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Review

Integrating genetic factors into management of tropical Asian production forests: A review of current knowledge

Jalonen Riina [a,*], Hong Lay Thong [a], Lee Soon Leong [b], Loo Judy [c], Snook Laura [c]

[a] Bioversity International, PO Box 236, UPM Post Office, Serdang, 43400 Selangor Darul Ehsan, Malaysia
[b] Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor Darul Ehsan, Malaysia
[c] Bioversity International, Via dei Tre Denari 472/a, 00057 Maccarese, Rome, Italy

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ABSTRACT

Maintaining the genetic viability of timber species is especially important to sustaining the productivity and quality of timber in tropical production forests because the diversity of tree species is high, their population densities are low, and pollen dispersal of many species is limited to short distances. Conservation of the genetic diversity of timber species also enhances the conservation value of production forests and contributes to landscape connectivity. Tropical forests are commonly managed under selection logging regimes with minimum diameter cutting limits. These typically result in systematic removal of the largest and often the most fecund trees. Very little guidance is available to forest managers on the measures needed to maintain viable populations of timber species in production forests. We reviewed current knowledge regarding the impacts of logging on genetic processes in tropical Asian tree species to find foundations for developing practical guidelines for managing these impacts and to identify research needs. The review focuses on mixed dipterocarp forests, where the canopy layer is dominated by trees of the Dipterocarpaceae family, one of the most globally important timber families. We examined the impacts of practices including logging intensity, minimum diameter cutting limits and spatial patterns of tree removal with regards to biological parameters such as effective breeding units, size at reproductive maturity, fine-scale spatial genetic structure and the importance of general flowering in producing diverse seed. Research conducted to date shows that because of characteristics such as naturally low population densities, limited pollen dispersal and fine-scale spatial genetic structure, many tree species in mixed dipterocarp forests are sensitive to reductions in the density of reproductive conspecifics; in most cases tree extraction resulted in increased inbreeding. Although genetic research in these forests is still limited, enough knowledge exists to initiate the development of practical management guidelines e.g. on minimum population densities as a precondition for logging or documentation of sources of propagation material used in enrichment planting. Future research should focus on studying species characteristics which can indicate vulnerability to genetic erosion and the prevalence of these characteristics among species in mixed dipterocarp forests, to identify species or species groups which may require specific measures to maintain genetically viable populations in logged forests and in the larger landscape. Such characteristics may include large size at reproductive maturity or slow increase in fecundity with size, fine-scale spatial genetic structure, low population densities, limited pollen dispersal, or high juvenile mortality.

Contents

* Corresponding author. Tel.: +60 3 89423891; fax: +60 3 89487655.
E-mail address: r.jalonen@cgiar.org (R. Jalonen).

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1. Introduction

The focus of biodiversity conservation in production forests is often the protection of rare and endangered species. To sustain productivity and quality of timber yields over time, forest management practices should also maintain genetically viable populations of timber species which are not subject to inbreeding, produce large numbers of progeny with good survival and retain evolutionary potential in the longer term. Consideration of population size is particularly important in tropical forests where diversity of tree species is high, population densities are low, and many species are insect-pollinated, which may limit pollen flow to relatively short distances (Dick et al., 2008). Natural forests in the humid and subhumid tropics are commonly managed under selection logging regimes (Putz et al., 2012), applying minimum diameter cutting limits which may result in removing trees before they reach their optimal regeneration size. This can result in smaller reproductive populations which are at risk of inbreeding. Increased inbreeding and loss of genetic diversity can have severe negative effects on populations, for instance, reducing growth, reproductive output, ability to resist pests and diseases and capacity to adapt to environmental variation (Ellstrand and Elam, 1993; Hughes et al., 2008).

Incorporating genetic conservation measures in the management of the approximately 400 million hectares of production forests in the tropics (Blaser et al., 2011) would enhance the conservation value of these forests and complement other strategies for genetic conservation, such as the establishment of genetic reserves and restoration of endangered tree species. International criteria and indicators for sustainable forest management already require that forest managers take measures to conserve genetic diversity (e.g. ITTO, 2005; FSC, 2010; PEFC, 2010), but little guidance is available on how to integrate genetic conservation in the management of production forests (see, however, Jennings et al., 2001; Sist et al., 2003a).

In tropical Asia, selective logging of natural mixed dipterocarp forests is an important economic activity. These forests are among the most species-rich in the world, with 150–250 tree species ha^{-1} (Manokaran and Kochummen, 1987; Cannon et al., 1998; Brearley et al., 2004) and correspondingly low densities of individual species. The canopy is dominated by dipterocarp species (Dipterocarpaceae; including the genera *Anisoptera, Cotylelobium*, *Dipterocarpus*, *Dryobalanops*, *Hopea, Neobalanocarpus*, *Parashorea*, *Shorea*, *Upuna* and *Vatica*). The proportion of dipterocarps species varies according to forest type and site but is, on average, 25–30% of all stems and 50–80% of stems in the emergent layer (Appanah, 1998). Population densities of dipterocarps in unlogged forest vary from less than one reproductive tree ha^{-1} up to 10–15 trees ha^{-1}, depending on the gregariousness of the species and the forest type (Kitamura et al., 1994; Konuma et al., 2000; Lee et al., 2006). Logging prescriptions in dipterocarp forests generally allow the cutting of all trees of commercial species which exceed the minimum diameter cutting limits (Table 1). Extraction rates vary between 8–15 stems or 50–100 m^3 ha^{-1} (Sist et al., 2003a). In some cases, maximum cutting limits or maximum volumes for timber extraction are defined to control logging (Table 1). Some guidelines also exist to control species composition of the residual stand; for example, in Peninsular Malaysia, a higher minimum diameter cutting limit is applied to dipterocarp species than to non-dipterocarps, with the goal of maintaining the proportion of dipterocarps in emergent canopy layers over time (Forestry Department of Peninsular Malaysia, 1997; Shaharuddin, 2011). The aim of the Selective Management System (SMS) of Malaysia is to ensure sufficient residual stock and advanced regeneration (Appanah, 1998) and enrichment planting is usually limited to cleared areas such as forest roads, logging tracks and timber collection areas (Forestry Department of Peninsular Malaysia, pers. comm.). In contrast, large-scale propagation and planting has been carried out in Indonesia as part of the Selective Cutting and Planting System TPTI (Weinland, 1998) which has involved clearing the understory and the destruction of advanced regeneration.

Dipterocarps have many unique characteristics which suggest that their genetic response to disturbance differs from other species. Most of the dipterocarps flower and produce seeds at irregular intervals, typically at synchronized general flowering events occurring every few years (also known as mast fruiting; Ashton, 1982; Cannon et al., 2007). They are monoecious and pollinated by insects, many of which are small, which limits pollen flow (Chan and Appanah, 1980; Momose et al., 1998), yet they have relatively high outcrossing rates (Lee et al., 2000a; Tsumura,

Table 1
Typical prescriptions in selective logging guidelines, with examples from Malaysia. *Sources:* The Government of the State of Sabah (1968), Thang (1988), Forestry Department of Peninsular Malaysia (1997), Shaharuddin (2011); Forestry Department, Peninsular Malaysia (pers. comm.).

Prescription	Example
Pre-felling inventory	All tree species ⩾5 cm dbh or ⩾15 cm of height by dbh class, species and volume or stems ha^{-1}, inventoried 1–2 years before logging, to assess harvestable volume and regeneration (Peninsular Malaysia)
Minimum diameter cutting limit	65 cm and 55 cm dbh for dipterocarps and non-dipterocarps, respectively (Peninsular Malaysia)
Maximum diameter cutting limit[a]	120 cm dbh (Sabah, Malaysia)
Maximum extraction limit [a]	85 m^3 ha^{-1} (including trees damaged during logging, typically estimated at 30%; Peninsular Malaysia)
Target length of cutting cycle	30 years (Peninsular Malaysia)
Species protected from harvesting	Fruit tree species: *Mangifera* spp., *Durio* spp., *Lansium* spp., *Nephelium* spp.; bee nesting trees: *Koompassia excelsa* (Fabaceae); valuable threatened timber and non-timber spp.: *Intsia* spp., *Aquilaria malaccensis* (Thymelaeaceae) (Sabah, Malaysia)
Residual trees	At least 32 trees ha^{-1} exceeding 30 cm dbh. Preferred species are defined in a Reference Species list. (Peninsular Malaysia)
Parent trees	At least 4 healthy trees ha^{-1} exceeding 30 cm dbh, at an approximately even spacing. Preferred species are defined in a Reference Species list (Peninsular Malaysia)
Post-felling inventory	2–5 years after logging, using systematic line plots to determine residual stocking and appropriate silvicultural treatments (Peninsular Malaysia)

[a] Not a common prescription.