

Seed Dispersal: Methods, Agents, Global Research Trends and Networks

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Abstract

Seed dispersal is one of the essential aspects of plant life cycles that promote the recolonization of degraded sites and naturally restored lands. Bibliometrics has become a necessary tool for analyzing and assessing the output of scientists, cooperation between universities and other related parameters. This review covered the studies carried out between 2001 and 2024. It aims to identify the frequency methods used and dispersal agents and analyze publication trends by utilizing network analysis, identifying leading countries, and visualizing keyword co-occurrence patterns. The results found that seed traps and animal faeces collection are frequently used, while animal dispersal (zoochory) is the most intensive seed dispersal agent studied. However, the findings reveal that scholars from 51 countries were actively engaged in seed dispersal research based on study site and 83 based on institutional affiliations, with the USA leading in both options. Additionally, the analysis revealed that genetic structure and biological control, such as DNA, are emerging fields in seed dispersal studies. The study recommends that future seed dispersal research emphasize explosive, gravity, and water dispersal mechanisms with limited agents and larger coverage.

Keywords: Seed dispersal agents, Methods, Publication trends, Vosviewer analysis

Introduction

Tree population structure and forest composition are significantly impacted by the production, germination, establishment, and survival of seeds (Chen et al., 2014; Francisco et al., 2007; Lalfakawma et al., 2009; Sahoo & Lalfakawma, 2013; Thakur et al., 2021).

The spatial distribution of mature trees within a forest community is determined by seed dispersal and recruitment of seedlings (Chen et al., 2014; McEuen & Curran, 2004; Leslie et al., 2017). However, because of the diverse spatial patterns of seed dispersal, tree seed output frequently varies significantly from year to year (Sahoo & Lalfakawma, 2013). Accordingly, seedfall significantly impacts a forest ecosystem's regeneration process (Gómez et al., 2004).

Seed dispersal is the seed movement process from the mother plant to a new habitat/location, increasing the offspring's survival rate (Martínez et al., 2008). Although it is an important seed escape mechanism from the mother plant (Tabarelli & Peres, 2002) and a key process for forest regeneration (San-José et al., 2020). Dispersal syndromes and seed size, along with dispersing agents, are essential to understanding the role of plant ecology, ecosystem functioning, and biodiversity conservation (O'farrill et al., 2013; González-Varo et al., 2019), as well as connecting the reproduction of adult plants to recruitment processes (Blendinger et al., 2011). Notwithstanding, it is a multifaceted process encompassing several critical stages of a plant's life cycle, including seed removal and treatment, deposition, survival, regeneration, and recruitment (Tsujino & Yumoto, 2009). Animals are essential in seed dispersal, maintaining terrestrial ecosystems (McConkey & O'Farril, 2016; Rogers et al., 2021) and promoting restoration of disturbed habitats (Howe & Miriti, 2004). While dispersal distance and forest density are two important features influencing spatial tree patterns (Bleher et al., 2002), the mean and maximum seed dispersal distances vary across different regions (Campos-Arceiz & Blake,

2011). Muller-Landau et al. (2008) and Sebastián-González et al. (2017) found similarities in dispersal mode and seed properties amongst species. As a result, seeds that travel great distances from the parent tree are more likely to colonize new environments (Lehouck et al., 2009) and influence plant dynamics at different distances from the parent trees.

To study the seed dispersal of each plant, it is important to identify the seed dispersal agent, which helps monitor and assess the quantity of seed movement. Therefore, seed dispersal agents can be classified as: (a) animal (Zoochory), which are divided into: endozoochory, a seed dispersal procedure in which animals devour fruits and then expel the seed at varied distances from the parent plant (Rubalcava-Castillo et al., 2021); epizoochory, seeds attached to the feathers, fur, or animal skin and carried to new location, and myrmecochory, seed dispersed by ants (Leal et al., 2007), (b) wind (Anemochory) seeds have adaptations like hairs, wings or lightweight structure that allow them to be carried by wind (Muller-Landau et al., 2008; Griz & Machado, 2001), (c) water (Hydrochory) seeds are adapted to float and can be dispersed by water current (Muller-Landau et al., 2008), (d) gravity (Barochory) where the seed falls beneath the parent plant crown (Sant'Anna et al., 2013), and (e) ballistic mechanisms (Autochory) seeds forcefully eject from fruit, e.g., explosive (Muller-Landau et al., 2008; Griz & Machado, 2001).

A bibliometric review provides an invaluable contribution to the existing scientific research (Ferreira et al., 2016). It is a method used to analyze scientific literature on a specific field or topic quantitatively (Gutiérrez-Salcedo et al., 2018), and an integral part of research

evaluation methodology, particularly within scientific and applied fields (Ellegaard & Wallin, 2015). However, biometric analysis has been increasingly used as a tool within the scientific research community (Ellegaard, 2018). It can be used to identify research terms in any scientific field, assess the impact of publications, map influential institutions and authors, identify key journals and research gaps, evaluate evidence-based decisions, and track international collaborations. Consequently, in the academic world, ranking and other productivity measurements are routinely applied to bibliometric indicators (Harvey, 2008). A review article summarizes critically selected scientific content (Ellegaard & Wallin, 2015). In recent years, several tools have made producing reports much easier. In contrast, this ranges from databases such as Web of science (WoS), Google scholar or Scopus (Li et al., 2010), which have added capabilities of incorporating reference handling. On the other hand, Vosviewer, bibioshiny, CiteSpace and other related software are used intensively in analyzing these kinds of data (Wu et al., 2023; Moral-Muñoz et al., 2020).

Literature intensively covered seed dispersal issues including loss of seeds through various means (McConkey & O’Farril, 2016; Rogers et al., 2021), maximum dispersal distant (Tamme et al., 2014), empirical plant dispersal kernals synthesis (Bullock et al., 2017), causes of seed dispersal (Beckman & Sullivan, 2023), seed dispersal effectiveness (Schupp et al., 2010), methodological overview of seed dispersal (Quintero et al., 2021), meta-analysis of seed dispersal (Albert et al., 2015), and seed dispersal effectiveness framework (Beckman et al., 2020). However, limited studies summarise

seed dispersal methods, dispersal agents, bibliometric analysis of global trends, and research networks of seed dispersal. Therefore, this study aims to identify the frequency methods used and dispersal agents and analyze publication trends by utilizing network analysis, identifying leading countries based on study site and affiliation, key terms, and visualizing keyword co-occurrence patterns. To achieve these objective the following research questions were highlighted; a) what are frequency methods used?, b) what are most dispersal agents studied?, c) what are the leading countries in field of seed dispersal studies based on study site and affiliation?, d) what is most term used?, e) what are the sources published seed dispersal studies?, and f) what is emerging trends? The study hypothesized that the most frequent methods used are based on dispersal agents studied. In contrast, the leading countries in seed dispersal studies could differ based on study site and affiliation. However, the emerging trend in the field follows the innovative technologies for examining the seed movement. This review will help researchers in seed ecology, particularly seed dispersal, identify the best methods for specific dispersal agents, countries not explored, and emerging trends.

Methodology

Data extraction and approach

This review focused on research of seed dispersal studies conducted during 2001 and 2024. The data were acquired from Web of Science (WoS). However, the used key search terms were “seed dispersal and dispersal distance”, “seed dispersal of plant”, and “tree seed dispersal”. All research articles in English were exported using the plain text file option

and downloaded for network analysis. Conversely, all research titles and abstracts were extracted from plain text files and sorted based on the study objectives following the method described in (Fig. 1). All relevant papers were downloaded using Google Scholar to extract the methodologies used, dispersal agents, study site based on country, and the study duration of each research.

Data sorting and analysis

All extracted data were summarized and presented in tables and figures.

All methods and sampling procedures were listed, and their percentages were recorded. The frequently used methods in seed dispersal and agents were identified based on their frequencies. At the same time, all studies were sorted to identify the most commonly studied countries based on study site. Additionally, we conducted network analysis using VOSviewer to examine research trends in seed dispersal during the determined period (2001- 2024), the key terms used in seed dispersal studies, number of studies based on affiliation were visualized using

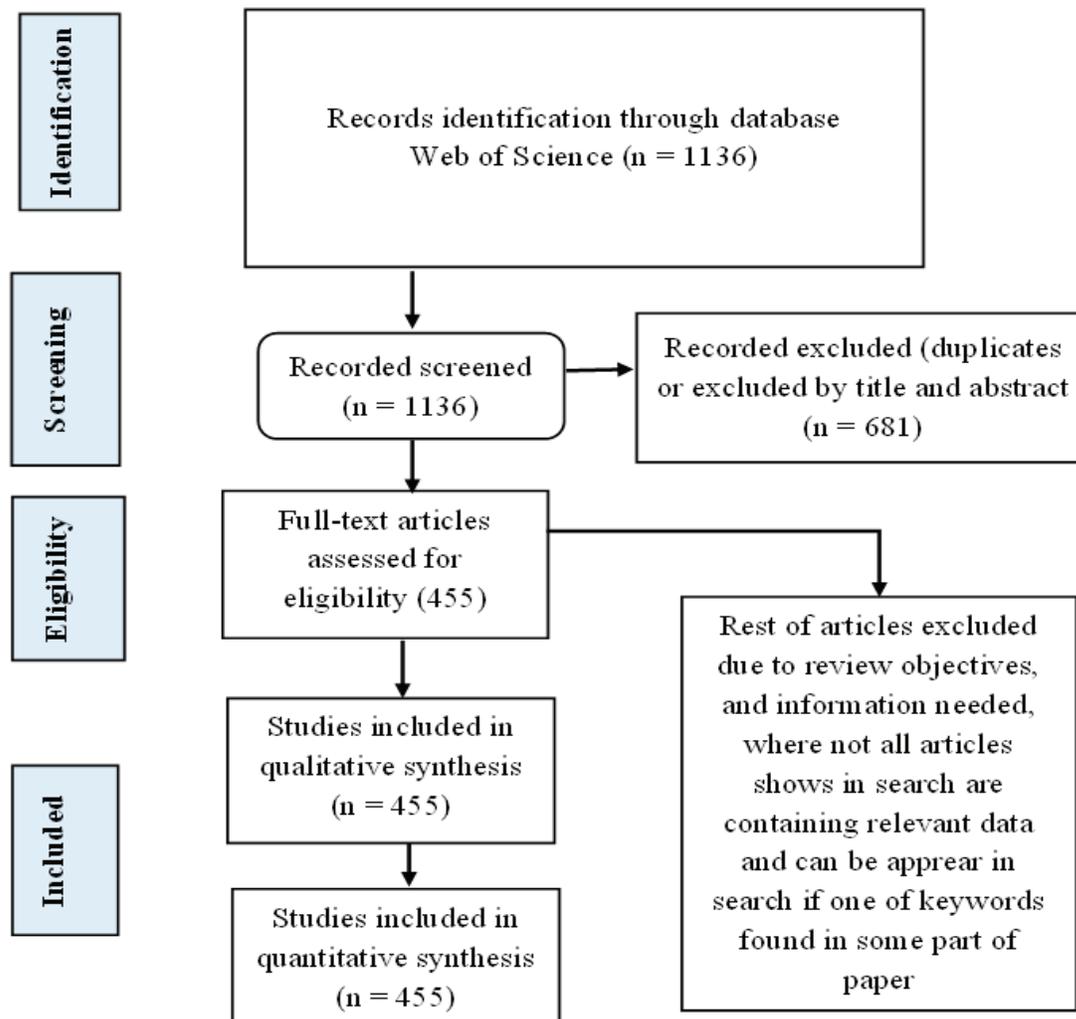


Figure 1. Preferred reporting items for systematic review and meta-analyses (PRISMA) flow diagram (Adopted from Moher et al., 2010)

VOSviewer overlay visualization, where the new trend were identified based on recent year used and its relation to seed dispersal field. Moreover, timeline visualization was applied to model the track evolution of research themes with time. Besides that, network visualization was created using VOSviewer (v1.6.20) to identify the key terms, journals, leading countries and explain the relationships between clustering terms, co-citation, and occurrence from the literature database of seed dispersal studies.

Results

Publication trends and global distribution based on institutional affiliation and study sites

The publication trends varied between years, showing an increasing trend with

years, except during the COVID-19 period. In contrast, publications index shows a good value from 2012 to 2018 (Fig. 2). As many as 83 countries were actively engaged in seed dispersal studies, while the font size and circle label of each country based on number of documents (Fig. 3). However, based on the institutional affiliation and the study sites, the USA followed by China, Brazil, and Spain were the most leading countries in seed dispersal research (Fig. 4).

Study duration, methods, and sampling procedures

We found that the studies with duration of two years were the highest, followed by one and three years (Fig. 5). Ten methods were frequently used by researchers for the study of seed dispersal, led by application of seed traps (36.94% studies)

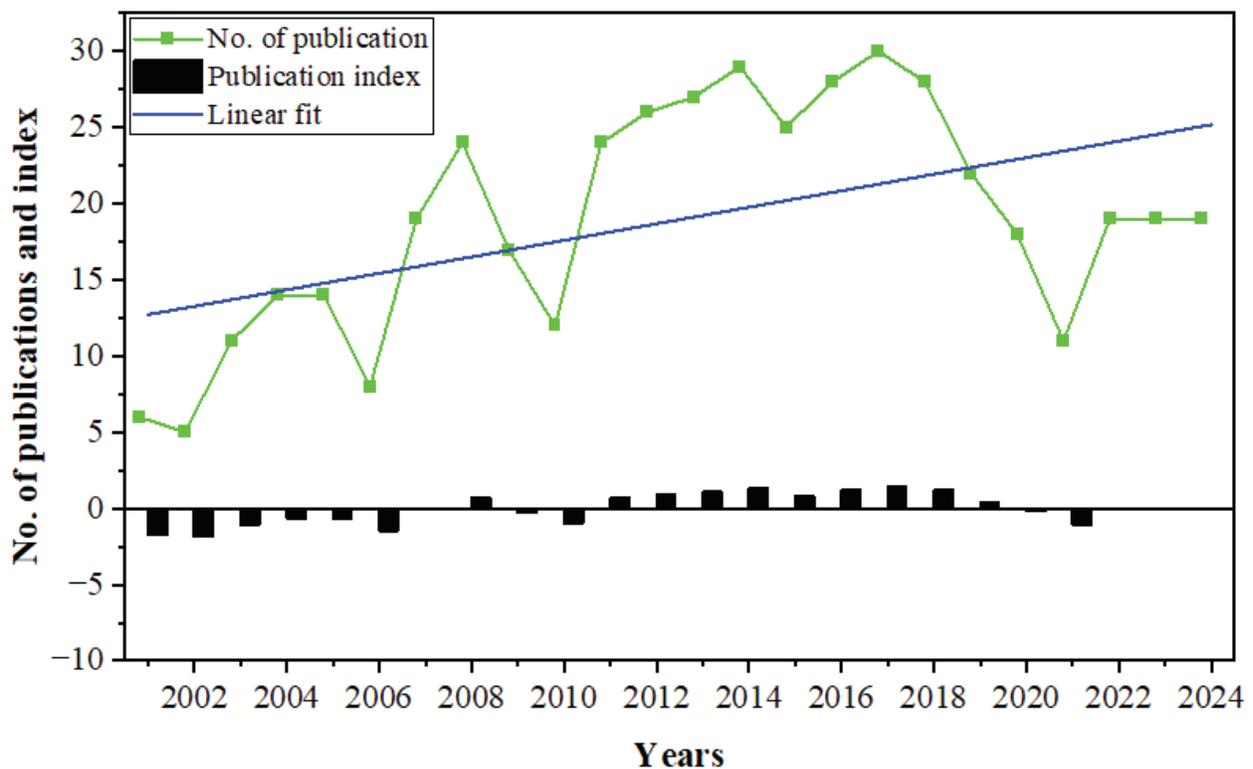


Figure 2. Number of publications during the period of 2001 to 2024 and publication index

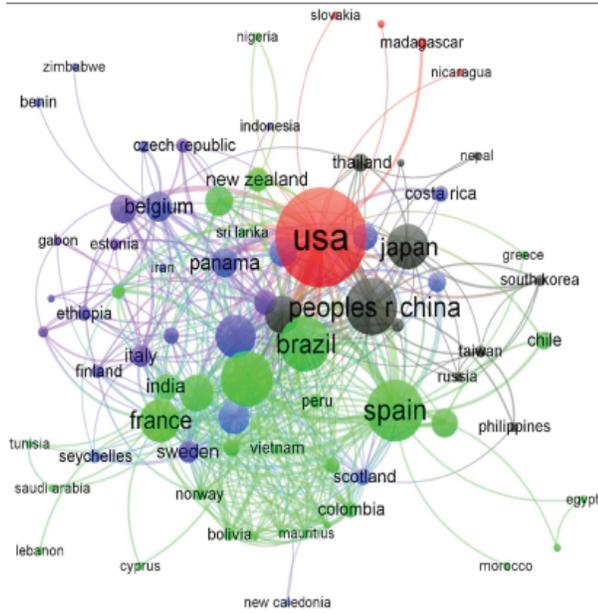


Figure 3. Countries engage in seed dispersal research based on institutional affiliation using VOSviewer analysis

and faeces collection (26.13% studies) (Table 1). These methods are applied practically via 15 sampling procedures, dominated by transect line procedures (28.89% studies) (Table 1). Moreover, each method used and its sampling design/procedures were listed and summarized in Table 2.

Dispersal agents covered by previous studies

Seed dispersal is classified into five categories based on the main dispersal agents. The findings revealed that most of the studies (363 studies) were covered by animal dispersal (zoochory), followed by other dispersal agents (Table 3), while within zoochory, most of the studies were covered by large/medium animals (151 studies), followed by birds (122) (Table 3).

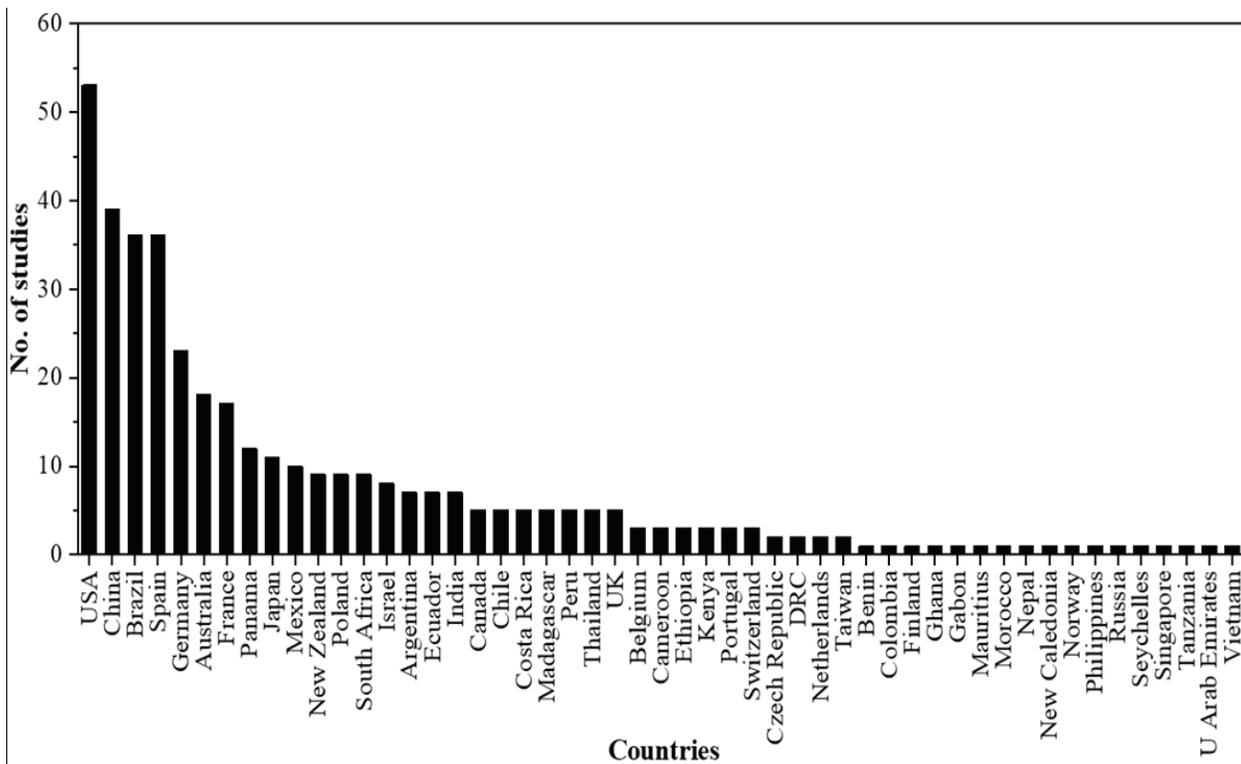


Figure 4. Global distribution of seed dispersal studies based on study site

Table 1. Methods and sampling procedures of seed dispersal

	%
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Method used	
Count number of fruits in tree	9.01
Count number of seedlings	1.80
Faeces collection	26.13
Experiment using seed under mother tree	8.11
Using camera traps	2.70
Using drift net	0.90
Using model for wind	5.41
Using plots in forest	3.60
Using seeds traps	36.94
Using seeds traps and faeces collection	5.41
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Sampling procedure	
Classified dispersal agents and seed size	2.22
Correlate with seed dispersal	7.78
Estimate seedling for seed and dispersal distance	1.11
Measuring distance and sow seed under the tree	3.33
Measuring distance from the mother tree	5.56
Record the birds and seed removal	18.89
Record the seed removed by rodents	2.22
Recorded faeces position using GPS	1.11
seed collection and counting	2.22
Sample plot around mother tree	6.67
Targeting bat roosts	2.22
Tracking animals	11.11
Transect line	28.89
Transect line and count seed remove by animals	3.33
Used genetic approach (DNA)	3.33

Key terms, journals, authors, and an emerging cluster of seed dispersal studies

The findings show that the frequency key terms used in seed dispersal studies from 2001 to 2024 were summarized into 3171 key terms, while based on the analysis of minimum five occurrences of key terms, only 158 key terms met the criteria, and term (seed dispersal) mainly was used among other (Fig. 6). Although the node size indicates the frequency of term use compared to other, the connection

between nodes (edges) represents a strong co-citation relationship. Additionally, we found that 237 journals were actively engage in publishing seed dispersal studies, with only 49 journals publishing at least five papers during the study period (Fig. 7). In contrast, the leading journals include Journal of Ecology, Forest Ecology and Management, Molecular Ecology, and Journal of Global Ecology and Conservation (Fig. 7). Based on analysis, the findings revealed that 3180

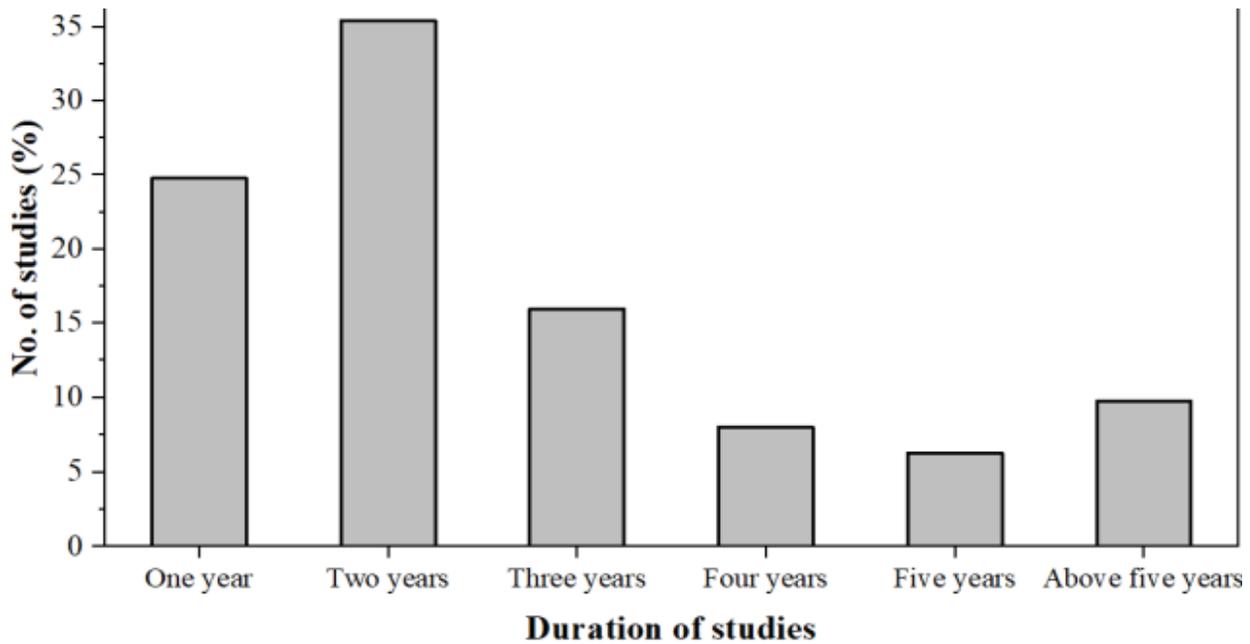


Figure 5. Duration of seed dispersal studies research

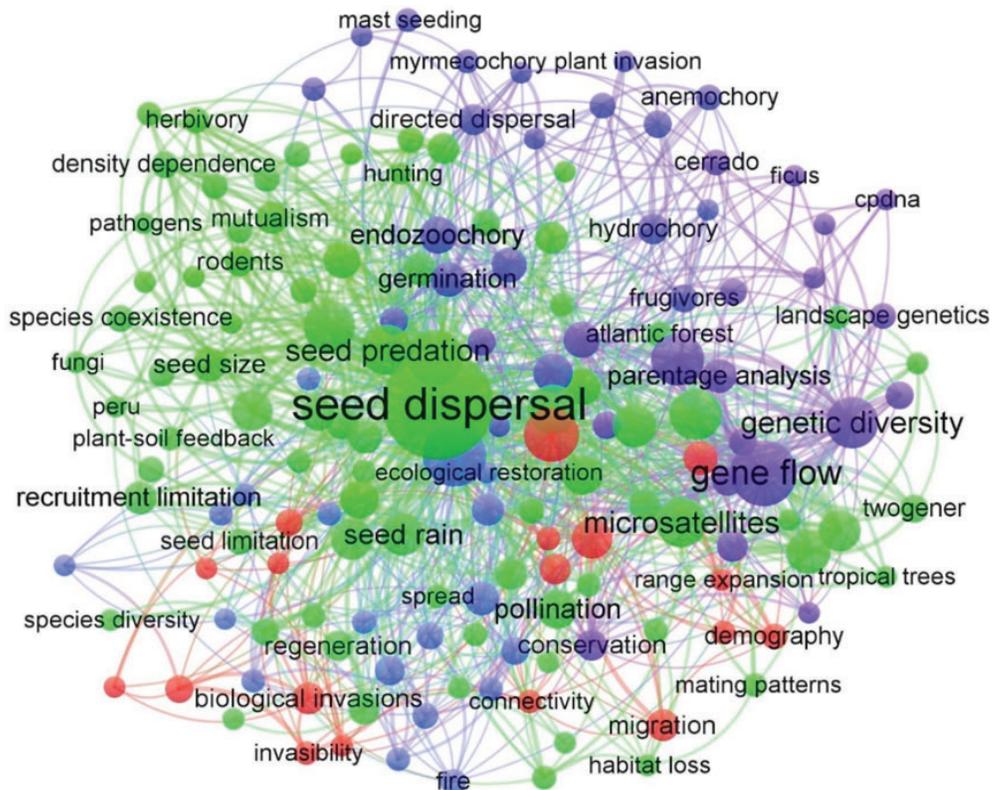


Figure 6. Most key terms used in seed dispersal research are based on Vosviewer analysis

Table 2. Summary of studies in each method with sampling procedure

Methods	Sampling procedure	References
Count number of fruits in the tree	Record bird type and number of seed removal	(Brodie et al. 2009; Jacomassa and Pizo 2010)
Count number of seedlings	Estimated seedling for seed and dispersal distance	(McEuen and Curran 2004)
Faeces collection	Transect line, record faeces position using GPS, targeting bat roosts, and measuring distance from mother tree	(Fragoso et al. 2003; Link et al. 2006; Lenz et al. 2011; Mahandran et al. 2018)
Experiment using seed under mother tree	Record the seed removed by rodents	(Fedriani and Delibes 2009; Leal et al. 2007)
Using camera traps	Tracking animals	(Babweteera and Brown 2008; Niu et al. 2018)
Using drift net	Seed collection and counting	(Greet et al. 2012)
Using model for wind	Correlate wind speed with seed dispersal distance	(Heydel et al. 2014; Nathan et al. 2011; Nathan et al. 2002)
Using plot in forest	Sample plot around the mother tree, transect line and seed removed by animals, measuring distance and sow seed under tree	(Stevenson and Guzmán 2008; Chen et al. 2014; Farwig et al. 2006)
Using seeds traps	Seed collection and counting, measuring distance from the mother tree, and record seed removed by rodents or birds	(San-José et al. 2020; Miranda et al. 2019)
Using seeds traps and faeces collection	Transect line and seed removed by animals, tracking animals, classified dispersal agents and seed size, targeting bat roosts, using genetic approach (DNA)	(González-Varo et al. 2019; Millerón et al. 2013; Blendinger et al. 2011; Griz and Machado 2001; Jordano et al. 2007)

authors were actively engaged in the field of seed dispersal according to their affiliations. In contrast, only 46 authors met the threshold based on five minimum documents. However, “Nathan, r” was the most cited author (1502 citation)

(Fig. 8). Moreover, the trend of seed dispersal is summarized into 5 cluster based on VOSviewer analysis, though new emerging trend introduced in seed dispersal studies are genetic structure, scatter hoarding, microsatellites, climate

Table 3. Number of studies based on dispersal agents

Dispersal agent	Number of studies	References
Zoochory (animal)	363	Stevenson & Guzmán, 2008; Guimarães et al., 2008; Martínez et al., 2008; Khan et al., 2005
Anemochory (wind)	52	Nathan et al., 2011; Damschen et al., 2014; Larson-Johnson, 2023
Hydrochory (water)	15	Cabra-Rivas, 2014; Greet et al., 2012; Kowarik & Sämel, 2008
Barochory (gravity)	14	Chen et al., 2014; Sant' Anna et al., 2013
Autochory (ballistic mechanisms)	11	Muller-Landau et al., 2008
Zoochory		
Large/medium animals (Elephant, monkey, etc.)	157	Clark et al., 2004; Godoy & Jordano, 2001; Brockelman et al., 2022; Mason et al., 2022
Ants	9	Leal et al., 2007; Gallegos et al., 2014
Bat	21	Mahandran et al., 2018; Jacomassa & Pizo, 2010
Rodents	61	Briggs et al., 2009; Bogdziewicz et al., 2020
Birds	119	Herrera et al., 2011; Wang et al., 2019; Tsunamoto et al., 2020
Fish	2	Costa et al., 2023; Anderson et al., 2011

change, habitat fragmentation, gene flow, and genetic diversity but still seed dispersal is used recently (Fig. 9).

Discussion

Publication trends and global distribution based on institutional affiliations and study sites

The publication trends for seed dispersal studies show an increasing pattern during the study period, except for COVID-19, which experienced lockdown and postponement of activities. Several studies showed that seed dispersal publications

increased before lockdown (Schupp et al., 2010; Beckman & Sullivan, 2023; Nogales et al., 2024). The active engagement in research is usually associated with the availability of funds, a well-equipped team, and experts. Consequently, Musa et al. (2023) observed that the number of studies in a particular area depends on the experience and availability of study materials. These findings indicate that developed countries primarily support scientific research, conduct research in varied fields, and share the findings in peer-reviewed publishing houses. Therefore, the number of seed dispersal

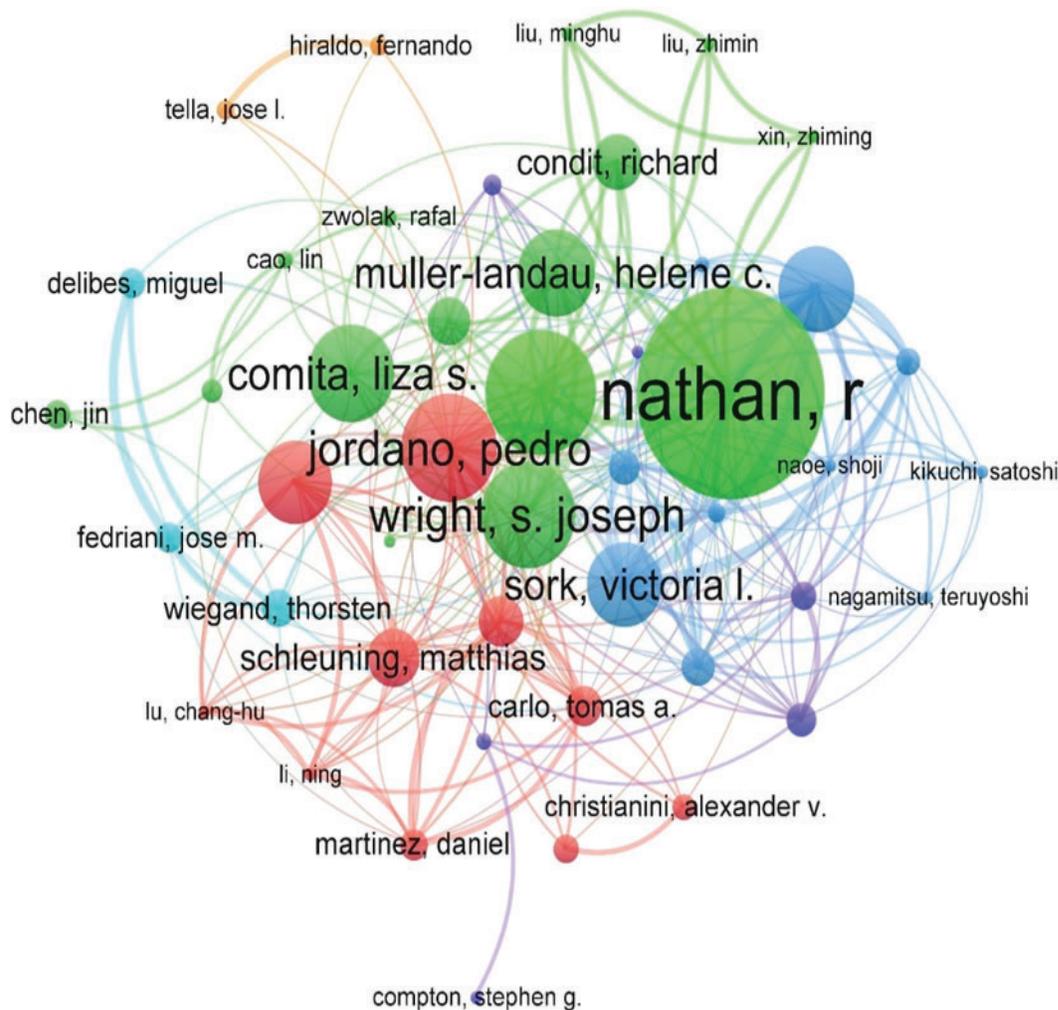


Figure 8. Most active author in the field of seed dispersal studies based on citation

to the dispersal agents and conditions. Although the remaining methods are less used, this does not mean that these methods are not recommended to be used in seed dispersal studies, but they have still not been studied intensively based on dispersal agent, and similarly reported by (Tamme et al., 2014; Bullock et al., 2006).

Dispersal agents covered by previous studies

As discussed earlier, the findings showed that many studies are emerging to examine the processes that connect seed dispersal with seedling distribution. In

this context, the dispersal agents can have far-reaching consequences on the regeneration or survival of a species. We found five main dispersal agents covered by scientific literature, and most dispersal agents studied were animal (zoochory), covering different types of sub-dispersal agents (Table 3). These findings indicate that most plants tend to disperse their seeds via animals; therefore, most studies focused on particular dispersal agents. Similarly, other investigators reported that animals, such as mammals, birds, ants, reptiles, and fish, disseminate more than half of seed-bearing plants (Rogers

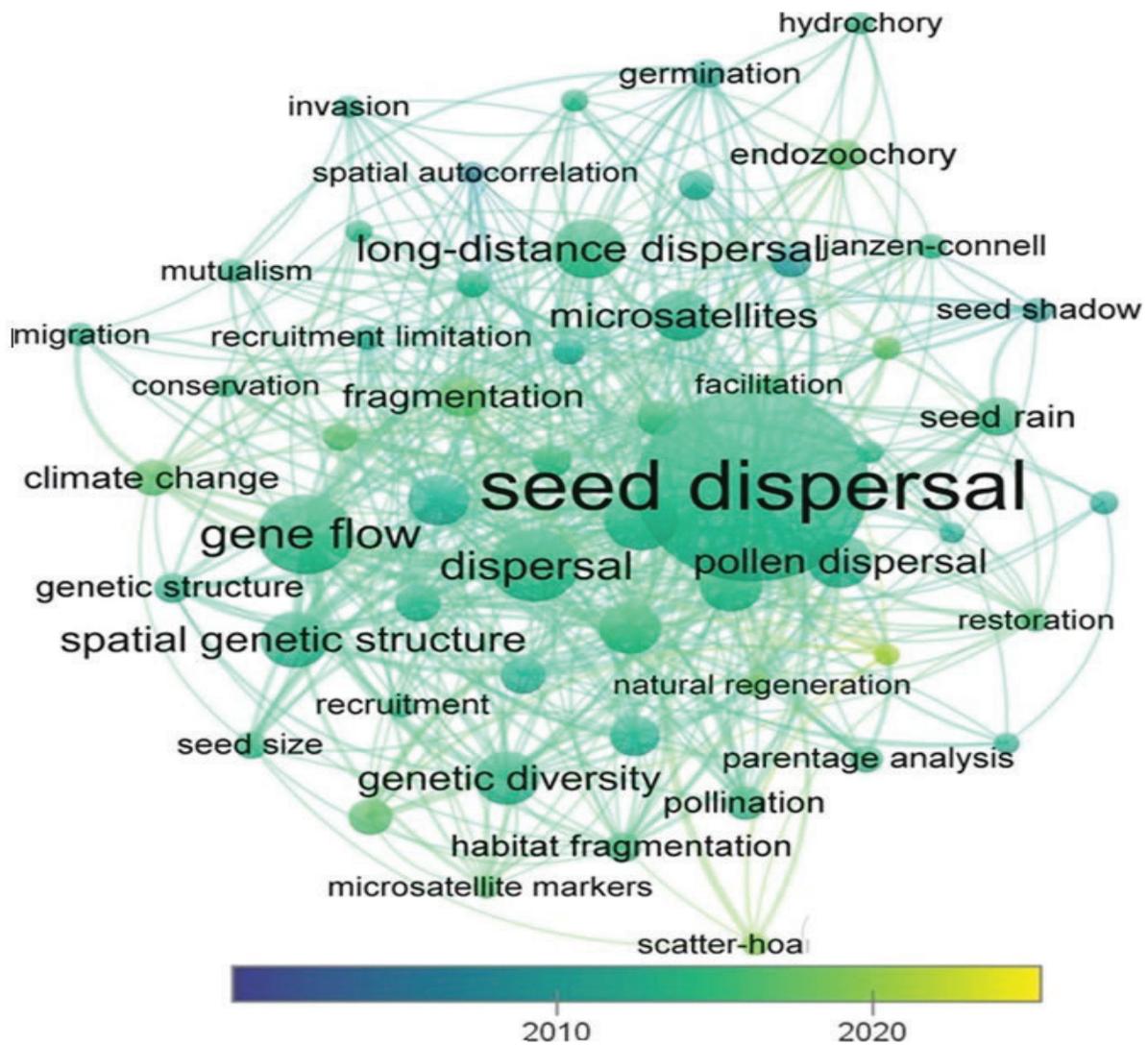


Figure 9. Emerging trend in seed dispersal studies based on the term used

et al., 2021; Beckman & Sullivan, 2023). Conversely, fleshy fruits are vital in seed dispersal by attracting the endozoochory. Valenta & Nevo (2020) reported that mammals disperse large fruits with an odour and colour (such as green and yellow), whereas birds disperse smaller fruits with contrasting colours (such as black, blue and red) and Koike et al. (2011) confirmed seed dispersal by birds and bats. The other dispersal agents have received less attention than animal seed distribution. Several plants distribute their seeds by abiotic mechanisms such

as wind and water (Backman & Sullivan, 2023), and wind and water velocity determine seed dispersal distance in these situations (Soons et al., 2017; Beckman et al., 2020). Conversely, Tamme et al. (2014) and Thomson et al. (2011) discovered that plants with vertebrate dispersal vectors have the most significant seed dispersal distance, followed by wind dispersal, ants, ballistic, and unsupported dispersal ways and Schupp et al. (2010) present in detail the intensive seed dispersal efficacy framework.

The seed dispersal by animals can

disperse over large distances, particularly by migratory animals, and has a high probability of colonizing new habitats (Lehouck et al., 2009) by depositing seeds in nutrient-rich environments. Some adaptations, such as hooks or nutritious fruit, will encourage animals to carry them. The disadvantage of animal seed dispersal relies on animal behaviour, which can be unpredictable and variable; also, potential predation before dispersal may not visit all potential habitats, limiting the range of dispersal. Additionally, the advantage of water seed dispersal is practical for plants near water bodies and could transport over long distances through streams, rivers or the ocean, but is also limited by water flow patterns, timing, and may end up in unsuitable environments and high risk or mortality due to submersion or other water-related factors.

Ballistic seed dispersal (ballochory) is effective for short-distance (Muller-Landau et al., 2008; Rubalcava-Castillo et al., 2021) and occurs when the seeds are forcibly ejected from the parent, due to explosive dehiscence of the fruit, ensuring immediate separation. Meanwhile, the disadvantage of ballistic dispersal is that it leads to a limited dispersal range, requires a specific plant structure to facilitate seed ejection, and may not reach diverse areas. Moreover, seed dispersal by gravity is reported to be a reliable and straightforward mechanism, through which seeds fall close to the parents, ensuring some degree of habitat suitability, while the disadvantage of this agent is that it limits dispersal range, higher competition with parents and siblings and leads to potential seed predation on the ground. Chen et al. (2014) explained that seeds aggregating around the parent trees due to gravity can die

easily due to competition. Furthermore, the researchers have noted that specific dispersal methods should be avoided because of accuracy problems (e.g., wind, ants, and water dispersal can be variable and unpredictable, and animal dispersal can be challenging due to tracking complexity). Another factor to avoid specific dispersal methods was difficult to quantify the seeds disseminated by animal herds, while water and wind involved large-scale and rapid movement, which complicated accurate counting. Measuring the dispersal distance and environmental variables in such studies was another obstacle noted by several researchers.

Fruit types and seed dispersal

Many plants invest in dispersed appendages such as diaspora, velcro-like projections, and in-built mechanisms to disperse themselves. However, vascular plants use diaspore, a modified plant part or dispersal unit of a seed or spore, plus extra tissues that aid dispersal, as an efficient method. The important determinant of seed dispersal distance and distribution pattern in a fragmented landscape is the form of the diaspores in these species. Fruits with a unique protrusion or sticky pericarp can spread far by adhering to the fur of mammals or birds' feet. The same applies to colourful, meaty fruits, which attract animals and birds and aid their spread. Although plant features like fruit production, nutrient reward, secondary compounds, and fruit colour influence birds' fruit choice, and fruit attributes like fruit colour, fruit or infructescence size, pulp/seed ratio, and nutritional content are crucial for drawing frugivores (de Sá Dechoum et al., 2015; Francisco et al., 2007). Large seed size reduces the number of seeds dispersed,

affects handling time and determines the number of fruits moved (Parrado-Rosselli et al., 2002). Christianini & Oliveira (2010) highlighted that trees that produce large fruit are likely to attract a greater number and variety of frugivores (successful seed dispersal increases) compared to trees with small fruits. Additionally, the plants disperse their seeds by wind, which depends on the wind velocity/speed (Horn et al., 2001), and the dispersal distance of winged seeds increases with decreasing seed size and increasing wind speed (Muller-Landau et al., 2008). Though moist tropical and subtropical rainforests represent 70% of fleshy fruit plant species (Moran et al., 2004) and species dispersed by gravity, the seeds are aggregated around the parent trees (Chen et al., 2014) and can be post-dispersed by various external agents (Kasi & Ramasubbu, 2021). Furthermore, it has been noted that secondary dispersal, such as wind, causes further movement and alters the species regeneration dynamics once the diaspores leave their mother plants and land (Tian et al., 2023).

Key terms, journals, authors' citation, and an emerging cluster of seed dispersal

Several terms were recorded in seed dispersal studies; however, seed dispersal is mainly used, which may directly refer to its presence in the keyword list and the research titles. We found that “journal of ecology” and “forest ecology and management” are the most frequent journals publishing such studies, due to their closeness to the seed dispersal and applied ecology research. Consequently, the findings revealed that the emerging research, such as spatial genetic structure, biological control, and genetic diversity, are new research themes in seed dispersal

studies. Utilization of the advanced technology could improve the research outcomes, restoration plans, and the management strategies. Quintero et al. (2021) and Mata et al. (2019) stated that emerging modern techniques such as DNA-based molecular analysis and artificial intelligence, seed dispersal analysis and detection become more relevant and precise. Meanwhile, Miguel et al. (2018) reported that using camera traps or other multimedia recording systems allows researchers to observe the interactions taking place in seed dispersal studies. These findings offer powerful, non-invasive tools for understanding how seeds move across forest landscapes, contributing to broader knowledge of plant ecosystem connectivity and population dynamics. These findings indicate that the themes within the field of seed dispersal change, and more sub-disciplines are emerging due to the new technology. Thus, ecologists are now utilizing innovative technologies and software in conducting seed dispersal research to understand better the interlinkages within the field and their association with other disciplines.

Conclusion

The study highlighted the ongoing global research efforts in seed dispersal, with 51 countries actively contributing to the field. The results found a gradual increase in seed dispersal research, except during the COVID-19 lockdown. A significant bias was evident in these studies, with a strong focus on animals (zoochory) such as large animals, rodents, bats, and birds. Additionally, limited attention was given to dispersal mechanisms like explosive dehiscence and gravity, which could provide key insights into seedling

recruitment patterns. Most of the research was for a short duration; therefore, this study recommends extending seed dispersal research beyond one year to improve data accuracy and ecological relevance. The researchers intensively used seed traps and animal faeces to extract seed dispersal data. However, the recent shift towards genetic tools, such as DNA and camera traps, presents a promising advancement in the field; however, their applicability requires further validation. Future research should prioritize seed deposition pattern analysis, considering traditional and molecular methodologies to bridge the existing knowledge gap. Addressing these gaps will improve our ability to forecast vegetation reactions to environmental changes, guide conservation measures, and guarantee the resilience of ecosystems globally, given the crucial role that seed distribution plays in forming plant communities.

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References

- Albert A, Auffret AG, Cosyns E, Cousins SA, D'hondt B, Eichberg C, Eycott AE, Heinken T, Hoffmann M, Jaroszewicz B & Malo JE 2015. Seed dispersal by ungulates as an ecological filter: A trait-based meta-analysis. *Oikos*, 124(9): 1109-1120. <https://doi.org/10.1111/oik.02512>
- Anderson JT, Nuttle T, Saldaña Rojas JS, Pendergast TH & Flecker AS 2011. Extremely long-distance seed dispersal by an overfished Amazonian frugivore. *Proceedings of the Royal Society B: Biological Sciences*, 278(1723): 3329-3335. <https://doi.org/10.1098/rspb.2011.0155>
- Andresen E 2002. Primary seed dispersal by Red Howler Monkeys and the effect of defecation patterns on the fate of dispersed seeds. *Biotropica*, 34(2): 261-272. <https://doi.org/10.1111/j.1744-7429.2002.tb00537.x>
- Babweteera F & Brown N 2009. Can remnant frugivore species effectively disperse tree seeds in secondary tropical rain forests? *Biodiversity and Conservation*, 18(6): 1611-1627. <https://doi.org/10.1007/s10531-008-9546-6>
- Beckman NG, Aslan CE, Rogers HS, Kogan O, Bronstein JL, Bullock JM, Hartig F, Lambers JHR, Zhou Y, Zurell D & Brodie JF 2020. Advancing an interdisciplinary framework to study seed dispersal ecology. *AoB Plants*, 12(2): plz048. <https://doi.org/10.1093/aobpla/plz048>
- Beckman NG & Sullivan LL 2023. The causes and consequences of seed dispersal. *Annual Review of Ecology, Evolution, and Systematics*, 54(1): 403-427. <https://doi.org/10.1146/annurev-ecolsys-102320-104739>
- Bleher B, Oberrath R & Böhning-Gaese K 2002. Seed dispersal, braeding system, tree density and the spatial pattern of trees – A simulation approach. *Basic and Applied Ecology*, 3(2): 115-123. <https://doi.org/10.1078/1439-1791-00088>
- Blendinger PG, Blake JG & Loiselle BA 2011. Connecting fruit production to seedling

- establishment in two co-occurring *Miconia* species: consequences of seed dispersal by birds in upper Amazonia. *Oecologia*, 167(1): 61-73. <https://doi.org/10.1007/s00442-011-1956-6>
- Bogdziewicz M, Crone EE & Zwolak R 2020. Do benefits of seed dispersal and caching by scatterhoarders outweigh the costs of predation? An example with oaks and yellow-necked mice. *Journal of Ecology*, 108(3): 1009-1018. <https://doi.org/10.1111/1365-2745.13307>
- Briggs JS, Wall SBV & Jenkins SH 2009. Forest rodents provide directed dispersal of Jeffrey pine seeds. *Ecology*, 90: 675-687. <https://doi.org/10.1890/07-0542.1>
- Brockelman WY, McConkey KR, Nathalang A, Somnuk R, Santon J & Matmoon U 2022. Dispersal success of a specialized tropical tree depends on complex interactions among diverse mammalian frugivores. *Global Ecology and Conservation*, 40: e02312. <https://doi.org/10.1016/j.gecco.2022.e02312>
- Brodie JF, Helmy OE, Brockelman WY & Maron JL 2009. Bushmeat poaching reduces the seed dispersal and population growth rate of a mammal-dispersed tree. *Ecological Applications*, 19: 854-863. <https://doi.org/10.1890/08-0955.1>
- Bullock JM, Shea K & Skarpaas O 2006. Measuring plant dispersal: an introduction to field methods and experimental design. *Plant Ecology*, 186: 217-234. <https://doi.org/10.1007/s11258-006-9124-5>
- Bullock JM, Gonzalez LM, Tamme R, Gotzenberger L, White SM, Partel M & Hooftman DAP 2017. A synthesis of empirical plant dispersal kernels. *Journal of Ecology*, 105(1): 6-19. <https://doi.org/10.1111/1365-2745.12666>
- Cabra-Rivas I 2014. Does stream structure affect dispersal by water? A case study of the invasive tree *Ailanthus altissima* in Spain. *Management of Biological Invasions*, 5: 179-186. <https://doi.org/10.3391/mbi.2014.5.2.11>
- Campos-Arceiz A & Blake S 2011. Megagardeners of the forest – The role of elephants in seed dispersal. *Acta Oecologica*, 37: 542-553. <https://doi.org/10.1016/j.actao.2011.01.014>
- Chen L, Wang L, Baiketuohan Y, Zhang C, Zhao X & von Gadow K 2014. Seed dispersal and seedling recruitment of trees at different successional stages in a temperate forest in northeastern China. *Journal of Plant Ecology*, 7: 337-346. <https://doi.org/10.1093/jpe/rtt024>
- Christianini AV & Oliveira PS 2010. Birds and ants provide complementary seed dispersal in a neotropical savanna. *Journal of Ecology*, 98: 573-582. <https://doi.org/10.1111/j.1365-2745.2010.01653.x>
- Clark CJ, Poulsen JR, Connor EF & Parker VT 2004. Fruiting trees as dispersal foci in a semi-deciduous tropical forest. *Oecologia*, 139: 66-75. <https://doi.org/10.1007/s00442-003-1483-1>
- Costa G, Piedade MTF, Ferreira EJ & Maltchik L 2023. The effectiveness of ichthyochoric dispersal in forested wetlands of the Amazon depends on the species of fish and its size. *Forest Ecology and Management*, 549: 121481. <https://doi.org/10.1016/j.foreco.2023.121481>
- Damschen EI, Baker DV, Bohrer G, Nathan R, Orrock JL, Turner JR, Brudvig LA, Haddad NM, Levey DJ & Tewksbury JJ 2014. How fragmentation and corridors affect wind dynamics and seed dispersal in open habitats. *Proceedings of the National Academy of Sciences*, 111(9): 3484-3489. <https://doi.org/10.1073/pnas.1308968111>
- de Sá Dechoum M, Rejmánek M, Castellani TT & Zalba SM 2015. Limited seed dispersal may explain differences in forest colonization by the Japanese raisin tree (*Hovenia dulcis* Thunb.), an invasive alien tree in Southern Brazil. *Tropical Conservation Science*, 8(3): 610-622. <https://doi.org/10.1177/194008291500800303>
- Ellegaard O 2018. The application of bibliometric analysis: disciplinary and user aspects. *Scientometrics*, 116(1): 181-202. <https://doi.org/10.1007/s11192-018-2765-z>
- Ellegaard O & Wallin JA 2015. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics*, 105: 1809-1831. <https://doi.org/10.1007/s11192-015-1645-z>
- Farwig N, Böhning-Gaese K & Bleher B 2006. Enhanced seed dispersal of *Prunus africana* in fragmented and disturbed forests? *Oecologia*, 147: 238-252. <https://doi.org/10.1007/s00442-005-0288-9>
- Fedriani JM & Delibes M 2009. Seed dispersal in the Iberian pear, *Pyrus bourgaeana*: A role for infrequent mutualists. *Ecoscience*, 16: 311-321. <https://doi.org/10.2980/16-3-3253>
- Ferreira JJM, Fernandes CI & Ratten V 2016. A co-citation bibliometric analysis of strategic management research. *Scientometrics*, 109: 1-32. <https://doi.org/10.1007/s11192-016-2008-0>
- Fragoso JMV, Silvius KM & Correa JA 2003. Long-distance seed dispersal by tapirs increases seed survival and aggregates tropical trees. *Ecology*, 84: 1998-2006. <https://doi.org/10.1890/01-0621>
- Francisco MR, Lunardi VO & Galetti M 2007.

- Bird attributes, plant characteristics, and seed dispersal of *Pera glabrata* (Schott, 1858), (Euphorbiaceae) in a disturbed cerrado area. *Brazilian Journal of Biology*, 67: 627-634. <https://doi.org/10.1590/s1519-69842007000400006>
- Gallegos SC, Hensen I & Schleuning M 2014. Secondary dispersal by ants promotes forest regeneration after deforestation. *Journal of Ecology*, 102: 659-666. <https://doi.org/10.1111/1365-2745.12226>
- Godoy JA & Jordano P 2001. Seed dispersal by animals: exact identification of source trees with endocarp DNA microsatellites. *Molecular Ecology*, 10: 2275-2283. <https://doi.org/10.1046/j.0962-1083.2001.01342.x>
- Gómez JM, Valladares F & Puerta-piñero C 2004. Differences between structural and functional environmental heterogeneity caused by seed dispersal. *Functional Ecology*, 18: 787-792. <https://doi.org/10.1111/j.0269-8463.2004.00912.x>
- González-Varo JP, Díaz-García S, Arroyo JM & Jordano P 2019. Seed dispersal by dispersing juvenile animals: a source of functional connectivity in fragmented landscapes. *Biology Letters*, 15: 20190264. <https://doi.org/10.1098/rsbl.2019.0264>
- Greet JOE, Cousens RD & Webb JA 2012. Flow regulation affects temporal patterns of riverine plant seed dispersal: Potential implications for plant recruitment. *Freshwater Biology*, 57(12): 2568-2579. <https://doi.org/10.1111/fwb.12028>
- Griz LMS & Machado ICS 2001. Fruiting phenology and seed dispersal syndromes in caatinga, a tropical dry forest in the northeast of Brazil. *Journal of Tropical Ecology*, 17: 303-321. <https://doi.org/10.1017/s0266467401001201>
- Guimarães PR, Galetti M & Jordano P 2008. Seed dispersal anachronisms: Rethinking the fruits extinct megafauna ate. *PLoS ONE*, 3: e1745. <https://doi.org/10.1371/journal.pone.0001745>
- Gutiérrez-Salcedo M, Martínez MÁ, Moral-Munoz JA, Herrera-Viedma E & Cobo MJ 2018. Some bibliometric procedures for analyzing and evaluating research fields. *Applied Intelligence*, 48: 1275-1287. <https://doi.org/10.1007/s10489-017-1105-y>
- Harvey L 2008. Rankings of higher education institutions: A critical review. *Quality in Higher Education*, 14(3): 187-207. <https://doi.org/10.1080/13538320802507711>
- Herrera JM, Morales JM & García D 2011. Differential effects of fruit availability and habitat cover for frugivore-mediated seed dispersal in a heterogeneous landscape. *Journal of Ecology*, 99: 1100-1107. <https://doi.org/10.1111/j.1365-2745.2011.01861.x>
- Heydel F, Cunze S, Bernhardt-Römermann M & Tackenberg O 2014. Long-distance seed dispersal by wind: disentangling the effects of species traits, vegetation types, vertical turbulence and wind speed. *Ecological Research*, 29(4): 641-651. <https://doi.org/10.1007/s11284-014-1142-5>
- Horn HS, Nathan RAN & Kaplan SR 2001. Long-distance dispersal of tree seeds by wind. *Ecological research*, 16(5): 877-885. <https://doi.org/10.1046/j.1440-1703.2001.00456.x>
- Howe HF & Miriti MN 2004. When seed dispersal matters. *BioScience*, 54: 651. [https://doi.org/10.1641/0006-3568\(2004\)054](https://doi.org/10.1641/0006-3568(2004)054)
- Jacomassa FAF & Pizo MA 2010. Birds and bats diverge in the qualitative and quantitative components of seed dispersal of a pioneer tree. *Acta Oecologica*, 36: 493-496. <https://doi.org/10.1016/j.actao.2010.07.001>
- Jordano P, García C, Godoy JA & Garcia-Castaño J 2007. Differential contribution of frugivores to complex seed dispersal patterns. *Proceedings of the National Academy of Sciences*, 104(9): 3278-3282. <https://doi.org/10.1073/pnas.0606793104>
- Kasi KS & Ramasubbu R 2021. Phenological patterns, fruit predation, and seed dispersal in two endangered trees (*Elaeocarpus* spp.) of Southern Western Ghats, India. *Journal of Asia-Pacific Biodiversity*, 14: 275-282. <https://doi.org/10.1016/j.japb.2021.02.002>
- Khan ML, Bhuyan P & Tripathi RS 2005. Effects of forest disturbance on fruit set, seed dispersal and predation of Rudraksh (*Elaeocarpus ganitrus* Roxb.) in northeast India. *Current Science*, 88(1): 133-142. <https://www.jstor.org/stable/24110103>
- Koike S, Masaki T, Nemoto Y, Kozakai C, Yamazaki K, Kasai S, Nakajima A & Kaji K 2011. Estimate of the seed shadow created by the Asiatic black bear *Ursus thibetanus* and its characteristics as a seed disperser in Japanese cool-temperate forest. *Oikos*, 120(2): 280-290. <https://doi.org/10.1111/j.1600-0706.2010.18626.x>
- Kowarik I & Säumel I 2008. Water dispersal as an additional pathway to invasions by the primarily wind-dispersed tree *Ailanthus altissima*. *Plant Ecology*, 198: 241-252. <https://doi.org/10.1007/s11258-008-9398-x>
- Lalfakawma L, Sahoo UK, Roy S, Vanlalhriatpuia K & Vanlalhluna PC 2009. Community

- composition and tree population structure in undisturbed and disturbed tropical semi-evergreen forest stands of North-East India. *Applied Ecology and Environmental Research*, 7(4): 303-318. https://www.aloki.hu/pdf/0704_303318.pdf
- Larson-Johnson K 2023. Wind variability limits the potential influence of propagule morphology and descent rate on dispersal in the winged fruits of *Carpinus* (Betulaceae). *Review of Palaeobotany and Palynology*, 310: 104829. <https://doi.org/10.1016/j.revpalbo.2022.104829>
- Leal IR, Wirth R & Tabarelli M 2007. Seed dispersal by ants in the semi-arid Caatinga of north-east Brazil. *Annals of Botany*, 99: 885-894. <https://doi.org/10.1093/aob/mcm017>
- Lehouck V, Spanhove T, Demeter S, Groot NE & Lens L 2009. Complementary seed dispersal by three avian frugivores in a fragmented afro-montane forest. *Journal of Vegetation Science*, 20(6): 1110-1120. <https://doi.org/10.1111/j.1654-1103.2009.01109.x>
- Lenz J, Fiedler W, Caprano T, Friedrichs W, Gaese BH, Wikelski M & Böhning-Gaese K 2011. Seed-dispersal distributions by trumpeter hornbills in fragmented landscapes. *Proceedings of the Royal Society B: Biological Sciences*, 278(1716): 2257-2264. <https://doi.org/10.1098/rspb.2010.2383>
- Leslie AB, Beaulieu JM & Mathews S 2017. Variation in seed size is structured by dispersal syndrome and cone morphology in conifers and other nonflowering seed plants. *New Phytologist*, 216(2): 429-437. <https://doi.org/10.1111/nph.14456>
- Li J, Burnham JF, Lemley T & Britton RM 2010. Citation analysis: Comparison of Web of Science®, Scopus™, SciFinder®, and Google Scholar. *Journal of Electronic Resources in Medical Libraries*, 7(3): 196-217. <https://doi.org/10.1080/15424065.2010.505518>
- Link A & Di Fiore A 2006. Seed dispersal by spider monkeys and its importance in the maintenance of neotropical rain-forest diversity. *Journal of Tropical Ecology*, 22: 235-246. <https://doi.org/10.1017/s0266467405003081>
- Mahandran V, Murugan CM, Marimuthu G & Nathan PT 2018. Seed dispersal of a tropical deciduous Mahua tree, *Madhuca latifolia* (Sapotaceae) exhibiting bat-fruit syndrome by pteropodid bats. *Global Ecology and Conservation*, 14: e00396. <https://doi.org/10.1016/j.gecco.2018.e00396>
- Martínez I, García D & Obeso JR 2008. Differential seed dispersal patterns generated by a common assemblage of vertebrate frugivores in three fleshy-fruited trees. *Ecoscience*, 15: 189-199. <https://doi.org/10.2980/15-2-3096>
- Mason DS, Baruzzi C & Lashley MA 2022. Passive directed dispersal of plants by animals. *Biological Reviews of the Cambridge Philosophical Society*, 97: 1908-1929. <https://doi.org/10.1111/brv.12875>
- Mata VA, Rebelo H, Amorim F, McCracken GF, Jarman S & Beja P 2019. How much is enough? Effects of technical and biological replication on metabarcoding dietary analysis. *Molecular Ecology*, 28(2): 165-175. <https://doi.org/10.1111/mec.14779>
- McConkey KR & O'Farrill G 2016. Loss of seed dispersal before the loss of seed dispersers. *Biological Conservation*, 201: 38-49. <https://doi.org/10.1016/j.biocon.2016.06.024>
- McEuen AB & Curran LM 2004. Seed dispersal and recruitment limitation across spatial scales in temperate forest fragments. *Ecology*, 85: 507-518. <https://doi.org/10.1890/03-4006>
- Moher D, Liberati A, Tetzlaff J, Altman DG & Prisma Group 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery*, 8(5): 336-341. <https://doi.org/10.1016/j.ijss.2010.02.007>
- Miguel MF, Jordano P, Tabeni S & Campos CM 2018. Context-dependency and anthropogenic effects on individual plant-frugivore networks. *Oikos*, 127(7): 1045-1059. <https://doi.org/10.1111/oik.04978>
- Millerón M, López de Heredia U, Lorenzo Z, Alonso J, Dounavi A, Gil L & Nanos N 2013. Assessment of spatial discordance of primary and effective seed dispersal of European beech (*Fagus sylvatica* L.) by ecological and genetic methods. *Molecular Ecology*, 22(6): 1531-1545. <https://doi.org/10.1111/mec.12200>
- Miranda A, Vásquez IA, Becerra P, Smith-Ramírez C, Delpiano CA, Hernández-Moreno A & Altamirano A 2019. Traits of perch trees promote seed dispersal of endemic fleshy-fruit species in degraded areas of endangered Mediterranean ecosystems. *Journal of Arid Environments*, 170: 103995. <https://doi.org/10.1016/j.jaridenv.2019.103995>
- Moran C, Catterall CP, Green RJ & Olsen MF 2004. Functional variation among frugivorous birds: implications for rainforest seed dispersal in a fragmented subtropical landscape. *Oecologia*, 141(4): 584-595. <https://doi.org/10.1007/s00442->

- 004-1685-1
- Moral-Muñoz JA, Herrera-Viedma E, Santisteban-Espejo A & Cobo MJ 2020. Software tools for conducting bibliometric analysis in science: An up-to-date review. *Profesional de la Información*, 29(1): e290103. <https://doi.org/10.3145/epi.2020.ene.03>
- Muller-Landau HC, Wright SJ, Calderón O, Condit R & Hubbell SP 2008. Interspecific variation in primary seed dispersal in a tropical forest. *Journal of Ecology*, 96(4): 653-667. <https://doi.org/10.1111/j.1365-2745.2008.01399.x>
- Musa FI, Sahoo UK, Eltahir ME, Magid TDA, Adlan OE, Abdelrhman HA & Abdelkarim AA 2023. Contribution of non-wood forest products for household income in rural area of Sudan - A review. *Journal of Agriculture and Food Research*, 14: 100801. <https://doi.org/10.1016/j.jafr.2023.100801>
- Nathan R, Horvitz N, He Y, Kuparinen A, Schurr FM & Katul GG. 2011. Spread of North American wind-dispersed trees in future environments. *Ecology Letters*, 14: 211-219. <https://doi.org/10.1111/j.1461-0248.2010.01573.x>
- Nathan R, Katul GG, Horn HS, Thomas SM, Oren R, Avissar R, Pakala SW & Levin SA 2002. Mechanisms of long-distance dispersal of seeds by wind. *Nature*, 418: 409-413. <https://doi.org/10.1038/nature00844>
- Nogales M, McConkey KR, Carlo TA, Wotton DM, Bellingham PJ, Traveset A, González-Castro A, Heleno R, Watanabe K, Ando H & Rogers H 2024. A review on the state of the art in frugivory and seed dispersal on islands and the implications of global change. *The Botanical Review*, 90(2): 160-185. <https://doi.org/10.1007/s12229-023-09296-8>
- Niu HY, Xing JJ, Zhang HM, Wang D & Wang XR 2018. Roads limit of seed dispersal and seedling recruitment of *Quercus chenii* in an urban hillside forest. *Urban Forestry & Urban Greening*, 30: 307-314. <https://doi.org/10.1016/j.ufug.2018.01.023>
- O'Farrill G, Galetti M & Campos-Arceiz A 2013. Frugivory and seed dispersal by tapirs: an insight on their ecological role. *Integrative Zoology*, 8(1): 4-17. <https://doi.org/10.1111/j.1749-4877.2012.00316.x>
- Parrado-Rosselli A, Cavelier J & van Dulmen A 2002. Effect of fruit size on primary seed dispersal of five canopy tree species of the Colombian Amazon. *Selbyana*, 23(2): 245-257. <https://www.jstor.org/stable/41760123>
- Quintero E, Isla J & Jordano P 2021. Methodological overview and data-merging approaches in the study of plant-frugivore interactions. *Oikos*, 2022(2): e08379. <https://doi.org/10.1111/oik.08379>
- Rogers HS, Donoso I, Traveset A & Fricke EC 2021. Cascading impacts of seed disperser loss on plant communities and ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, 52(1): 641-666. <https://doi.org/10.1146/annurev-ecolsys-012221-111742>
- Rubalcava-Castillo FA, Sosa-Ramírez J, Luna-Ruiz JDJ, Valdivia-Flores AG & Íñiguez-Dávalos LI 2021. Seed dispersal by carnivores in temperate and tropical dry forests. *Ecology and Evolution*, 11(9): 3794-3807. <https://doi.org/10.1002/ece3.7201>
- Sahoo UK & Lalfakawma L 2013. Population dynamics of *Castanopsis tribuloides* A.(DC) in an undisturbed and disturbed tropical forest stands of North-east India. *Journal of Experimental Biology and Agricultural Sciences*, 1(6): 454-463. <https://www.jebas.org/wp-content/uploads/2014/09/Sahoo-and-Lalfakawma-JEBAS.pdf>
- San-José M, Arroyo-Rodríguez V & Meave JA 2020. Regional context and dispersal mode drive the impact of landscape structure on seed dispersal. *Ecological Applications*, 30(2): e02033. <https://doi.org/10.1002/eap.2033>
- Sant'Anna CS, Sebbenn AM, Klabunde GH, Bittencourt R, Nodari RO, Mantovani A & dos Reis MS 2013. Realized pollen and seed dispersal within a continuous population of the dioecious coniferous Brazilian pine [*Araucaria angustifolia* (Bertol.) Kuntze]. *Conservation Genetics*, 14(3): 601-613. <https://doi.org/10.1007/s10592-013-0451-5>
- Schupp EW, Jordano P & Gómez JM 2010. Seed dispersal effectiveness revisited: A conceptual review. *New Phytologist*, 188(2): 333-353. <https://doi.org/10.1111/j.1469-8137.2010.03402.x>
- Sebastián-González E, Pires MM, Donatti CI, Guimarães PR & Dirzo R 2017. Species traits and interaction rules shape a species-rich seed-dispersal interaction network. *Ecology and Evolution*, 7: 4496-4506. <https://doi.org/10.1002/ece3.2865>
- Soons MB, de Groot GA, Cuesta Ramirez MT, Fraaije RG, Verhoeven JT & de Jager M 2017. Directed dispersal by an abiotic vector: wetland plants disperse their seeds selectively to suitable sites along the hydrological gradient via water. *Functional Ecology*, 31(2): 499-508. <https://doi.org/10.1111/1365-2435.12771>

- Stevenson P & Guzmán A 2008. Seed dispersal, habitat selection and movement patterns in the Amazonian tortoise, *Geochelone denticulata*. *Amphibia-Reptilia*, 29: 463-472. <https://doi.org/10.1163/156853808786230442>
- Tabarelli M & Peres CA 2002. Abiotic and vertebrate seed dispersal in the Brazilian Atlantic forest: implications for forest regeneration. *Biological Conservation*, 106(2): 165-176. [https://doi.org/10.1016/S0006-3207\(01\)00243-9](https://doi.org/10.1016/S0006-3207(01)00243-9)
- Tamme R, Götzenberger L, Zobel M, Bullock JM, Hooftman DA, Kaasik A & Pärtel M 2014. Predicting species' maximum dispersal distances from simple plant traits. *Ecology*, 95(2): 505-513. <https://doi.org/10.1890/13-1000.1>
- Thakur U, Bisth NS, Kumar A, Kumar M & Sahoo UK 2021. Regeneration potential of forest vegetation of churdhar wildlife sanctuary of India: implication for forest management. *Water, Air, & Soil Pollution*, 232(9): 373. <https://doi.org/10.1007/s11270-021-05315-9>
- Thomson FJ, Moles AT, Auld TD & Kingsford RT 2011. Seed dispersal distance is more strongly correlated with plant height than with seed mass. *Journal of Ecology*, 99(6): 1299-1307. <https://doi.org/10.1111/j.1365-2745.2011.01867.x>
- Tian L, Liang W, Liu Z, Liu M, Phartyal SS, Zong L, Qian J, Xin Z, Zhu J, Ba C & Li X 2023. The influence of vegetation structure on lift-off velocity of diaspores during secondary wind dispersal. *Ecological Indicators*, 155: 111050. <https://doi.org/10.1016/j.ecolind.2023.111050>
- Tsujino R & Yumoto T 2009. Topography-specific seed dispersal by Japanese macaques in a lowland forest on Yakushima Island, Japan. *Journal of Animal Ecology*, 78: 119-125. <https://doi.org/10.1111/j.1365-2656.2008.01482.x>
- Tsunamoto Y, Naoe S, Masaki T & Isagi Y 2020. Different contributions of birds and mammals to seed dispersal of a fleshy-fruited tree. *Basic and Applied Ecology*, 43: 66-75. <https://doi.org/10.1016/j.baae.2019.07.005>
- Valenta K & Nevo O 2020. The dispersal syndrome hypothesis: How animals shaped fruit traits, and how they did not. *Functional Ecology*, 34: 1158-1169. <https://doi.org/10.1111/1365-2435.13564>
- Wang GH, Yang ZX, Chen P, Tan WN & Lu CH 2019. Seed dispersal of an endangered *Kmeria septentrionalis* by frugivorous birds in a karst habitat. *Pakistan Journal of Zoology*, 51(3): 1195-1198. <https://doi.org/10.17582/journal.pjz/2019.51.3.sc5>
- Wu YY, Li CC, Lin X, Xu F, Shan SK, Guo B, Li FXZ, Zheng MH, Xu QS, Lei LM & Duan JY 2023. Global publication trends and research trends of necroptosis application in tumor: A bibliometric analysis. *Frontiers in Pharmacology*, 14: 1112484. <https://doi.org/10.3389/fphar.2023.1112484>