions change during succession, and how do they respond to concurrent global climate change? These questions may be answered in future BEF-China research.

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