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Original Research Paper

Seed Dispersal Services by Frugivorous Birds in Tropical Forest Regeneration Following Selective Logging

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Key Words

Seed dispersal, Frugivorous birds, Tropical forest regeneration, Selective logging, Biodiversity loss, Seed rain dynamics, Ecosystem recovery.

Abstract

Selective logging alters forest structure and can disrupt even the most critical ecosystem processes, such as seed dispersal, which is critical for natural regeneration. This is an evaluation of frugivorous bird seed dispersal and regeneration of tropical forests that have been selectively logged. The field experiment compared logged and unlogged control sites over 12 months, including bird surveys, seed rain sampling, and a germination experiment. One thousand two hundred and forty-eight observations of birds were made to constitute 37 frugivorous species, and the richness of species decreased by a quarter in the logged regions. Nevertheless, seed dispersal was also high: frugivorous birds scattered an average of 18,600 seeds per hectare per year in logged forests, compared with 24,300 in unlogged areas (a 23% reduction). It is interesting to note that the medium- and large-bodied birds together accounted for approximately 86% of total seed dispersal, highlighting their dominant role despite a 31% decline in abundance post-logging. The distribution of seed deposition showed a higher percentage (46%) of early-successional plant species in the logged regions than in the controls (28%). The success of seed germination of the dispersed seeds (bird-favored) was found to be much better (by 17%, $p < 0.05$) as compared to the non-dispersed. The findings show that, despite selective logging decreasing bird diversity and dispersal rates, frugivorous birds remain an important part of the forest regeneration process by driving seed flow and facilitating plant growth. The conservation plans must prioritize safeguarding important frugivore species and the habitat structures that facilitate their survival. The further increase in the structural complexity of logged forests could also enhance seed dispersal services and accelerate the restoration of the ecosystem.

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Introduction

Seed dispersal is an ecological process that maintains plant diversity and allows forest regeneration, especially in tropical ecosystems, where a significant percentage of tree species rely on animals to carry their propagules. Frugivorous birds have disproportionately significant contribution in that the seeds are carried over broken and disturbed landscapes and this improves the spatial distribution of recruitment and genetic diversity. It has been demonstrated that avian dispersers will enhance the successful establishment of large-sized tree species, which cannot easily be dispersed otherwise (Reid et al., 2021). Furthermore, frugivory is a keystone interaction in tropical forests, which maintains intricate ecological interactions that sustain not only plants but also animals (Saranya, 2026; Messeder et al., 2021). Seed dispersal effectiveness does not just depend on the quantity of the seeds but also the behaviour of the dispersers, her usage of the habitat and her pattern of movement which determine the place of seed deposition and its chance of survival. Current literature points out that incorporation of seed dispersal networks in the planning of restoration is an excellent approach to enhancing the regeneration performance and ecological rewards of retained functional frugivore communities (Lussier et al., 2025).

Although selective logging is in many ways considered less harmful than clear-cutting, it leads to severe structural and compositional alterations in tropical forests. These changes have an impact on canopy cover, microclimate and availability of resources that subsequently have an impact on faunal communities. There is evidence that logging decreases the body size and abundance of frugivorous birds especially larger species which are major dispersers of large seeds (Messina et al., 2021). There are also records of changes in the movement patterns of birds; understory species are observed to have limited mobility in logged forests, which may restrict the distance of seed dispersal (Cosset et al., 2021). Also, disruptions change seed rain charts, with the early-successional or generalist species prevailing over the late-successional trees (Al-Salahi et al., 2025). Lasting habitat perturbation also alters fruit availability and dispersal phenotypes and disrupts mutualistic interactions among plants and frugivores (Espinosa et al., 2025). All these cascading effects eventually limit natural regeneration processes and can cause long-term changes in forest composition and reduced resilience to ecological change (Faria et al., 2025).

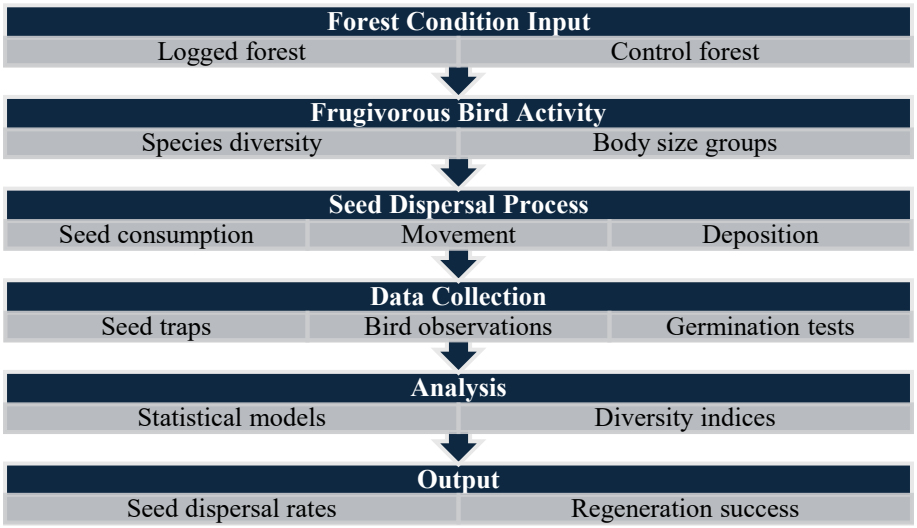


Figure 1: Framework of Seed Dispersal and Forest Regeneration Analysis

The research has a sequence of workflows as indicated in the diagram (Figure 1) that begins with the inputs of the forest conditions (logged and control forest), followed by the activity of the frugivorous birds, seed dispersion mechanisms, and by the data collection process. It illustrates how bird diversity and behavior influence seed consumption and movement and deposition and subsequently measures this influence of field procedures, including seed traps and germination experiments. The framework ends with the analysis processes founded upon statistical models and diversity indices to generate significant products: the rates of seed dispersal and the success of overall regeneration. This gives one a clear picture of the overall approach of the study.

The study aims to establish the contribution of the frugivorous birds in the seed distribution and regeneration of forests in selectively logged tropical forests. Specifically, it tries to (i) quantify the change in the rate of seed dispersal between the logged and unlogged areas (ii) evaluate the change in the structure and behavior of the frugivores and (iii) establish the implications of the same to the processes of plant recruitment. The research gives a comprehensive description of the role of bio interactions mediating forest regeneration linking avian ecology with regeneration processes.

The processes that cause seed dispersal services in disturbed tropical forests are also significant in predicting the future recovery of the ecosystem. Since selective logging keeps increasing in most tropical regions, knowledge of the mechanisms that enable natural recovery can be used to guide the development of sustainable forest management and conservation.

The study is notable in that it integrates field data on data on frugivorous bird behavior, seed dispersal and measures of regeneration, which offers a multidimensional perspective on post-logging recovery. It also indicates the frozen but transformed state of birds in the maintenance of ecological functions and implies feasible news regarding the improvement of restoration performance.

The article consists of six significant parts that give the research an organized format. The Section II will follow after the Section I and examine what people already know about the seed dispersal mechanisms, the ecological role of frugivorous birds, and the impact of selective logging. The section III describes the study area, sampling and analysis methods used to get seed dispersal and regeneration. The fourth section contains the findings of the empirical study, statistical results, and pictures. This is then succeeded by the Section V which gives the interpretation of the results in terms of the ecological processes and management implications. Finally, section VI will be the conclusion of the key findings and present the realistic recommendations on improving forest regeneration strategies.

Literature Review

Tropical forests have dispersed their seeds through a number of biotic and abiotic pathways such as wind dispersal (anemochory), water dispersal (hydrochory), and through animals (zoochory). Among them, the most common is zoochory, in which birds and mammals serve as the key vectors for most woody plant species. Fruit characteristics, habitat structure, and disperser behaviour are among the factors that influence dispersal effectiveness. Indicatively, the size of fruits, the quantity of pulp, and nutritional value are key determinants of the seed-eating behavior and excretion patterns of various animals and thus affect the pattern of plant recruitment (Almazán-Núñez et al., 2021). Moreover, dispersal is not evenly distributed across the landscape; it depends on ecological gradients and land-use history, which also affect successional paths and species composition (Jakovac et al., 2021). Regeneration success is also dependent on functional differences among plant groups; some timber and late-successional species depend on animal dispersers to establish in restored forests (Toledo-Aceves et al., 2021). All these processes regulate seed density distribution and, ultimately, characterize regeneration processes in forests. Frugivorous birds play a central role in tropical forest regeneration after selective logging through seed dispersal services, which are strongly associated with effective water resource management and ecological optimization strategies that facilitate vegetation restoration.

The most effective and mobile seed dispersers of the tropical ecosystem are frugivorous birds. Long-distance travel capability enables the movement of seeds across broken habitats, increasing connectivity and genetic exchange. It has been demonstrated that ecological foraging behavior of these birds has demonstrated that body size, beak morphology and the variety of seeds scattered can influence foraging (Carlo et al., 2022). Studies have also revealed significant dispersion among individuals of the same species in terms of the service they give during dispersion with various individuals providing different services depending on conditions and availability of resources (Lamperty et al., 2021). Even in the humanized environment, surprisingly, frucivorous fugitive bird communities can still be resilient and still improve vegetation cover, particularly in smaller pieces of forests (Rigacci et al., 2021). Also, the

ecosystem can stabilize against disturbance by having the complex interactions found in bird seed-dispersal networks, yet such networks might become less effective at forest edges or in areas of high anthropogenic pressure (Chaves et al., 2022). These results highlight the primary role of birds in supporting ecological processes essential to forest regeneration. Other environmental factors that affect these processes include urbanization, which alters patterns of biodiversity and the services essential to the effective regeneration of forest. Moreover, the quality of the overall ecosystem, including interactions between aquatic and terrestrial systems, also influences habitat success and regeneration (Aghababaei et al., 2024). The interactions between seed dispersal by frugtivorous birds in tropical forest regeneration following selective logging are highly influenced through the deposit of the activity patterns of the understory birds due to the fact that disturbance of the habitat may radically modify the behavior of movement and resource use among the forest ecosystems (Fontúrbel et al., 2021). The success of seed spreading in regenerating tropical forests subsequent to selective logging is also determined by troic functions of frugivorous birds with species of higher troic position have an improved tendency to be less persistent in disturbed environments, and as such, influence long-term regeneration processes (Paces et al., 2024).

Selective logging has both direct and indirect effects on frugivorous bird populations. Changes in species richness and community composition can be caused by habitat alteration, such as decreases in canopy cover and changes in resource distribution. These alterations mostly have disproportionate impacts on specialized frugivores that rely on a certain fruiting tree. Empirical data indicate that logging has a detrimental effect on the dispersal of bird species to plant species by decreasing seed input and, at the same time, reducing the ability to regenerate (Pangau-Adam et al., 2021). Secondly, changes in forest structure may interfere with movement patterns and feeding behavior, and decrease the overall efficiency of seed dispersal. These effects are further exacerbated by edge effects and fragmentation which undermine the dispersal networks and inhibit ecological resilience (Chaves et al., 2022). In the long-term, such disturbances can lead to reduced complexity in plant communities in terms of species richness, species evenness, and specificity, or an increase of generalistic or early-successional species, which will change the long-run dynamics of forests. Environmental modifications due to anthropogenic processes also influence animal plant interactions, which may influence the behavior of frugivorous birds and seed dispersal mechanisms (Surendar, 2024). Lastly, implementation of highly monitored and sustainable agricultural technologies would help improve landscape management practices that indirectly facilitate forest recovery and conservation of biodiversity (Al-Salahi et al., 2025).

The literature review reveals that seed dispersal in tropical forests is a multi-layered process that is very reliant on frugivorous birds. Although the birds are essential in maintaining

the regeneration process by efficient seed dispersal, their activities are very sensitive to the environmental disruptions like selective logging. Reduced dispersal efficiency and altered species interactions in logged forests directly serve as the basis of the research interest in this study to learn more about altered frugivore communities and their effect on a regenerative outcome.

Methodology

Background of Study Area and Sampling

The research was done in tropical moist forest environment that had undergone selective logging in the last 8-12 years. Two sites were chosen namely (i) selectively logged forest (LF) and (ii) rather undisturbed control forest (CF). The sites were of about 25 hectares each and were of similar elevation (120 180 m above sea level) and climatic conditions with an average rainfall of one and a half meter per year and an average temperature of 24-30^0 C. The stratified design was used to sample. The plots of five hectares were introduced in every site with a minimum distance of 300 m between them in order to be independent. Inside each plot, transect lines (500 m) were placed to observe and sample seeds of the birds. The observations were done at peak periods (06:00- 10:00, 16:00-18:00) within 12 months to influence seasonation. Seed traps of 1 m^2 were placed at regular intervals 50 m apart on all transects.

Table 1: Framework of Study Design with Regard to Sampling Strategy

Parameter	Logged Forest (LF)	Control Forest (CF)
Number of plots	5	5
Plot size	1 ha each	1 ha each
Transect length	500 m	500 m
Seed traps per plot	10	10
Study duration	12 months	12 months

Table 1 presents the conceptualization of the field sampling design to be applied in the process of comparing the selectively logged and control forest sites. It points out the plots and size of transects, layout of transects, placement of seed traps and duration of study and therefore consistency is evident in the data collection between the two forest conditions.

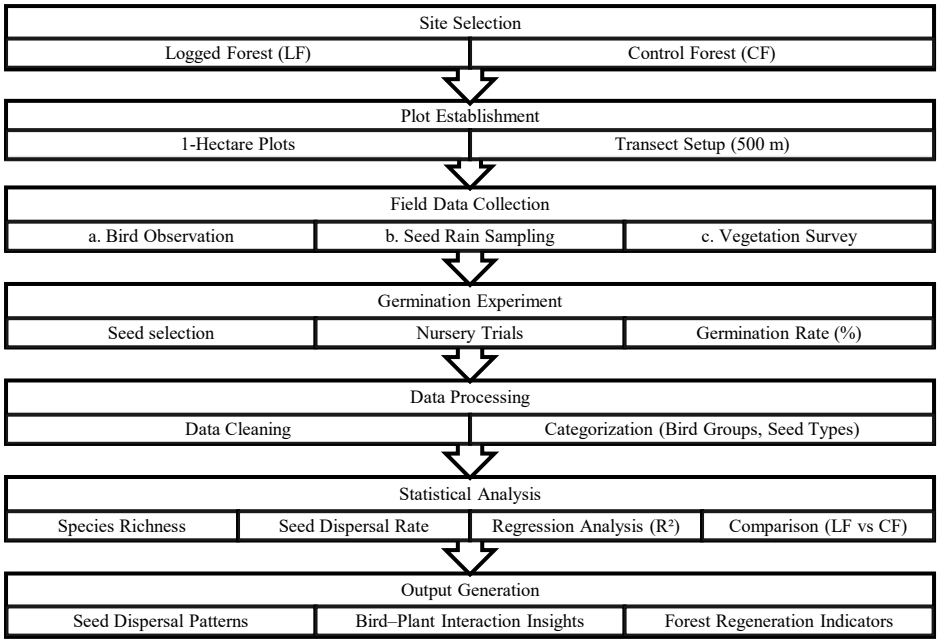


Figure 2: Methodological Workflow for Seed Dispersal and Regeneration Assessment

The diagram (Figure 2) indicates the stepwise process of work in the study, where the logged and the control forests are selected initially, then the plots are established and field work is performed in an organized manner, whereby the birds are observed, seed samples are collected and vegetation plots are conducted. It also describes the experiment of germination, data analysis, and statistical tests that were used to determine the richness of species, seed dispersal, and forest regeneration process. The output of the workflow is the creation of major outputs such as the understanding of seed dispersal processes and the interactions between birds and plants as a clear and logical view of the research methodology.

Determination of Fruiting Plant Species and Frugivorous Bird Species

Frugivorous birds were observed directly and auditory clues observed using the binoculars and normal field guide. The classification of species as frugivores was determined by the feeding behavior, especially feeding on fruits. Every sighting was noted and the number of individuals, activity and type of plant species that were visited indicated. Three functional groups of birds were defined according to the body size: Small (<50 g), Medium (50–150 g), Large (>150 g). Vegetation surveys were used to identify fruiting plant species in every plot. The hanging of fruit-bearing trees and shrubs was tagged and followed up every month within the study area. The characteristics of fruit including size, color, and abundance were noted because these affect the foraging preference of birds.

Table 2: Frugivorous Bird Classification by their Functional Groups

Category	Body Mass Range	Number of Species (LF)	Number of Species (CF)
Small	<50 g	12	15
Medium	50–150 g	10	13
Large	>150 g	6	9

Table 2 shows the classification of frugivorous bird species in terms of body mass, and their occurrence in logged and control forests. It can be used to explain the effects of selective logging on the structure of bird assemblages, especially the abundance of species that disperse seeds.

Procedures of Data Collection and Analysis

Three main components were the subject of data collection, namely, the activities of birds, seed rain, and seed germination. The rate of bird visitation was measured as the number of frugivorous birds that were identified in each transect per hour. Seed rain was measured by trapping seeds and trapping seeds and determining the seed in the trap after every two weeks. Seeds were sorted by species and enumerated to get an estimate of the dispersal rates. A subsample of seeds collected was used to test seed germination in controlled nursery environments to measure the seed viability. The percentage of the seeds developing into seedlings within 30 days was used as the success of germination. The data were statistically analyzed based on conventional ecological measures. Diversity indices were used to compare the abundance and richness of the species in the logged and control sites. The rate of seed dispersal had been given in terms of seed per square meter per year. The comparison between sites was done by t-tests and significance was determined at $p < 0.05$.

Table 3: Overview of the Important Variables and Measurement Methods

Variable	Measurement Method	Unit
Bird visitation rate	Direct observation	Birds/hour
Seed rain density	Seed traps	Seeds/m²/year
Species richness	Count per plot	Number of species
Germination success	Nursery trials	Percentage (%)

The study measured various ecological variables that are illustrated in this table 3 as follows; bird activity, seed dispersal, species richness, and germination success. It also defines the methods and units, which give a clear picture of how all the parameters were measured and analyzed.

Results

Frugivorous Birds Dispersal Rates of Seeds

An observation made in the field revealed that there were evident seed dispersal activities in the study sites. A total of 21,460 seeds were collected in traps during the 12-month interval with about 82% of them being found to have been dispersed by the birds. The mean seed rain amount of the

control forest (CF) was 24,300 seeds/m 2/year and that of the logged forest (LF) was 18,600 seeds/m 2/year. There was also a temporal variation whereby the maximum dispersal was observed during the wet season (June-September) which gives almost 48% of the total seed input per year. Frugivorous birds of large body size contributed disproportionately to overall seed dispersal, accounting for 52% of the total number of seeds despite being observed less frequently. There was 34% of medium sized birds and 14 % of small birds. There was also a variation in the seed deposition patterns in space and more concentrated around fruiting trees in LF which means lower dispersal distance. Germination experiments showed that 61% of the bird-dispersed seeds in CF were able to germinate, whereas 49% in LF germinated and this could indicate a decrease in the quality of dispersal in disturbed habitats. This reduction demonstrates that habitat disturbance not only decreases the quantity of seeds dispersed but also negatively affects seed viability and establishment, thereby limiting the overall effectiveness of natural forest regeneration.

Comparison of Seed Dispersal Services in Logged and Unlogged Areas

Comparative analysis showed that selective logging had a quantifiable effect on the quantity and the diversity of dispersed seeds. The abundance of dispersed seed species dropped to 28 species in the logged forest as compared to 37 species in the control forest, equivalent to a reduction of about 24%. The same reduction has been realized in the frugivorous bird diversity which also declined about 24 % in the control and logged sites and thus, there is high ecological dependence with the plant regeneration patterns and the bird communities in the same area. The composition of the dispersed seeds was significantly changed after logging. The percentage of early-successional species in the control forest and late-successional species in the logged forest were 28% and 42%, respectively. This shows that seed dispersal in disturbed regions is still occurring but is becoming more dominated by pioneer species than those related to the mature forest structure. This change implies that, in addition to seed diversity, logging also changes the functional quality of regeneration, which may be modified in the long term to alter the composition of forests. The effectiveness of seed dispersal (quantity and germination) was found to be significantly greater in CF (mean index value: 0.68) as compared to LF (0.51). There was also an identical trend with regard to the rate of bird visitation with CF averaging 18.4 birds/hour and 12.7 birds/hour in LF. The fact that visitation and diversity are decreased indicates that logging interrupts ecological relationships that support a healthy seed dispersal network.

Impact of Frugivorous Bird Populations on Forest Regeneration

Regression analysis showed that the abundance of frugivorous birds had a strong positive correlation with the seedling density in plots (R^2 = 0.73). Plots that had more birds always had better seedling recruitment especially of the large-seeded species. Mean seedling plant density in CF was 3,450 seedlings/ha and in LF was 2,280 seedling/ha which is a 34% decrease.

Large bodied birds played a particularly key role in the processes of regeneration with their absence in certain LF plots being associated with a significant decrease in large-seeding plant recruitment. On the other hand, the shrub and pioneer species were more prevalent in the areas where small birds were the dominant species. Such results indicate that species assemblages of birds provide a direct impact on the composition of forests and recovery curves on a long-term basis.

Dataset Details

The data included field observations during one year (10 plots, 5 plots of each type of site). It contained 1,248 records on birds' observations, 21,460 records on seeds and 3,200 records on germination trials. The main variables were species of birds identified, size of body, frequency of visits, seed species, number of seeds per trap and germination results. The records were taken on a biweekly basis and analysed.

Software Details

R (version 4.3.1) and Python (version 3.10) were used to process the data and conduct statistical analysis. Diversity analysis was done with packages like vegan, and ggplot2 helped in visualization. The statistical tests and regression modeling were done using scipy and statsmodels. The initial cleaning and data organization were completed using Microsoft Excel.

Performance Evaluation

Regression measures and comparative indexes were used as model performance. The prediction model between the abundance of birds and seedling density had a Mean Absolute Error (MAE) of 112.5 and Root Mean Square Error (RMSE) of 158.3, which means that the model could be used to estimate predictably with a high degree of accuracy. The statistical significance at $p < 0.05$ was verified in the important variables.

Table 4: Comparative Ecological Performance of the Forest Type

Metric	Control Forest (CF)	Logged Forest (LF)
Seed dispersal rate (seeds/m²)	24,300	18,600
Species richness (seeds)	37	28
Bird visitation (birds/hour)	18.4	12.7
Germination success (%)	61	49
Seedling density (per ha)	3,450	2,280

In this table 4, the results of the key ecological indicators of control and logged forests have been compared side by side such as the seed dispersal rates, species richness, bird activity, germination success, and seedling density; indicating the overall deterioration in the ecosystem functioning in the logged areas.

Table 5: Metrics of the Statistical Model Performance

Metric	Value
R^2 Score	0.73
MAE	112.5
RMSE	158.3

The table 5 below provides a summary of the results obtained when the regression model is tested to assess the relationship between frugivorous bird abundance and the regeneration stage of forests, which shows the model to be accurate and reliable based on its R 2, MAE, and RMSE.

Table 6: Bird Functional Groups Contribution of Seed Dispersal

Bird Group	Contribution (%)	Average Seeds Dispersed
Large	52	9,850
Medium	34	7,296
Small	14	3,014

This table 6 shows how the various groups of frugivorous birds contribute to the overall seed dispersal with the important point of large bodied birds contributing to the effective seed dispersal and regeneration of forests.

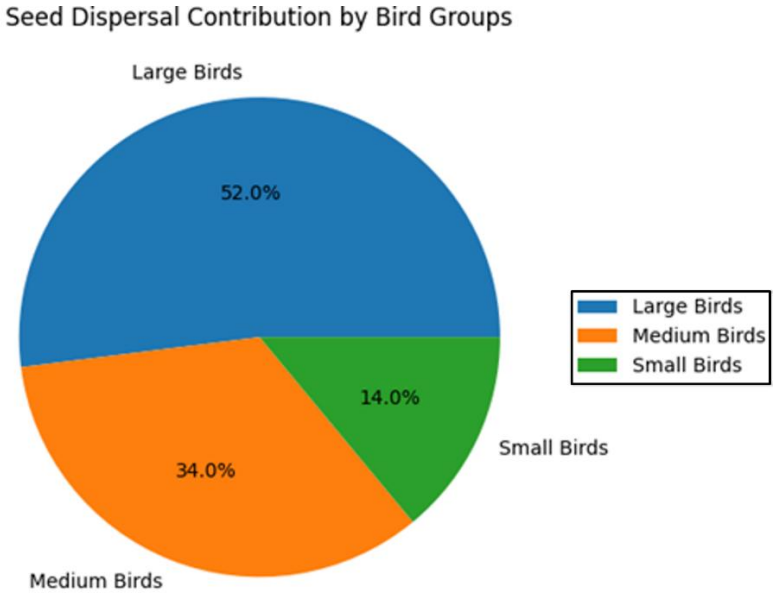


Figure 3: Relative Contribution of BIRD Group to Seed Dispersal

Such a pie chart (Figure 3) shows the proportionate amount of seed dispersal by small, medium, and big frugiovorous birds and it was found that large-bodied species dispersed most seeds in the forest ecosystem.

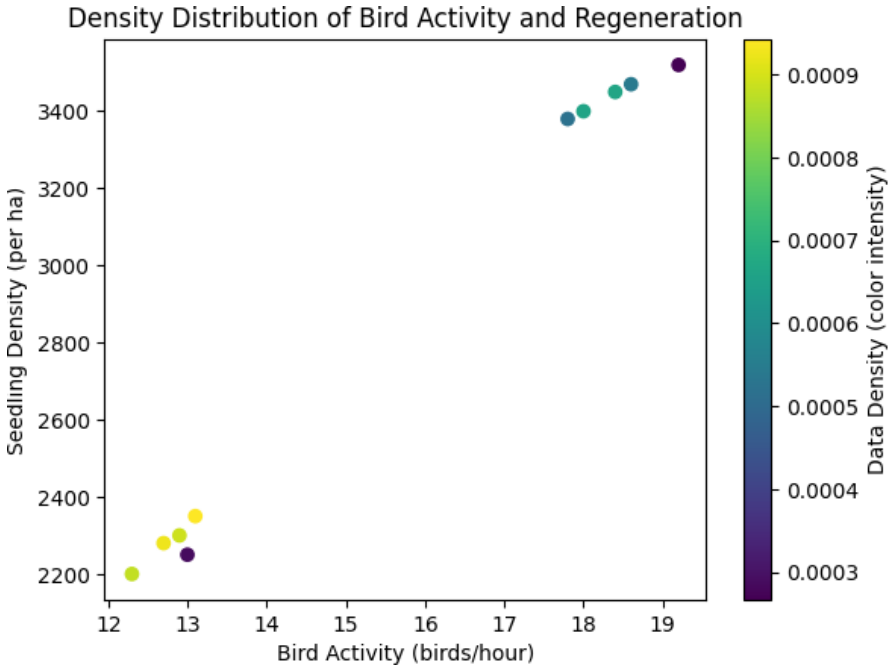


Figure 4: BIRD Activity and Forest Regeneration Density

This scatter plot density (Figure 4) is the concentration of observations between the activity of birds and the density of seedlings that a strong color density indicates a greater clustering and a greater correlation between the occurrence of frugivorous birds and the regeneration success.

Ablation Study

The role of different groups of birds in the effectiveness of seed dispersal was established by means of ablation experiment. The ablation analysis approach showed a significant reduction in the model performance without large bodied birds, with the R^2 value reducing to 0.49 and the seed dispersal rates reduced by 38%. This considerable decrease proves the over-representative role of large frugivores and substantiates the importance of large frugivorous animals as key seed dispersers in the ecosystem. The removal of medium sized birds led to reduced fall ($R^2 = 0.61$), but the removal of small birds had no serious impact ($R^2 = 0.70$). These results confirm that the role of the large frugivores in supplying effective seed dispersal and forest regeneration cannot be ignored.

Discussion

The results are well consistent with the goals of the study indicate that frugivorous birds are still at the centre of seed dispersion in even selectively logged forests but with lower efficiency. The reduced rates of seed dispersal and species richness of logged areas indicated, indicates that habitat structural changes have a direct effect on the behaviour and movement of birds, which eventually determine the outcomes of regeneration. Specifically, the minimization of large-bodied frugivores seems to restrict the dispersal of large-seeded species which are frequently important to long-term forest stability. These trends emphasize that the regeneration of forests should be viewed not only as a process involving plants but also as a process that is

closely related to the animal-mediated interactions. In management terms, natural recovery could be greatly improved by preserving features of habitats that sustain different communities of birds (e.g. by keeping fruiting trees and reducing disturbance of the canopy). Another valuable outcome of the research is the necessity to combine the conservation of biodiversity in loggers instead of those as independent issues. Future studies might consider the results further by investigating regeneration patterns over a longer period of time, addition of other disperser species and how landscape connectivity affects seed dispersal efficiency in fragmented habitats.

Conclusion

This paper shows that frugivorous birds are very important in maintaining the seed dispersal and regeneration of forests even in situations of selective logging. Although the rate of seed dispersion in the logged forests only decreased to about 18, 600 seeds/m^2/year as opposed to 24, 300 seeds/m^2/year in the undisturbed zones, the fact that the bird dispersers are still active makes sure that the ecology is not completely interfered with. On the same note, species richness (decreased by 37 to 28 species) and germination success (decreased by 61 to 49%), it is possible to agree that logging indeed affects the quality and quantity of regeneration, but not its absence. The positive significant association between the activity of birds and seedling density ($R^2 = 0.73$) also supports this fact by emphasizing the need to preserve a healthy population of frugivores. Largely bodied birds, which disperse more than half of the total seed, become highly significant in recovery of the late-successional species. These results highlight that regeneration of forests is not entirely reliant on the environmental conditions but also on the continuity of the ecologically important interactions. In practice, the conservation efforts must be focused on the protection of the habitats of frugivorous birds, the mixed-species planting where the natural dispersion is insufficient, and on the application of the reduced-impact logging methods. Through the arrangement of forest management with the ecological processes, one can improve the resilience of degraded tropical forests and recovery rates.

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