

Review

Post-Fire Restoration Plan for Sustainable Forest Management in South Korea

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Abstract: This review was to determine a standard post-fire restoration strategy for use in South Korea according to the magnitude of the damage and the condition of the affected site. The government has strongly enforced reforestation in deforested areas as well as fire prevention and suppression since the 1960s. These efforts have successfully recovered dense even-aged forests over the last five decades. However, high fuel loading and the homogeneous structure have made forests vulnerable to large fires. In recent years, large forest fires have occurred in the eastern coastal region of Korea. Forest fires can significantly influence the economic and social activities of the residents of such affected forest regions. Burned areas may require urgent and long-term restoration strategies, depending on the condition of the affected site. Erosion control is the most important component of an urgent restoration and should be completed before a rainy season to prevent secondary damage such as landslides and sediment runoff in burned areas. Long-term restoration is necessary to renew forest functions such as timber production, water conservation, ecosystem conservation, and recreation for residents. Sound restoration for burned areas is critical for restoring healthy ecological functions of forests and providing economic incentives to local residents.

Keywords: ecosystem function; large burned area; long-term restoration; urgent restoration

1. Introduction

Climate change is expected to increase dryness globally because of the warmer temperatures and reduced precipitation [1]. Overall, this tendency will lead to increasing climatic fire risk. Widespread increases in fire activity, including the areas that are burned [2,3], number of large fires [4,5], and fire season length [6,7], have been apparent worldwide over the past half century [8,9]. However, this trend is also influenced by fuel availability, which is determined by both the quantity of fuel and climate-driven fuel moisture [1,4]. Although lower air humidity and fuel water content are positively related to fire ignition and propagation, a drier climate will eventually lead to a decrease in fuel load due to lower productivity [10,11].

Fire affects soil properties, because any organic matter (OM) that is located on or near the soil surface, is combusted [4]. These results depend on fire severity and intensity. The changes in OM, in turn, affect several chemical, physical, and microbiological properties of the underlying soil. Although some nutrients are volatilized and lost, most nutrients become more available. Fire

acts as a rapid mineralizing agent [12] that releases nutrients instantaneously, in contrast to natural decomposition processes, which may require years or even decades. Fire is integral in maintaining the stability and sustainability of forest health and thereby facilitating the architecture of overstory trees and the composition of vegetation communities [4,13]. The interactions of historic land use and climate change have resulted in high levels of fuel loading, which have produced historically uncommon frequent, large, and severe stand-replacing crown fires [4,14,15]. The effects of these fires include increased post-fire tree mortality [4], initial decreases in the understory plant cover [16] and the subsequent susceptibility of the landscape to invasion of non-native species, soil erosion, and flooding [16,17]. Highly severe fires generally cause greater and longer-lasting effects [4,18] and significantly reduce the timber supply and forest by-products [19]. Forest fires can also decrease the income of farmers [4,18,20]. Forest fires can change the habitat quality for wildlife by altering the abundance, distribution, productivity, and diversity of the animals occupying these habitats [21–24]. Many animals often require more than one type of habitat due to their different requirements for each stage of their life cycles. A mosaic of habitats is thus ideal for a rich biodiversity of wildlife [25,26].

The growing stock (m^3 of wood ha^{-1}) of Korean forests increased from 9.6 (1960) to 142.2 (2014) owing to advanced silvicultural practices and fire prevention efforts [27]. However, higher forest growing stock means high fuel loading, which may lead to more intense and larger forest fires [28]. Despite both the central and local governments' fire suppression efforts in recent years [4], the size and frequency of forest fires have been increasing in South Korea and are expected to continue to increase under the changing global climate. This, consequently, requires developing a standard protocol for prompt and sound restorations. A sound restoration protocol should be built on thorough understandings of the effects of forest fires on forest ecosystems and the post-fire recovery processes. The Korea Forest Research Institute (KFRI) has designated areas burned by the Goseong forest fire in 1996 (100 ha) and the Donghaean forest fire in 2000 (400 ha) as long-term ecological research (LTER) sites [29]. Multidisciplinary joint studies have been conducted at the LTER sites to better understand the impact of forest fires on the ecosystems and the recovery process [4,20]. As a result, standard restoration principles have been established by integrating ecological, social, and economic factors to support the restoration of burned forest [4,29]. The objective of this study was to summarize and describe a standard restoration plan based on the identified principles to maintain sound and sustainable forest ecosystems in Korea. In addition, we provide an update on the current state of restoration projects and suggest improved restoration methods. In particular, we discuss approaches with apparent adaptive value in fire-prone environments and methods for implementing ecologically sound post-fire forest restoration practices.

2. Formation of Modern Korean Forests

Korean forests were degraded during the Japanese colonial rule period (1910–1945). Korea only had $13.2 \text{ m}^3 \text{ ha}^{-1}$ growing stock (main trunk only) over 16.1 m ha of forests in 1943 [30]. After the establishment of the Korean Government in 1948, the Ministry of Agriculture and Forestry legislated and enforced three major forest policies: (1) planting five saplings for each harvested mature tree; (2) substituting firewood with charcoal firewood; and (3) banning illegal logging [27]. However, these efforts did not lead to any tangible results due to the Korean War between 1950 and 1953. After the Korean War, the South Korean government initiated the establishment of forest protection areas in 1955 under the supervision of the Ministry of Home Affairs and the Ministry of Defense [27,30]. However, this was not successful due to social instability and a lack of responsibility among government bodies.

Forests were protected properly only after the 1960s, when social and political conditions were stabilized [27]. However, South Korea only had 4.1 m ha of forested land in 1952. Several decades of illegal harvesting and the Korean War left 2.3 m ha deforested [27]. These deforested areas were susceptible to soil erosion and landslides due to the steep topography and concentrated rainfalls in the summer. A strong forest management policy and artificial planting were desperately needed for successful forest rehabilitation. The 'Forest Law' and 'Law of Enforcement of Illegal Forest Products'

were implemented in 1961. The South Korean government strictly prohibited illegal forest harvesting and illegal shifting cultivation [27]. The government also implemented the 'First National Forest Development Plan' between 1973 and 1978 and applied a stricter forest protection policy. There were two noteworthy enforcements: (1) allowing fine fuel (e.g., leaves and branches) collection within a limited time and only under the supervision of forest officers and village leaders and (2) putting the full responsibility on the local governments to minimize the anthropogenic impacts on forests [27]. In addition, rapid economic development has replaced wood, which is the main energy source for rural residents, with fossil fuels. Furthermore, imported timber from foreign countries lessened the pressure on newly planted forests [27].

Forest planting projects from 1946 to 2000 restored 5.3 m ha (average 97,000 ha year⁻¹) of forest, achieving approximately 83% forest coverage of total forestland [27]. Approximately 59% of total forestland was planted between 1961 and 1980. Artificial forestations have definitely had a great influence on the state of current forests. These efforts resulted in higher growing stock and more mature forests [27]. The growing stock in South Korea reached 125.6 m³ ha⁻¹ in 2010 [27] and was composed of 52.8 m³ ha⁻¹ of coniferous forest, 39.0 m³ ha⁻¹ of mixed forest, and 33.8 m³ ha⁻¹ of broad-leaved forest. The growing stock in South Korea would be expected to increase rapidly [27]. However, denser and even-aged forests resulted in continuous high fuel loading, which would lead to a high risk of large fires [4].

3. Modern Korean Forest Fires

Fires can have significant effects on biodiversity, local economy, and aesthetic values [18,19,31–33]. From 2005 to 2014, 3842 forest fires were reported, and a total of 6307 ha of forests were burned [27]. Approximately 60% of these fires occurred in the dry and windy spring season. More than 80% of these forest fires were accidental anthropogenic fires caused by camping, memorial ceremonies, children's pranks, and levee fires [27].

The severity of fire depends greatly on local conditions such as fuel loading, fuel type, temperature, humidity, and topography [28]. Most of the recent large forest fires in Korea occurred in the eastern coastal region, including the Goseong forest fire in 1996 (3762 ha), the Donghaean forest fire in 2000 (23,794 ha), and the Yangyang forest fire in 2005 (973 ha), where fire-prone dense pine forests dominate. In addition, winds in this area are stronger and dryer than those in the western interior region due to Föhn winds that blow over the Taebaek Mountains [28,34]. High fuel loading in this region was mainly the result of inadequate forest management practices [4]. In particular, artificial forests, such as the Korean forests, require proper forest management. Without proper management, abundant ladder fuel is built up, and forests become prone to crown fires. Fire prevention requires continued management efforts, including pruning and thinning [20,35]. The pine mushroom (*Tricholoma matsutake* (S. Ito & S. Imai) Singer), an ectomycorrhizal basidiomycete associated with *Pinus* spp., grows extensively throughout the region. Local residents have traditionally protected and conserved pine forests in order to harvest pine mushrooms as a valuable source of income [18].

4. Review on the Current Post-Fire Forest Restoration Planning

Burned forests are subject to restoration by maximizing their economic, ecological, and social value (Figure 1). A restoration plan must be completed prior to conducting any restoration to circumvent the need for later modifications, which would otherwise incur higher costs with more technical difficulties. The following six fundamental functions should be considered in preparing a restoration plan: timber production, water conservation, disaster prevention, natural environment conservation, ecosystem conservation, and recreation [20]. Furthermore, a restoration plan after a large fire should follow the appropriate land use laws. If a fire does not allow the original land use designation to be maintained, a full plan should be developed that is suitable for the new land use classification. In contrast, a plan after a small fire should maximize the six forest functions. If burned areas are vulnerable to secondary damage such as soil erosion or landslide, which are very common post-fire

natural hazards in Korea following heavy rain, burned forests should have a restoration plan that includes erosion control to prevent disaster. Previous studies [20] showed that a log strip terrace barrier (Figure 2a) is the most effective way to prevent soil erosion in the burned areas and it is a good way to utilize dead trees following a fire. Piling up burned trees horizontally (Figure 2b) is also an affordable option. In addition, a landslide forecasting program can be utilized to identify sites that are vulnerable to landslides and establish disaster-prevention forests beforehand. There are also several land use objective-specific rules to follow. Patch clearing and strip cutting are recommended for burned areas to regain timber production capability. The size of clear-cut patches should be less than 5 ha to minimize the soil disturbance [20]. The right tree species selection guide developed by the KFRI can be used to select tree species appropriate for timber production and forest establishment for the target area. Forests for water conservation should aim for mixed plant species restoration, with both deep- and shallow-rooted hardwood plants to make multi-layered root structures [20]. Forests with a natural environment conservation objective should adapt a passive restoration plan that includes the regeneration of remaining trees and sprouts to facilitate secondary growth forests [20]. Forests designated for ecosystem conservation and recreational use (e.g., near roads, cities, cultural landscape resource and tourist sites) can be restored through passive restoration, reforestation, and erosion control in a balanced manner. In addition, burned areas near former pine mushroom production sites should be reforested to reintroduce pine mushrooms for forest owners [4].

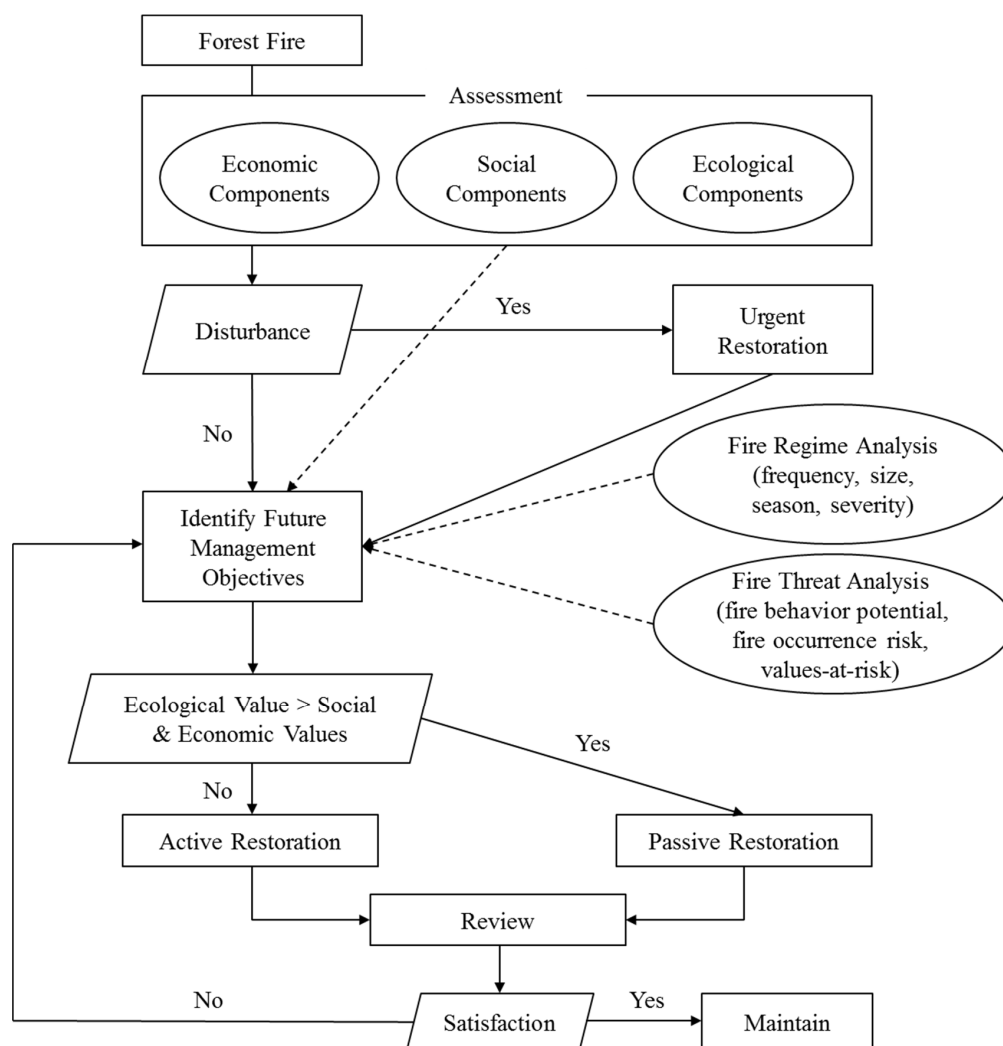


Figure 1. Flowchart of the development and execution of a plan to restore burned areas.

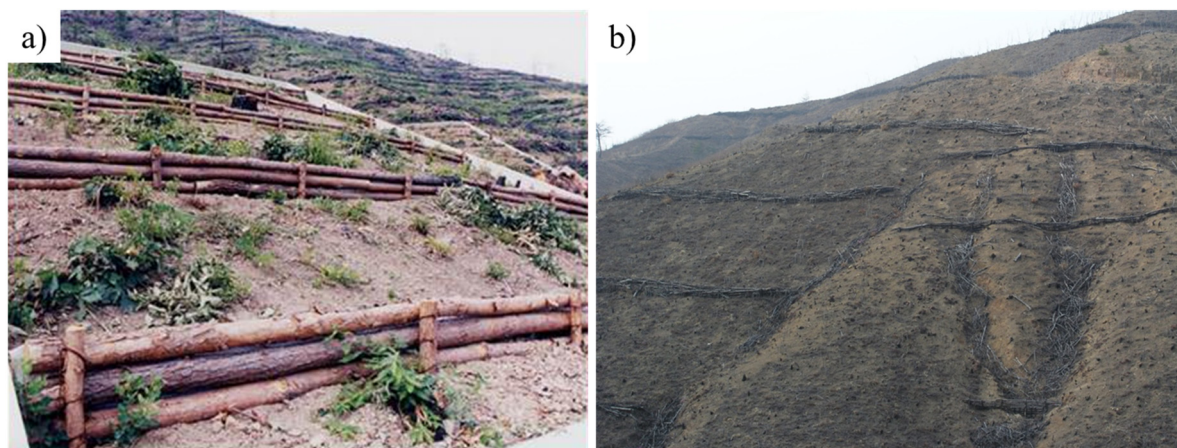


Figure 2. (a) Log strip terracing and (b) partially burned trees piling along a topographic contour in a burned area to prevent soil erosion (photos used with permission of the National Institute of Forest Science).

Passive and active restorations can be applied in a balanced way, depending on the site quality and vegetation conditions [20,36]. For active restoration, native and local tree seedlings can grow under similar weather conditions and site qualities. A plan for active restoration must seek the opinions of forest owners and residents to maximize the income for forest owners and/or benefits of residents [29].

5. Executing Restoration

The restoration of burned areas can use urgent and long-term restoration methods [20]. Some burned areas are vulnerable to secondary damage, such as landslide and debris flow, after heavy rainfall. Urgent restoration methods should be applied to these areas to prevent the loss of life and property. Long-term restoration methods can be used to maximize the economic, ecological, scenic, and environmental values. The opinions of residents should be considered in the long-term restoration process [4].

5.1. Urgent Restoration

Areas that are vulnerable to landslide and soil erosion or those near unstable streams require urgent restoration. Erosion control should be first implemented to prevent secondary post-fire damage. It is very important to stabilize slopes and install erosion control structures such as hillside stone masonry, sand bags, sod, and seed spraying (Figure 3). Hillside stone masonry is recommended for mountain slopes that have easy access and are steeper than 45° . Sod pitching is suitable for relatively fertile soil and a slope $<45^\circ$ [20]. Sand bag piling can be used for areas that are difficult to access or barren areas where sod is loosely attached to soil. Areas requiring quick vegetation establishment can be targeted for seed spraying after completing hillside stone masonry work or sand bag piling. The implementation must be completed before the rainy season and monitored by the “Erosion Control Regulation” of the Korea Forest Service [20]. Recently, field observations have shown that erosion control structures stabilize slopes and introduce vegetation [27]. Urgent restoration methods, such as hillside stone masonry, sand bags, sod, and seed-spraying treatments, in burned areas have been determined to be useful methods for preventing soil erosion and landslides.

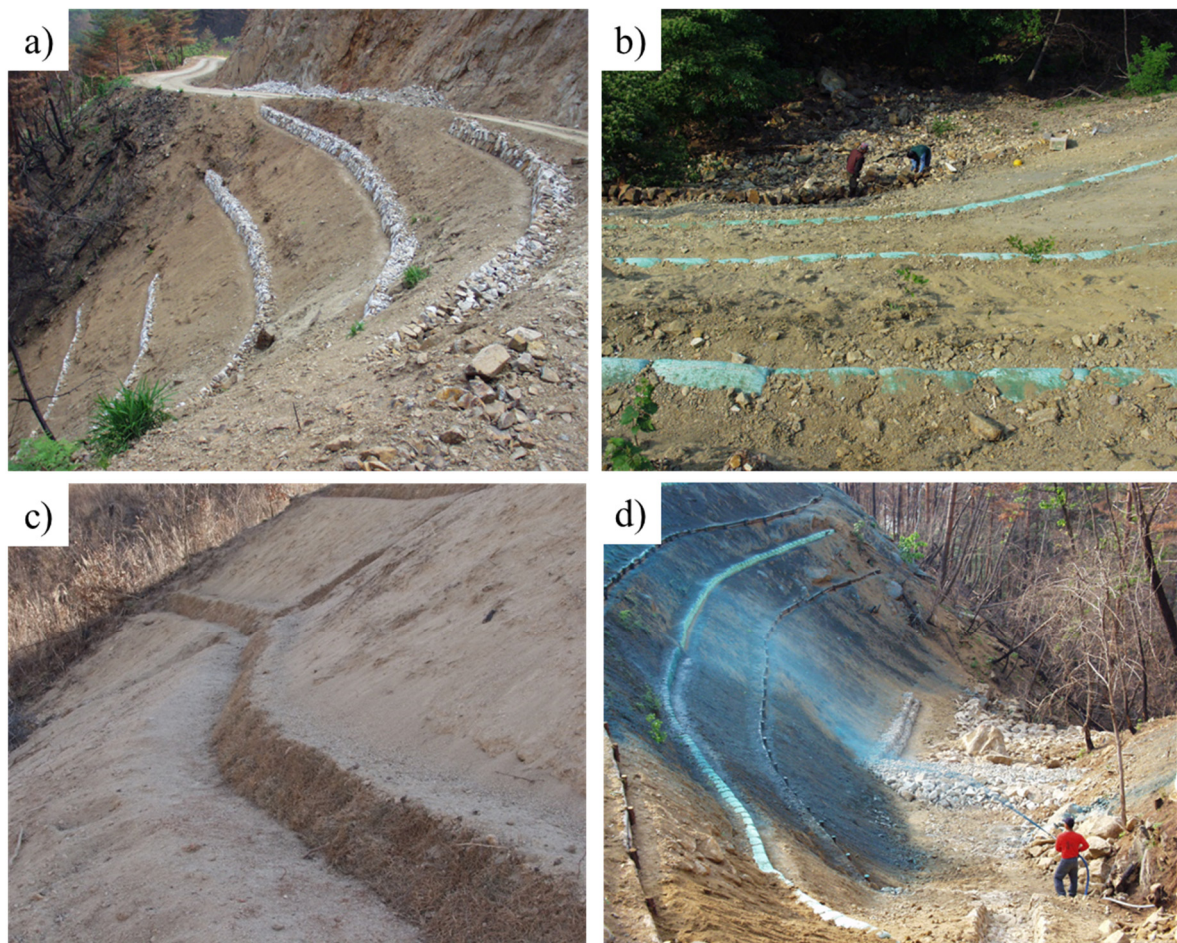


Figure 3. (a) Hillside stone masonry, (b) sand bags piling, (c) sod-pitching, and (d) seed spraying to control for soil erosion in an urgent restoration practice (photos used with permission of the National Institute of Forest Science).

5.2. Long-Term Restoration

Long-term restoration should consider the six forest functions and local priorities, such as the residents' preferences for pine mushroom production [4,29]. Long-term restoration can be divided into passive restoration and active restoration to maximize the economic, ecological, scenic, and environmental values [27]. Passive restoration can be used for areas that are minimally disrupted by forest fires and remnant forests. These areas are officially classified as environmental conservation forests and have the ability to naturally regenerate from the intact canopy. Passive restoration should avoid drastic changes to their forest structure [36]. Generally, passive restoration methods can be used for oak forests in Korea [4,20] because fire-damaged oaks can regenerate from their root sprouts and seeds. Shrubby bushclover (*Lespedeza bicolor* Turcz.) can also rapidly recover in burned areas. Oak seedlings and shrubby bushclover can gradually invade burned areas after forest fires (Figure 4). A typical commercial goal of oak management in Korea is to attain at least 350 harvestable trees per hectare with a minimum target diameter at breast height (DBH) of 30 cm at the end of a ca. 50-year rotation [27]. In burned areas, however, the goal for regenerated oak trees originating from root sprouts is at least 600 harvestable trees per hectare, with a target DBH of 20 cm and height of 6–8 m in a 30-year rotation (Figure 5a). This does not produce high-quality harvestable trees because of the damage to the roots from the forest fire [37]. The harvested oak trees in burned areas are mainly used for mushroom cultivation and pellet materials. Passive restoration can neglect the social and economic demands of local residents [4,38].

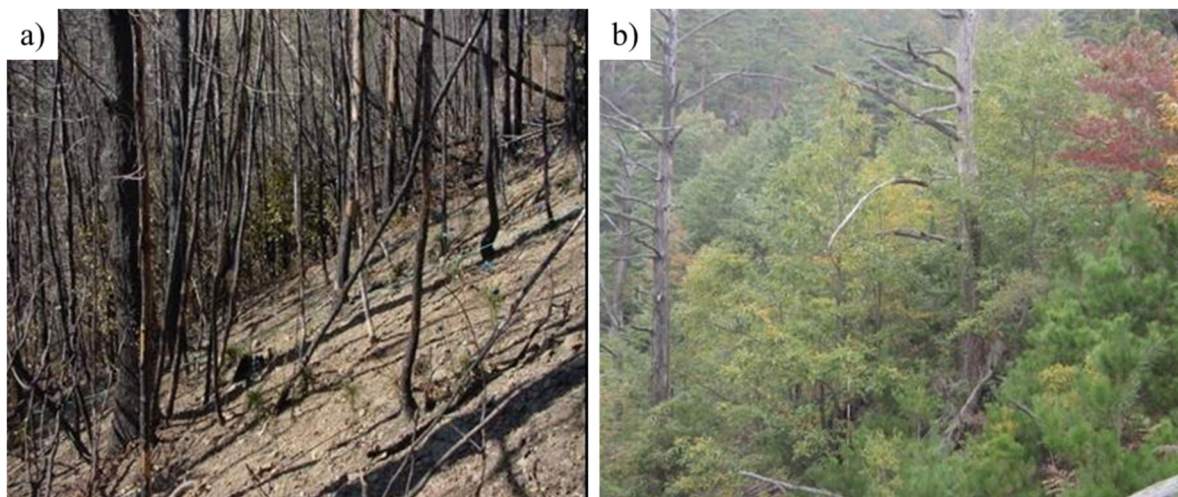


Figure 4. (a) Immediately after a fire (2000) and (b) passive restored site (2006) (photos used with permission of the National Institute of Forest Science).

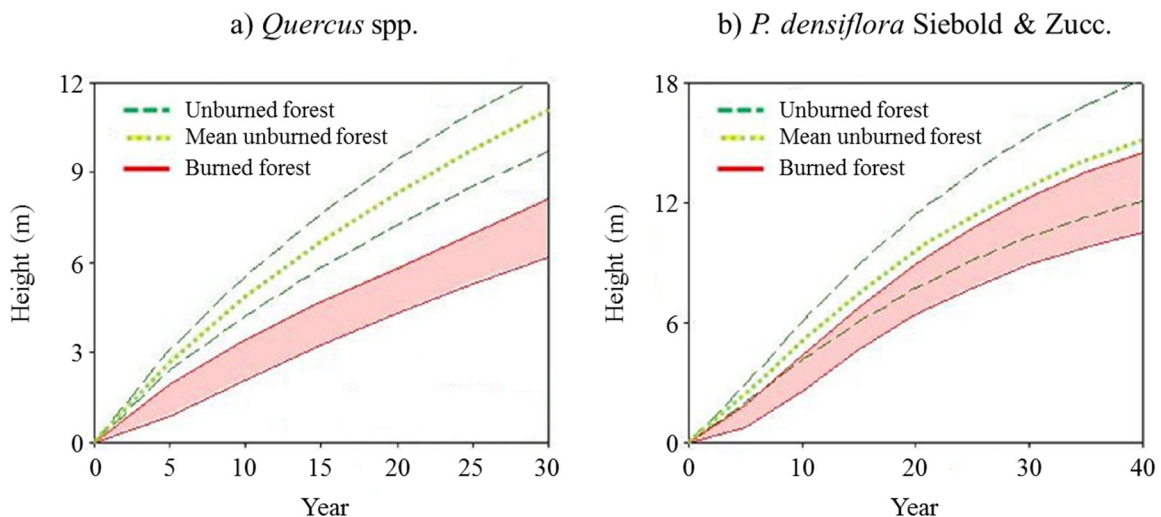
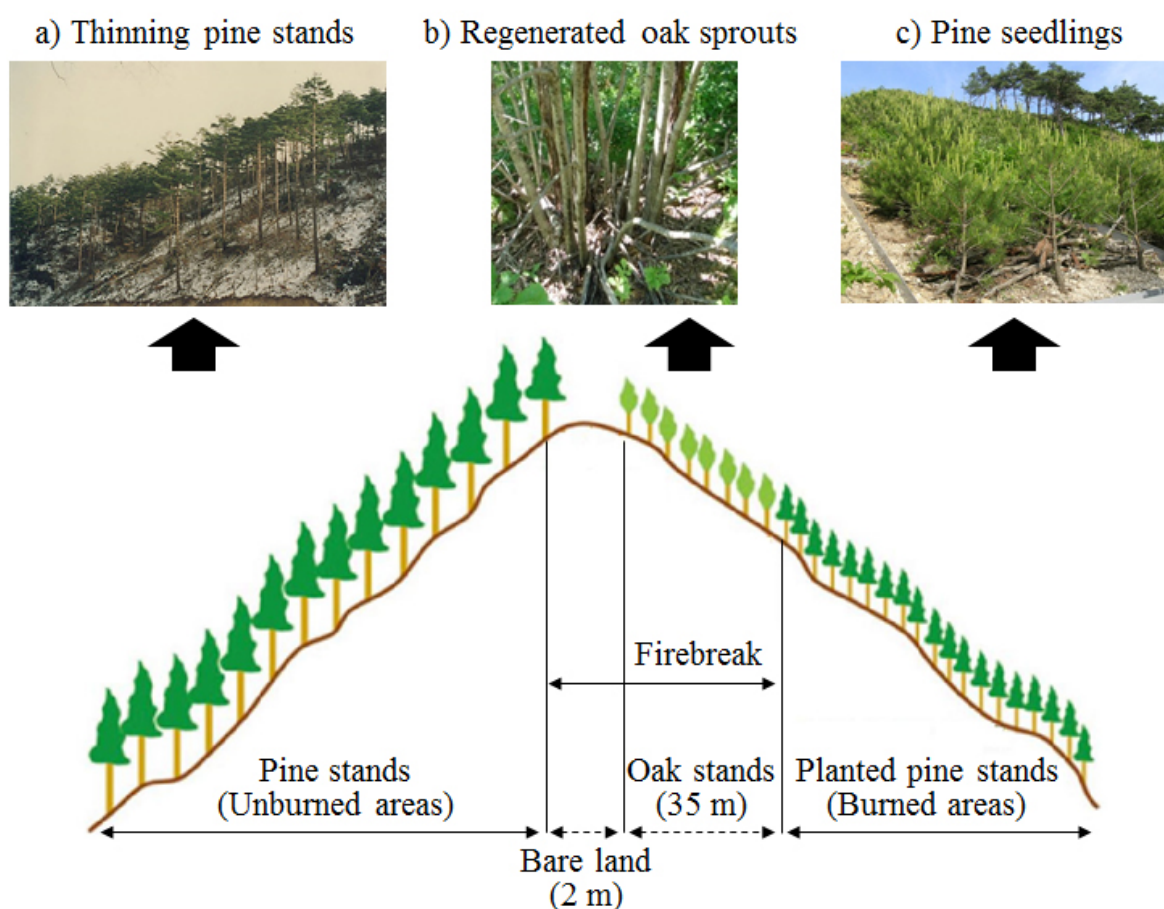


Figure 5. Growth curves of (a) *Quercus* spp. and (b) Japanese red pine (*Pinus densiflora* Siebold & Zucc. trees in unburned and burned areas (data modified from [37]).

The aim of active restoration is to improve the six major forest functions and local priorities such as pine mushroom production. It contains disaster prevention goals such as the construction of check dams and erosion dams [4,20]. Burned forests on gentle slopes (less than 30°) and fertile soil will offer the maximum timber yields. They can promote the sustainable production of high-quality timber by planting economic tree species to satisfy the national economic demands (Table 1). Pine forests have long been cultivated in Korea for the production of high-quality timber. Currently, a typical goal of pine management in Korea is to produce at least 600 harvestable trees per hectare [27]. The minimum target DBH is 25 cm with heights of 10–14 m at the end of a 40-year rotation period (Figure 5b). The recommended number of pine seedlings per hectare in row planting is approximately 5000–10,000 seedlings ha⁻¹ (Figure 6c). The aim of row planting is to achieve a regular distribution of trees and structural homogeneity of the crown layer in the early stages of stand development to foster natural pruning and the development of stem quality [39]. Pine tree growth in burned areas also tends to be slower (Figure 5b) because of the poor nutrient conditions induced by erosion and leaching losses [4,20].

Table 1. Major economic tree species by climatic zone of Korea [20].

Climate Zone	Main Species	Companion Species
Temperate	<i>Pinus koraiensis</i> Siebold & Zucc. <i>Larix kaempferi</i> (Lamb.) Carrière <i>P. densiflora</i> Siebold & Zucc. <i>Betula platyphylla</i> var. <i>japonica</i> (Miq.) H.Hara <i>Quercus</i> spp. <i>Liriodendron tulipifera</i> L.	<i>Pinus rigitaeda</i> S.K.Hyun & Ahn <i>Fraxinus rhynchophylla</i> Hance <i>Juglans mandshurica</i> Maxim.
Sub-Tropical	<i>Pinus thunbergii</i> Parl. <i>Chamaecyparis obtuse</i> (Siebold & Zucc.) Endl. <i>Liriodendron tulipifera</i> L.	<i>Pinus taeda</i> L. <i>Cryptomeria japonica</i> (L.f.) D.Don <i>Quercus myrsinifolia</i> Blume <i>Machilus thunbergii</i> Siebold & Zucc.

**Figure 6.** Formation of firebreak for reduction of forest fire damage near large planted pine stands (photos used with permission of the Korea Forest Service and National Institute of Forest Science).

However, high-intensity fire damage in pine forests has prompted forest managers to convert pure pine stands established on large areas into mixed forests of pine and other broad-leaved trees [20,38]. Forests near large areas of pine trees must have firebreaks to reduce the risk of rapid fire spread [4,20,39]. Firebreaks can utilize fire-resistant tree species (Table 2), such as those with thick bark and leaves containing high levels of moisture. In addition, these trees must be able to sprout vigorously after a fire. Oak species are the dominant deciduous trees in Korea and have low heat yield, making them an effective natural fire break [4,20]. Based on high-intensity forest fires in 2000, Lim et al. [20] recommended that regenerated oak sprouts in belt-shaped configurations at least 35 m in width were necessary for safety considerations in forests near large areas of pine trees (Figure 6). Forest fires

burn biomass in forests but do not destroy underground roots and seeds in plants. Oak in particular has the ability to regenerate from intact canopy naturally. Fast-growing oak sprouts develop in the upper layer (Figure 6b). Planting oak is a viable option when there are not enough sprouts and under conditions of high mortality [20]. The recommended oak restoration method is group planting, which was introduced to Europe in the 1980s and 1990s as an economic and ecological alternative to traditional row planting for reforestation of distributed areas [40–42]. Group planting uses larger seedlings or saplings (0.8–1.5 m tall) and a wider initial spacing (1 × 1 m). In group planting, both the total number of saplings per group (20–30) and the number of additional, shade-tolerant trainer tree saplings per group are designed. Trainer trees are commonly planted on the perimeter of groups to control ground vegetation and to shade oak stems, thus preventing development of epicormic sprouts. Irrespective of the group design, spacing between the group centers was kept at 10 × 10 m or 10 × 12 m, resulting in 80–100 groups ha⁻¹. Group planting resulted in greater stand-level tree species diversity than did row planting [40–42]. Oak group planting is a comparatively inexpensive option for the artificial regeneration of oak-dominated broad-leaved forests for a range of situations such as reforestation of disturbed areas. In addition, bare land installation (width 2 m) was recommended to reduce fire susceptibility (Figure 6). Fuel treatment outside the firebreak may contribute to their effectiveness. In particular, conifer forests that are not fire-resistant should be managed so they do not contact the crowns of other trees caused by pruning and thinning (Figure 6a). The suppression of forest fires requires ongoing management efforts, including branch pruning, thinning, and firebreak construction [4,20,38]. However, these initiatives mostly occur in government-owned forest areas because private forest owners are reluctant to undertake branch pruning, thinning, and firebreak construction, fearing their possible negative effects on pine mushroom growth [4]. Therefore, the effective planning of a systematic forest fire prevention system needs to encompass the stewardship of both government-owned and private forests.

Table 2. Fire-resistant tree species by climatic zone of Korea (data modified from [20,39]).

Climate Zone	Tree Species	Shrub Species
Temperate	<i>Ginkgo biloba</i> L.	<i>Picrasma quassioides</i> (D.Don) Benn.
	<i>Quercus variabilis</i> Blume	<i>Fraxinus sieboldiana</i> Blume
	<i>Quercus acutissima</i> Carruth.	<i>Sorbus commixta</i> Hedl.
	<i>Quercus dentata</i> Thunb.	
	<i>E. rhynchophylla</i> Hance	
	<i>Populus maximowiczii</i> Henry	
Sub-Tropical	<i>Myrsinaefoliae</i>	<i>Viburnum awabuki</i> K.Koch
	<i>Cinnamomum camphora</i> (L.) J.Presl	<i>Daphniphyllum macropodum</i> Miq.
	<i>Cinnamomum japonicum</i> Siebold	<i>Camellia japonica</i> L.
	<i>Ilex rotunda</i> Thunb.	<i>Illicium religiosum</i> Siebold & Zucc.
	<i>Machilus thunbergii</i> Siebold & Zucc.	<i>Cleyera japonica</i> Thunb.
	<i>Neolitsea sericea</i> (Blume) Koidz.	<i>Ternstroemia japonica</i> Thunb.

Fire burns biomass, and burned areas increase surface flow during rainfall events [4]. This may cause the collapse of soil aggregation and an increase in soil water repellency after fires, which results in a decline in the soil permeability, thereby reducing the water storage capacity in forests. Oak species are suitable for growth at sites with hydromorphic soil conditions that are prone to storm disturbance on bare slopes, where oaks can develop deep root systems (Figure 4b). To conserve the water supply within forests, deep-rooted tree species such as oaks should be planted [20]. Planting plays a major role in forests, especially in the reforestation of oak-dominated forests. In particular, artificial regeneration is the only way to establish oak stands in situations where acorn sources are lacking [20]. Supplementary shallow-rooted and intermediate-root species can be planted to increase water reservoirs in the soil through multi-layered root structures [20]. Therefore, a higher diversity of tree species in oak-dominated broad-leaved forests might provide more opportunity for

the establishment of multilayered root structures. However, oak planting based on row planting in burned areas indicates that the tree species richness has not been achieved [40–42]. Based on other studies, group planting of oak is recommended as an alternative to traditional row planting for greater stand-level tree species diversity and natural regeneration, which may result from an increase in the size of the unplanted area between groups [40–42]. Recreational forests aim to improve recreational value to visitors and residents while preserving the ecological value. Landscaping and endemic tree species should be planted together to form a multilayered mixed forest with indigenous species. To reintroduce pine mushrooms, burned trees can be clear-cut, and locally grown Japanese red pine seedlings can be planted to benefit forest owners. The pine mushroom grows only in early mature pine stands but does not grow in the early stages of fire-regenerated stands.

The goal of long-term restoration is to maximize the economic, ecological, and environmental values through recovering forest functions. Restoration success can be measured by multilayered, mixed forest establishment and the recovery of major forest functions such as timber production, water conservation, ecosystem conservation, and recreation to satisfy residents [4,20]. Economic indices of success include the forest products and generated ecological services. Profit from recreation services and pine mushroom production can provide strong incentives to local residents to support restoration projects. Thus, a successful restoration site will undergo post-restoration management. The site should be monitored to evaluate the efficiency of management methods and provide direction for future management. Poorly restored areas are subject to having supplementary restoration work. In addition, collaborations among stakeholders such as local communities, government officials, and scientists are important to sustain natural forests.

6. Conclusions and Recommendations

The impact of large-scale forest fires on human life has received attention in Korea since the Goseong forest fire in 1996 [29]. Restoration in burned areas is needed to rebuild their ecological, scenic, and economic values. Current diverse restoration methods need to be organized into a standard plan [4,20,29]. The Donghaean forest fire in 2000, which was the largest forest fire in modern Korean history, has triggered serious discussions about restoration methods, including controlling erosion to prevent damage to residential areas, planting fire-resistant trees to prevent the spread of fire, and planting pine trees to collect pine mushrooms in large-scale burned forests. To establish a standard post-fire restoration plan, the KFRI has studied burned areas extensively using the data about regional climate, vegetation, forest soils, hydrology, pests, wildlife, and pine mushrooms [29]. A standard restoration plan in burned areas has been developed to restore burned forests to full health (Figure 1). The proposed forest restoration method may not be perfect. Thus, it is crucial to monitor and evaluate the entire restoration, to obtain objective revisions. The concept of bioindication has been used to assess the restoration state in burned areas [4]. The abundance and species richness of microarthropod communities can be used to examine forest recovery in burned areas [4]. The dominant beetles in burned forests are members of the Curculionidae family, which attack trunks or branches of weakened trees, whereas detritivorous Scarabaeid beetles dominate unburned forests. The density of Collembola in burned forests declined because of the loss of aboveground vegetation and destruction of the litter layer [4]. Therefore, poorly restored areas may be dominated by the Curculionidae family, whereas successfully restored areas may be dominated by the detritivorous Scarabaeid beetles and Collembola. For cases with successful restoration, these sites will undergo post-restoration management. Poorly restored areas should be subjected to supplementary restoration work. The objectives of restoration are to return forest function and to provide incentives to local residents such as recreation services and pine mushroom production.

No species is 'fire adapted'; instead, they are all adapted to a particular fire regime, which can include fire frequency, fire intensity, and patterns of fuel consumption [43]. Oak trees have leaves containing high moisture levels and low heat yield, making them burn with less power [4,20]. Oak forests in Korea are resilient to periodic low-intensity fires at intervals of several decades. However,

when the fire frequency increases, oak forests vigorously sprout epicormically along the length of the bole and replace the tree canopy within several years of such fires (Figure 4b). These traits are adaptive in fire-prone environments, and are key to resilience, to periodic low-intensity fires. The fire-tolerant oaks are likely to increase in importance as the climate warms in Korea. Hence, the oak cover in the Korea now constitutes up to 25% of the total forested area [27] as an adaptive management strategy against possible fire impacts. Plant species that exhibit traits that are adaptive under a particular fire regime can be threatened when that regime changes [43]. Pine forests can be established in areas where no forest fires occur, in which case the local residents will be protected and pine forest can be conserved to produce pine mushrooms as a valuable source of income [4]. However, pine forests are prone to large-scale forest fires. In pine forests that are subject to high-intensity fires, pine trees restrict seedling recruitment in the post-fire years, being replaced by shrubby bush cover [4]. If the fire frequency in pine forests increases, pine forests can be rapidly lost [4,20]. The forest restoration methods should be considered economic benefits to local residents and a source of ecological stability. Therefore, oak stands in belt-shaped configurations were constructed near large areas of pine trees to prevent the spread of fire and to improve the fire-adaptive traits in fire-prone environments and pine trees in areas where pine mushrooms are collected (Figure 6).

Restorations based on traditional row planting in burned areas of Korea have been positively evaluated by forest scientists and local residents [4,20]. The burned areas have been restored to produce green and lush forests, such as oak and pine stands, which has resulted in the rapid stabilization of soil erosion and landslides in the burned areas (Figure 2, Figure 4, Figure 6). Despite the gradual recovery of the forests in the burned areas, oak and pine do not produce high-quality harvestable trees [37]. In addition, the lack of natural regeneration of other tree species and the low species diversity reported for row planting are undesirable attributes of this classic type of crop cultivation [40–42]. Overall, these factors motivated this study to seek alternatives to the conventional row planting approach for establishing crop stands. Group planting represents a reforestation method that not only offers the opportunity to produce high-quality oak timber but also promotes the natural regeneration of additional tree species between the groups [40–42]. This increases woody species diversity and possible productivity and allows natural successional processes to occur. For burned areas, future research needs regarding the production of high-quality harvestable timber and adaptation to fire via group planting are highlighted.

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