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Editorial

Connecting ecological science and management in forests for scientists, managers and pocket scientists

1. Introduction

The structures, patterns, and processes of the forests of the world develop from ecological interactions among hugely diverse types of organisms interacting with environmental factors at specific places and times on the Earth's surface. The science of ecology helps us develop frameworks for understanding these structures, patterns and processes, leading to descriptive studies and experiments that increase our insights into the nature of forests across space and time. Forest management changes the structure, patterns, and processes of forests, produce goods and services for people. These activities may be informed by scientific insights, though forest management has a much longer history than ecological science.

Modern forest management relies heavily on insights from ecological science. Management approaches may call for the use of "the best available science," but the dynamics of real forests may not be very deterministic and more flexible views of science and management may be productive (cf. Aplet and McKinley, 2017, Matonis et al., 2017). Various simple characterizations might represent the classical framework of ecological insight informing forest management (Fig. 1). In this Editors Note from the IUFRO Regional Congress for Asia and Oceania in Beijing in 2016, we suggest that a more effective framing is possible, where science and management are developed in interacting, powerful ways. We develop these ideas with two examples where science was used to inform management, and then flip the direction with two examples of how landscape-scale managed forests led to improved scientific understanding. The idea of "pocket science" is developed as an explicit approach that helps forest managers pull science and management together at the scale of forest operations, enhancing both understanding and management.

2. Classic science experimental design

Forest research often uses classical experimental designs with treatments applied to replicate plots within a single stand. The choice of locating all replicates (degrees of freedom) stems from a desire to minimize variation among plots, allowing the signal of the treatment response to be detected more clearly. Insights from these experiments may apply to other forests and other times if other ecological factors do not interact with the factors examined in the classic experimental design.

2.1. Biogeochemistry in fast-growing Eucalyptus plantations

Highly productive plantations *Eucalyptus* species are commonly established on low-fertility soils, and large nutrient exports at the harvest every 6–7 years pose a challenge for sustainability (Gonçalves et al., 2013). Large amounts of fertilizers are applied to increase nutrient supply and countered losses in forest harvest (Stape et al., 2006, 2010). How does the addition of fertilizers change the cycling of elements in forests and soils? Are the added nutrients retained in the soil, in the trees, or lost by leaching during the rainy seasons? How long after fertilization are rates of nutrient cycling increased? How variable would these responses be around the world? The scientific curiosity behind these questions has led to experiments that may be quite valuable for sustaining high growth rates in plantations. Matching fertilization regimes to tree requirements requires improving our understanding of the biogeochemical processes controlling the dynamics of nutrient availability in soils.

Comprehensive studies have been carried out in the Congo and in Brazil for contrasting nutrient supplies to quantify the main fluxes of N, P, K, Ca and Mg at the scale of the ecosystem in *Eucalyptus* plantations, from planting to harvesting (for details, see Laclau et al., 2010). These plantations are typically established on very deep soils, and *Eucalyptus* roots descend deep into the soil almost at the rate the crowns rise into the air. Soil mineralogy as well as the main soil physical and chemical properties have been characterized down to depths > 5 m. Nutrient accumulation in the trees, nutrient returns to soil with litterfall and nutrient releases during litter decomposition were also measured throughout stand rotation. Moreover, the nutrient fluxes dissolved in gravitational solutions were quantified to assess the losses by deep drainage after clear-cutting and to provide practical recommendations for the fertilization regimes.

Strong differences in soil, climate, eucalypt species and silvicultural practices between the commercial eucalypt plantations at the two sites led to much higher productivities in Brazil (about 50 $m^3\,ha^{-1}\,yr^{-1}$) than in the Congo (about 20 $m^3\,ha^{-1}\,yr^{-1}$). Although the soils in both locations was predominantly sand (90% sand in the Congo, 75–80% sand in Brazil), nutrient losses in deep drainage were very low at the two sites (lower than atmospheric deposition). The largest fluxes of nutrients deep into the soil came when the previous stands were clearcut, and post-logging residues as

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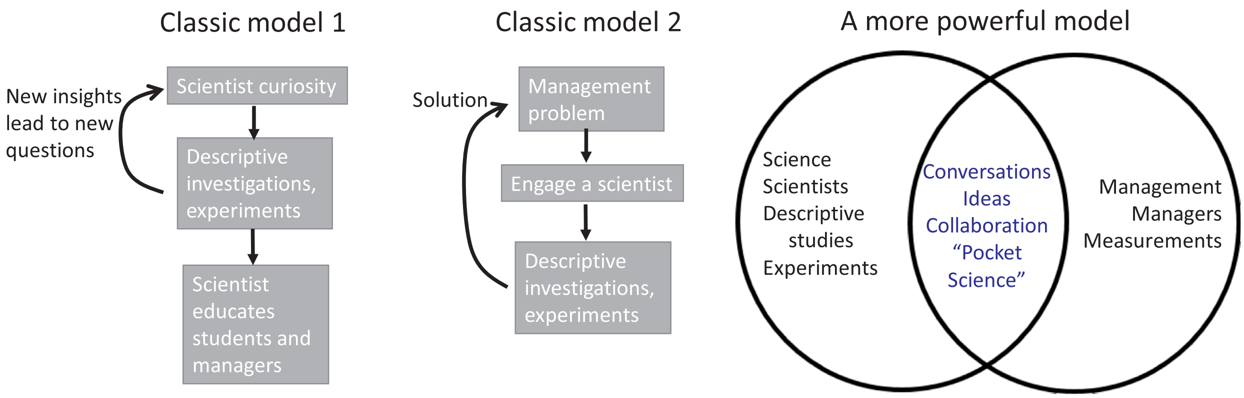

Fig. 1. One classic approach to the connection between science and management was the generation of new knowledge by curious scientists who expected that managers would find value and apply new knowledge (left). Another classic approach entailed the identification of a problem by managers, with a scientist brought into investigate and solve the problem (middle). We suggest the largest gains in both science and management may come from close engagement of scientists and managers, including the development of a culture embracing “pocket science” (right, described in more detail in the text).

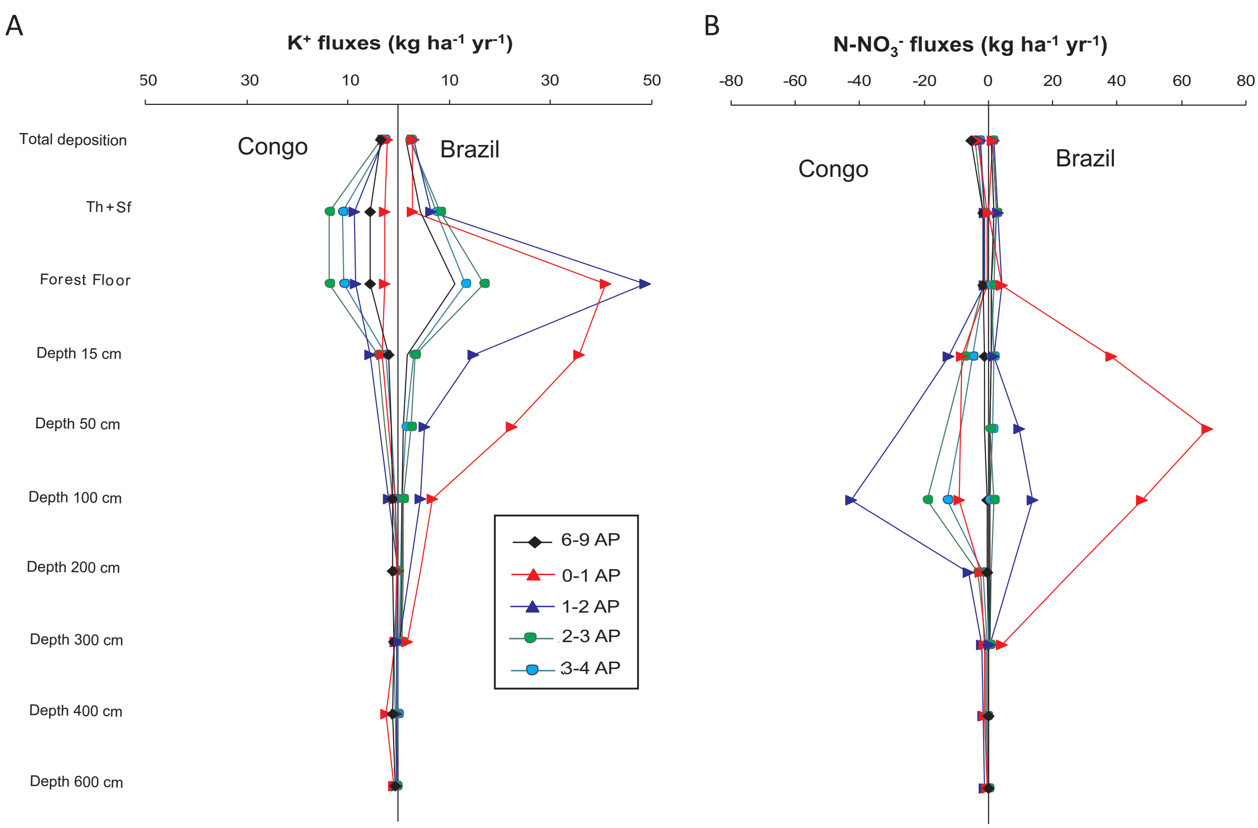

Fig. 2. Annual fluxes (kg ha^{-1} year^{-1}) of potassium in the Congo (A) and nitrogen (nitrate form) in dissolved in gravitational solutions in *Eucalyptus* plantations in Brazil (B; modified from Laclau et al., 2010). Th + Sf indicate the sum of annual throughfall and stemflow fluxes. Each colour represents the annual fluxes for years after planting (AP). For example, mean annual fluxes the first year after replanting are indicated by a red line for the two sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

well as fertilizers (120 kg N ha^{-1} and 100 kg K ha^{-1} in Brazil) provided pulses of nutrients in the upper soil for the early growth of planted trees (Fig. 2). However, nutrient concentrations remained very low at a depth of 3 m throughout the rotation. The main factors controlling soil solution chemistry were similar at the two sites: (i) high nutrient demand the first after planting to support growth of nutrient-rich leaves and fine roots, (ii) very fast root growth in deep soil layers (Pinheiro et al., 2016), (iii) high water demand from the first year after planting onward (Christina et al., 2017), which enhances the transport of ions up to the roots by mass flow, and (iv) slow velocity of ion displacement downward in gravitational soil solutions due to both root uptake and adsorption of ions on soil organic matter, oxides and clay minerals (Laclau et al., 2003, Mareschal et al., 2013). Low losses of nutrients by deep drainage have been confirmed in other tropical eucalypt plantations managed in short rotation (e.g. Silva et al., 2013).

The generality of the factors accounting for a sharp decrease in nutrient concentrations throughout the transfer of gravitational solutions in very deep soil layers led many forest companies to test effectiveness of fewer, larger applications of fertilizer, potentially with the same yield increases, lower cost, and low risk of large leaching losses of nutrients from the sites. The understanding of the main factors driving the chemistry of soil solutions led therefore to a simplification of fertilization regimes over huge areas of eucalypt plantations on deep soils in Brazil.