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The Effects of Forest Management Activities on Genetic Diversity of Forest Trees

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ABSTRACT

Genetic diversity helps to survive forest trees in several environmental changes and disease conditions. Different forest management activities such as harvesting, thinning, natural or artificial regeneration, seedlings or coppice forests, fragmentation, and overexploitation have a tremendous influence on the genetic diversity and population structure of forest trees. This paper aimed to review the impacts of these activities on the genetic diversity of forest trees. For this, we reviewed several scientific literature related to forest management practices that affect genetic diversity. Altogether,75 papers were reviewed, interpreted, and evaluated to prepare our final manuscript. The result of this study recommends that the level of genetic impacts varies with management activities, stand structure as well as species characteristics. There is very limited information about the impacts of forest management practices on the genetic diversity of forest trees since it is only focused on the growth of stands. The field research activities for species-specific must be executed considering ecological and reproductive parameters to assure sustainable forest ecosystems. Hence, this review will be beneficial for forest conservationists, researchers, and managers for the management of forests through better forest management activities preserving a genetic pool of the forest trees, and sustainable utilization of forest products.

INTRODUCTION

Genetic diversity refers to those individuals within a population who do not share the same genotype, resulting in differences in appearance and behavior (Koski, 2000). It is the basis for species and individuals to adapt, evolve, and survive, particularly in changing environments and disease conditions (Rajora & Pluhar, 2003). Genetic diversity intensifies the sustainable survival of populations (Bouzat, 2010). At the ecosystem level, the genetic diversity of keystone species affect species diversity in relevant communities (Vellend & Geber, 2005; Whitham et al., 2006). The population is on the verge of extirpation where genetic diversity is often lacking (Markert et al., 2010). The factors including inbreeding depression (ID), genetic drift, and small population size are responsible for reducing genetic diversity.

The risk of extinction of fragmented and threatened populations is likely to increase when exhibited to these conditions (Frankham et al., 2002; Madsen et al., 1999). The correlation between genetic and species diversity has received limited attention due to the complexity in methods in comparing evolutionary processes at the population and group(Fitzpatrick & Keller, 2015; Genung et al., 2011; Lowe et al., 2018; Vellend & Geber, 2005). The study of these two diversity in a population is used to evaluate evolutionary dynamics, diagnose potential threats and establish the conservation strategies for their preservation (Bailey et al., 2009; Frey et al., 2016; Laroche et al., 2015; Lowe et al., 2018; Messmer et al., 2012). The phenomenon including mutation, selection, migration, and mating system maintains evolution and modifies genetic diversity within the species(Mullin & Bertrand, 1999).

Forest management aims to provide a variety of forest products and services(Mendoza & Prabhu, 2000). The biodiversity within and among the forest ecosystems is not even completely represented by diverse forest management systems (Günter et al., 2011). The role of genetic diversity in forest management and regeneration is often neglected despite being explicitly mentioned in several kinds of scientific literature (Kettenring et al., 2014). Forest management activities concentrated on the partial or clear cut system, natural and artificial regeneration systems have effects on genetic diversity in remaining or regenerated forest populations (Buchert et al., 1997; Rajora, 1999; Rajora & Dancik, 2000). Comparing to virgin forests, forest management activities accompanying silvicultural practices during regeneration, stand growth, and harvesting can alter environmental conditions (Finkeldey & Ziehe, 2004).

The genetic variation that is attributed to basic evolutionary mechanism changes is due to forest management activities (Namkoong et al., 1996). The changes in the genetic structure of forest species may be visible and convenient to a specific management scheme, such as the establishment of clonal plantations. Forest management has mostly been used as an anthropogenic practice to received human needs, and its implementation has modified the succession, original composition, and structure of the forest (Fabbio et al., 2003). Moreover, forest managers; often change the genetic structures of forest trees incidentally (Finkeldey & Ziehe, 2004). Forest management can influence genetic resources through drift-related processes (small seeders), mating system-related processes (reproductive isolation), fertility and viability selection processes (plus tree selection), and migration-related processes (transfer of forest reproductive material) (Buiteveld et al., 2007).

This review is intended to provide updated and comprehensive information on the dynamics of genetic structures introduced from forest management practices. It also solves the questions on the variation of genetic diversity and vitality of trees regarding several forest management activities to sustain the forest ecosystem sustainably and producible. It also reveals the effect of stand management on their genetic constitution and will be helpful for forest and genetic researchers, policymakers, forest managers, and several institutions for the better management of the forest to intensify better genetic diversity within the forest trees.

MATERIALS AND METHODS

Search engine and search terms

The original aim of this paper was to undertake a systematic review of literature on genetic diversity in forest trees as a result of forest management activities. Research Gate, Google Scholar, and Scopus were the three databases used to find those relevant words which are mentioned in Table 1.

Table 1. Keywords searched in Google Scholar, Research Gate, and Scopus

Search Terms	**Search Terms**
Genetic Diversity	Genetic impacts
Forest management activities	Ecology
Silvicultural systems	Genetic drift
Demography	Forest conversion
Species diversity	Hereditary diversity
Gene flow	Genotypes
Population structure	

Article screening

We downloaded over 752 papers titled “Forest management and its effect on the gene of plant trees”, but most of them were duplicates, so we screened and deleted them first. We filtered the paper in the second process by looking at the title and results. The papers with unavailability of full text and not matched with our abstract were also removed. Finally, only those papers that included data on the genetic diversity of forest trees due to forest management practices.

Data review, collection, and analysis

We reviewed 75 articles as final documents for our research with the search limited to publications published from 1979 to 2020. They were closely analyzed several times, and information on plant species such as matting patterns, gene variation, and species distribution, ecology, and biological distribution, allele frequency in plant species, forest composition, and progeny were compiled in one section. The information was collected and organized to make this manuscript which we re-checked manually and with the free Grammarly app for Microsoft Office version 6.8.249 to eradicate errors.

RESULTS AND DISCUSSION

Some of the forest management activities that affect the genetic composition of forest trees are:

1. Harvesting

Harvesting practices have an impact on the genetic constitution of both existing and future stands which has the potential to affect the mating system dynamics of trees (Centre & Beaulieu, 2004). Forest harvesting is expected to have a large impact on the inbreeding, gene flow, mating system, selection, and the population structure of stands(Fageria & Rajora, 2013). It changes the demographics of forest populations, shortening age structure, and selection environments. So, the changes in genetic diversity due to harvesting should be interpreted from the perspectives of selection intensity (Ledig, 1992). The density and spatial distribution of parent trees are affected by the harvesting practices that alter the allele's frequency due to genetic drift (Gillies et al., 1999).

The impact of forest harvesting in genetic diversity practices is based on existing operational harvesting treatments since controlled experimental harvesting and regeneration trials are long-term and very costly (Ratnam et al., 2014). Nowadays, harvesting is chiefly focused on commercial species rather than non-commercial species. The studies of North American species i.e. Piceaglauca by Fageria and Rajora (2014) suggested that the genetic diversity in clear-cutting is less as compared to natural old-growth and young regeneration (Ratnam et al., 2014). Moreover, intensive or selective silvicultural harvesting degrades the population gene pool, so possibilities of inbreeding and genetic drift may occur due to a decline in gene exchange among populations (Finkeldey & Ziehe, 2004). However, the consequences of harvesting on genetic diversity differ according to the species, species traits, distribution, silvics, demography of forest populations, and harvesting and management practices (Buchert et al., 1997; Perry & Bousquet, 2001; Rajora, 1999; Rajora & Pluhar, 2003; Rajora & Dancik, 2000).

2. Thinning

It is the silvicultural procedure that is conducted to reduce densities of trees to strengthen the health and growth of residual trees(Hosius et al., 2006; Kavaliauskas et al., 2018; Kerr & Haufe, 2011). The principle of thinning is to promote the development of precious trees, for economic prospects, by excluding adjoining ones. Many investigations on genetic diversity mentioned both the positive and negative responses of logging (thinning and selective thinning) in forest trees. The growth and weevil damage was analyzed in seedlings between thinned and unthinned stands of eastern white pine (Pinusstrobus) by Ledig and Smith (1981)observed reduction in inbreeding and weevil damage due to the effectuality of selection.

However, the studies of Mediterranean species, such as in QuercusPyrenaica by Valbuena-Carabaña et al. (2008) advised that intensive thinning resulted in drastic losses in the genetic diversity of the populations. So, selective forest thinning preserves genetic diversity and adaptability since the forest is never completely felled and comprises trees of different species, sizes, and ages over time(Konnert & Hussendörfer, 2001). A silvicultural operation like thinning lessens the number of trees in the stand encourages natural regeneration, and the remaining trees become more vigorous(Hosius et al., 2006; Kavaliauskas et al., 2018; Kerr & Haufe, 2011).

3. Types of stand established

Forest stands can be established via natural regeneration, planting of seedlings, or direct seeding.

Natural regeneration

In the case of natural regeneration, there is no loss of genetic diversity because a large number of trees are included in the reproduction phenomenon (Monika Konnert & Hosius, 2010). But if only a few seeder trees are selected for the next generation, population sizes will be reduced because of genetic drift(Aravanopoulos, 2018). Natural regeneration does not constitute adaptive and non-adaptive changes of genetic structure but they convey the genetic character to succeeding generations during the regeneration period (O. Rajora & Pluhar, 2003). Natural regeneration can also be integrated with artificial regeneration depending on the management objectives (Paquette, Bouchard, & Cogliastro, 2006). Forest management and silvicultural practices target natural regeneration by protection from grazing and artificial regeneration is only carried out when natural regeneration appears to be unsuccessful (Aravanopoulos, 2018).

Artificial regeneration

Artificial regeneration boosts genetic variation and yield through the selection of superior provenances (White, Adams, & Neale, 2005). Enrichment planting (reforestation) can be performed to produce a high number of worthy species and to raise the stocking of trees where natural regeneration is inadequate or not uniformly disseminated (Paquette et al., 2006). Though plantation of commercial species improves genetic divergence when their population reaches to extent level, it may result in the extrusion of indigenous/endemic species which endangered the genetic diversity (Ledig, 1992).

However, the genetic constitution of the recently established stand is determined by the origin of seeds such as seed orchard, seed stand, etc. (Kavaliauskas et al., 2018). E.g., the genetic diversity is higher in the seed orchard having a large number of clones than in the seeds gathered from feral stands (Lefèvre, 2004). To ensure superior genetic variation in artificially regenerated stands, the quantity of trees from which the seed is gathered plays a significant role (Konnert & Hosius, 2010; Westergren et al., 2017). When large quantities of nursery stock are produced from the same seed source, the planted stands in a wide area may be genetically quite similar (Nicolls, 1979). The diseased seedlings may behave as a midway to transfer pathogens which might result in the outbreak of diseases around plantation sites (FRTC, 2017). The planted stands have lower juvenile mortality than naturally regenerated stands (Muona et al., 1988). de Lacerda et al. (2008) mentioned that the level of genetic variation increases from juvenile to adult stages. The lower number of seed trees that contributed to planted offspring's from fewer populations reflects the strong genetic differentiation (Al-Hawija et al., 2014).

4. Seedling vs. Coppice forests

Coppicing includes the sprouting of basal shoots which aids faster production of woods (Kadavý et al., 2011). Depending on the management objectives, coppicing rotation varies from 5- 40 years which is comparatively less than seed origin (Holišová et al., 2016). Coppicing increases the entire biodiversity of the forest, principally in the case of heliophile species, and also can be the suitable alternative when seedlings establishment is troublesome (Baeten et al., 2009; Spitzer et al., 2008; Van Calster et al., 2007). Coppicing management is cheaper than high forest (seedlings origin) but produces thin stems of inferior quality than of high forests (Fujimori, 2001; Kneifl et al., 2011). Seedlings have greater genetic diversity as compared to sprouts, so there are higher chances of increasing genetic drift and reduced adaptation to environmental constraints in coppicing (Lloret et al., 2004). However, Holišová et al. (2016) mentioned that coppicing is better drought tolerance because of self-shading and larger roots system of sprouts but the larger trees from seedlings origin may suffer from drought conditions due to greater reduction in the conductance in their leaves.

5. Fragmentation and Overexploitation

In recent decades, forest fragmentation is a comprehensive problem with disastrous degradation and overexploitation of forests throughout the world (Watson et al., 2016). Global diversity is declining due to habitat destruction, degradation, and fragmentation (Baur & Erhardt, 1995; Sala et al., 2000; Wilson et al., 2016). The detachment of habitat into smaller and more separated patches by a matrix of the human-modified land cover appears in long-term impacts on biodiversity and ecological processes (Haddad et al., 2015). Forest fragmentation and overexploitation may diminish productive population sizes that restrain gene flow and inbreeding depression occurs, which ultimately decreases the species' genetic diversity and fitness (Aravanopoulos, 2018). For example- If the gap among the populations is huge for pollination then, pollen exchange is restricted (Ward & Johnson, 2005) and inbreeding and/or outbreeding among intimately associated species takes place due to which plant fitness may be reduced(Hooftman et al., 2003).

Fragmentation may affect the vector of pollen transport itself, so animal pollinated plant species may be more vulnerable than wind-pollinated plant species. Thus, seeds and pollen dispersal cooperatively influence genetic diversity in plant species (Schlaepfer et al., 2018). Fragmented population, lack of dispersal medians, and restricted regeneration are the central threats in tropical and subtropical forests(Finger et al., 2012; Zeng & Fischer, 2020). The long-lasting consequences of overexploitation, population fragmentation, and isolation impose the continuous dropping of genetic variation that can lead to the extinction of species(Chapin Iii et al., 2000; Ewers & Didham, 2006; Fahrig, 2003). However, those negative results vary according to the organism population, habitat nature, and genetic measure(Schlaepfer et al., 2018). But most of the field studies cited that both fragmentation and overexploitation harm the genetic diversity of forest trees (Aravanopoulos, 2018).

Forest management activities have greater impacts on genetic, individual, population, species, and ecosystem levels of diversity. Therefore, the knowledge of it is vital for the conservation of the genetic resources of forests (Finkeldey & Ziehe, 2004; Ledig, 1992; Lefèvre, 2004; Ratnam et al., 2014). Several factors like forest types, site conditions, local traditions, and climatic zones are responsible to determine the forest management activities (Spiecker, 2003). It can change tree density and age class structure during forest stand rotation, so have significant effects on connectivity and effective population size (Ledig, 1992). Public authority along with the demands of societies is also the determinant for different silvicultural methods for forest management (Kimmins, 2008).

Silviculture practices can transform both selective and demographic phenomenon and can significantly modify the environment (Banks et al., 2013). The selective and clear-cut operations followed by natural or artificial regeneration have greater impacts on population composition and mating patterns, and ultimately genetic diversity of forest trees (Ratnam et al., 2014). The genetic characters of the upcoming generation are influenced by the selection criteria of seed trees such as spatial distribution, number, and phenotype. Genetic diversity can be improved by better management, intensity, and selection criteria applied (Ratnam et al., 2014; Schaberg et al., 2008). Furthermore, several factors have significant impacts on the genetic variability of the forest both directly through crop tree selection, management systems implemented, breeding, and seed transfer and indirectly through ecological circumstances dynamics (Lefèvre, 2004; Ratnam et al., 2014; Schaberg et al., 2008).

CONCLUSION

The broad survey of the literature concludes that forest management activities influence the structure of genetic diversity and evolutionary processes of forest stands. Higher genetic variation is demanded the sustainable durability and robustness of biological populations because it is a basis for future adaptation is required to sustain environmental stresses due to natural and anthropogenic factors. Trees reach their reproductive maturity in a longer period and due to their highest life span, they are more probable to face more environmental modifications. So, a higher degree of genetic diverseness is essential for their endurance and survival. Many variables affect the genetic variation and adaptive capacity of the forests. Silviculture and forest management activities such as harvesting, thinning, natural regeneration and artificial regeneration, seedlings and coppice forests, fragmentation, and overexploitation are the parameters to determine genetic diversity among forest populations. It also varies according to the species biology, ecological characteristics, and others factors aforementioned. In the nutshell, our review has established that: (1) Partial harvesting is more preferable than clear cut harvesting as the latter reduces the genetic diversity of forest populations, (2) Thinned stands are healthier than unthinned stands and selective forest thinning maintains genetic diversity and adaptation, (3) Natural and artificial regeneration, seedlings and coppices depends on the management objectives whether the purpose is to maintain genetic diversity or not, and (4) Adverse effects on genetic diversity of forest species are more prominent in intensive thinning, fragmentation and overexploitation.

Our review found that there is relatively less information about forest genetics worldwide especially in Nepal. So, in this modern era of research and technology, more experiments should be performed regarding forest genetics and the impact of forest management on the genetic diversity of tree species to manage forest ecosystems sustainably and effectively. Though, these studies revealed limited information; further study must be performed to develop the objectives of sustainable forest management concerning genetic diversity as it determines the longer health of forest trees.

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