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Concept note

Differential intensity of rehabilitation silviculture in mismanaged high-graded forest

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ABSTRACT There are an estimated two billion hectares of degraded forest worldwide. A high-graded forest is one from which the highest-quality individuals of commercial tree species have been selectively harvested. Successive high-grading results in degradation. Without proper management, these forests are unlikely to recover in the short term and will be unable to fulfil their potential capacity to provide goods and services to society. Human-led rehabilitation is required to restart essential processes such as regeneration. This concept note provides criteria for determining levels of degradation in high-graded old forests, citing implications for rehabilitation silviculture and proposing general strategies for their recovery.

KEYWORDS: Human-induced disturbances, selective logging, forest degradation, restoration.

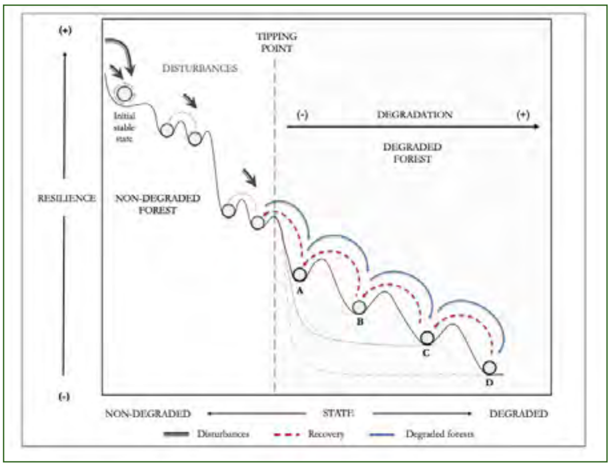
Levels of degradation in high-graded old forests

A degraded forest is one that has suffered deterioration or permanent loss of species structure and composition, primarily due to unsustainable harvesting of timber and/or non-timber forest products (Vásquez-Grandón et al. 2018a). High-grading is the harvesting of the most merchantable specimens of commercially valuable species. Indiscriminate and repeated selective logging is responsible for most cases of forest degradation (Mon et al. 2012, Yamada et al. 2013, Vásquez-Grandón 2020). The situation is exacerbated by the introduction of livestock, which further hinders regeneration (Zamorano-Elgueta et al. 2014). These combined pressures can have a severe effect on ecosystem function and communities (Cadotte et al. 2011), including a decline in productive capacity (Thompson et al. 2013). Thus, the forest's resilience—or capacity to recover its attributes in the short or medium term—is compromised (ITTO 2002, Peterson et al. 1998).

High-graded forests show varying levels of degradation depending on the degree of alteration suffered and their capacity to respond (i.e., the intensity and frequency of high-grading, and the long-term response to these disturbances). Disturbances alter composition and structure, including driving an increase in regeneration, density, and basal area of non-commercial species. In old forests, they can lead to a diameter structure that lacks large trees or certain diameter classes, at least for the most commercially valuable species. The degree of change is related to *(i)* the intensity of high-grading (from low-intensity harvesting to overexploitation) and its effect on the biotic (plant and tree species) and abiotic (soils, microclimate) systems (Su et al. 2010); and *(ii)* regeneration patterns, where increases in the number and size of gaps primarily favor pioneer species (Yguel et al. 2019), including non-desirable ones (e.g. invasive species or non-tree vegetation) that compete with valuable tree species (Gaui et al. 2019).

Identification of different degradation levels helps to pinpoint the location of a given forest along the degradation gradient (Fig. 1). This is essential to formulating appropriate silvicultural proposals for the recovery of key attributes (structure, composition, function) that determine the provision of goods and services and support the restoration or rehabilitation of degraded forests. Choice of approach depends on initial forest condition—degree of alteration, quantity and quality of residual trees, and the extent and distribution of advanced regeneration—and rehabilitation often requires multiple tailored strategies (Vásquez-Grandón et al. 2018b). These may include well-known silvicultural regeneration techniques, tending, or harvesting of the forest (Vásquez-Grandón 2020), and rehabilitation silviculture for high-graded forests.

Figure 1 - Theoretical illustration of the general pathways of forest degradation and recovery in relation to the state and degree of degradation (adapted from Vásquez-Grandón et al. 2018a).



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A forest subjected to pressures—either small but sustained, or brief but highly intense—will eventually lose its capacity to recover. The tipping point, or ecological threshold, is when the degradation process becomes irreversible (Fig. 1). Beyond this point, the forest is considered degraded due to the loss of capacity to recover to a given state following the disturbance(s) that triggered the degradation process. Forests can reach different degrees of degradation according to the extent of alteration to composition and structure and the response of the forest to this disturbance. In extreme cases, the degraded forest is unable to return to its original stable state by itself, and rehabilitation silviculture is needed to recover the desired species composition, structure, and ecosystem processes. Examples of different states of degradation are State A, low degradation; State B, moderate degradation; State C, high degradation; and State D, severe degradation (Fig. 1).

Implications for degraded old forest recovery through silviculture

Efficient classification of degraded forests into levels with established recovery-limiting factors is essential to silvicultural rehabilitation planning. Nyland (2016) states that separate approaches are often required for different parts of the stand, and Vásquez-Grandón et al. (2018b) mention the need for multiple treatment strategies adapted to varying degradation levels stands. Vásquez-Grandón (2020) studied old forests in south-central Chile (late-succesional uneven-aged forests with complex structures; *sensu* Wirth et al. 2009), finding that these can be positioned along a degradation gradient ranging from low to severe. Characteristics of forests with differing levels of degradation and stock include:

(i) Low: high regeneration of shade-tolerant, midtolerant, and some shade-intolerant commercial tree species (50% capacity and above compared to reference forest), generally those with good vegetative reproduction. Moderate to high basal area of commercial tree species. Commercial species refer to those common in old forests that were the main ones harvested in the past due to their high timber value. The variability of environmental conditions resulting from low or partial degradation facilitates the establishment of species with different ecological requirements. This category presents a few limiting factors for rehabilitation, but the abundance of non-commercial tree species may cause competition and slow the recovery process.

(ii) Moderate to high: moderate to low regeneration of commercial tree species (20-50% capacity compared to reference forest), mainly shade-tolerant, with a marginal presence of midtolerant species. A limiting factor for rehabilitation is a low to moderate basal area of commercial trees and a dense understory that limits regeneration and produces strong competition among tree seedlings and saplings.

(iii) Severe: moderate regeneration of shade-tolerant commercial tree species (20% capacity and below compared to reference forest). Major limiting factors are the high basal area of non-commercial trees and a very dense understory that precludes tree regeneration.

In a landscape context, when forests are at different levels of degradation, it is recommended that stands targeted for rehabilitation be jointly managed alongside non-degraded or well-managed stands. This is more financially viable and comprehensive in a context of ecosystem management (Nyland 2016), where decisions may include harvesting of timber and non-timber products, or no cutting in order to maintain the health and integrity of some stands (e.g., relict forests or those containing species under conservation objectives).

Prospects for rehabilitation silviculture in degraded forests

Rehabilitation silviculture is aimed to bring the managed forest to a mixed forest that includes the main original commercial and functionally important tree species (short-term) and a multi layered vertical structure (mid- to long-term). It must consider the existing limiting and favorable factors for recovery at the stand level, as well as the socioeconomic context and management challenges posed by climate change, implementing silvicultural adaptation strategies that allow, for example, to increase tree species richness and increase structural diversity (Brang et al. 2014). In particular, forests must have a high capacity to adapt to disturbances. Messier et al. (2013) indicate that forests should be treated as complex adaptive systems. For this reason, rehabilitation silviculture should increase forest ecosystem complexity as a guarantee of resilience, adaptive capacity, and multi-functionality (Nocentini et al. 2020). Variation in degradation levels means that some stands require only limited rehabilitation silviculture, since they comprise a diversity of tree species that facilitate regeneration and, to some extent, cover costs through harvesting. We propose the following measures (from low to high-intensity measures) for the rehabilitation of high-graded old forests with degradation levels ranging from low to severe:

(i) Low intensity. Limitations to rehabilitation are fewer. The presence of regeneration and the existence of mid- and shade-tolerant tree species allows rehabilitation through selection cuts, including harvesting of some financially mature trees to cover costs, improvement and sanitation cuttings in immature diameter classes, and understory control to release seedlings and saplings from competition.

(ii) Moderate intensity. Low regeneration capacity of commercially valuable original tree species due to their poor vigor, scarcity of suitable seedbeds caused by dense understories, and relatively high abundance of non-commercial arborescent and tree species necessitate multiple regeneration approaches. These include release cuts and creation of patches to facilitate regeneration in different seedbed types, planting high-quality seedlings, and felling poor-quality trees to reduce cover and create safe sites for

regeneration among felled logs. These operations should be conducive to the regeneration of multiple cohorts mixed with residual trees, eventually developing a multi-aged forest.

(iii) High intensity. Due to the high spatial variability of the forest and the limitations for rehabilitation, it is probable that silvicultural activities will give rise to a highly variable and multi-aged stand in terms of structure and composition. Faced with the absence of seed sources and little regeneration of commercial species, enrichment planting with original and relatively fast-growing species (mid- and shade-intolerant) would be the priority initially. This can then be complemented by some natural sexual or asexual regeneration (i.e., vegetative) from residual trees that must be enhanced following release cuttings, which will also promote the development of some existing seedlings and saplings of desired tree species.

In all cases, domestic animals must be excluded, at least during the early years.

Conclusion

Rehabilitation silviculture must operate upon the differentiation of levels of degradation of the forest to be managed. The aim must be the recovery of functional diversity of the forest, which means starting with the recovery of tree composition (or functional groups of trees) to advance to the recovery of forest structure. This is a transversal approach to the recovery of old forests. Its spatial priority must be in landscapes that include some well-conserved old stands that will aid in biodiversity recovery of managed stands, which will eventually aid in the creation of habitat linkages between old stands.

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