Ecology

Prioritizing where to restore Earth's ecosystems

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Targets for ecosystem restoration are usually specified in terms of the total area to be restored. A global analysis reveals that the benefits and costs of achieving such targets depend greatly on where this restoration occurs. See p.724

The declaration by the United Nations of 2021–30 as the UN Decade on Ecosystem Restoration is drawing worldwide attention to the challenge of restoring natural ecosystems that have been degraded or converted (for agricultural use, for example)[1]. Ecosystem-restoration targets already feature prominently in global and national policy frameworks aimed at limiting ongoing biodiversity loss and climate change. These targets are set mainly in terms of the total area or percentage of land to be restored. But how can this restoration effort be best distributed spatially to maximize benefits for both biodiversity conservation and efforts to tackle climate change? On page 724, Strassburg *et al.*[2] address this crucial question across all of Earth's biomes (broad zones of vegetation adapted to particular climates). To do this, they analyse data on the benefits and costs of restoration, using information assembled at high spatial resolution across the entire global land surface.

Ecosystem-restoration targets have long been regarded as complementing targets for protecting relatively intact ecosystems. For example, the Aichi Biodiversity Targets[3] for 2011–20, which were established under a key UN biodiversity treaty, the Convention on Biological Diversity, coupled the ambition of restoring "at least 15 per cent of degraded ecosystems" with that of increasing the coverage of protected areas to include "at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas". However, until now, the science of prioritizing where best to invest in ecosystem restoration at global and national scales has lagged behind the many notable scientific advances made in prioritizing additions to protected areas[4].

One of the biggest challenges in prioritizing areas for restoration (Fig. 1) is balancing the benefits for biodiversity conservation against those for climate-change mitigation. Forests are usually the biomes with the highest potential to sequester carbon. However, all biomes, including non-forest biomes such as natural grasslands and shrublands, can contain ecosystems in urgent need of restoration to prevent the extinction of species found only in those ecosystems. Even areas offering similar potential for carbon sequestration within the same biome (for example, in tropical rainforests) can vary greatly in terms of potential restoration benefits for biodiversity conservation. This is because such benefits depend on the number and uniqueness of the species associated with a given area of that biome, and the extent to which these species have lost habitat elsewhere across their range.

Balancing benefits is further complicated by variation in the probable costs of ecosystem restoration in different parts of the world — both the direct costs of restoration and the indirect costs of forgoing income from other land uses, particularly agricultural production. Strassburg and colleagues confront this daunting prioritization challenge head-on using a new multicriteria approach based on a mathematical technique called linear programming. This enabled them to optimize restoration outcomes that balance the benefits for biodiversity and climate-change mitigation, and the associated costs, in a variety of ways. The authors carried out their analysis using state-of-the-art data sets that describe the spatial distribution of: ecosystem types expected in the absence of major human activity; current land uses; the potential for carbon sequestration by living and dead organic matter; habitats of vertebrate species; and expected restoration costs.

Strassburg *et al.* show that the benefits and costs of restoring a given total area of land depend very much on where this restoration is undertaken. Prioritizing the spatial distribution of restoration using a single criterion of benefit or cost generally performs poorly in achieving desirable outcomes for the other criteria. For example, restoring 15% of the world's converted lands by focusing solely on maximizing benefits for climate-change mitigation would achieve only 65% of the gains potentially achievable for biodiversity (assessed as the resulting reduction in risk of species extinctions) if the restoration focused instead on maximizing biodiversity benefits. Restoration focused solely on minimizing costs would achieve only 34% of the maximum potential gain for biodiversity and 39% of the potential gain for climate-change mitigation. Encouragingly, however, optimizing for all three criteria simultaneously yields a solution that would achieve 91% and 82% of potential gains for biodiversity and climate-change mitigation, respectively, while maximizing cost-effectiveness.

These findings have major implications for the setting and implementation of global targets for ecosystem restoration. A key discovery by Strassburg and colleagues is that the total area restored is a relatively weak metric of how restoration might help in reaching fundamental goals for biodiversity conservation and

Figure 1 | Tree planting during forest restoration in Madagascar.

climate-change mitigation. This is conveyed most compellingly by the finding that the reduction in risk of species extinctions that is achieved by different spatial allocations of the same total area of restoration can vary by a factor of up to six. Thus, any high-level goal for ecosystem restoration, and associated indicators for assessing progress, should ideally be specified in a way that ensures actions are directed towards areas that will contribute most effectively to achieving fundamental biodiversity and climate goals.

Strassburg and co-workers' study is particularly laudable for linking perspectives on ecosystem restoration to bridge the domains of biodiversity conservation and climate-change mitigation. However, challenges remain in further linking such prioritization to other key drivers and pressures, and other types of action beyond restoration. Multiple interactions between these factors will together determine overall global outcomes for biodiversity and climate. Consider, for example, the scope of such interactions just in relation to the goal of preventing species extinctions. Strassburg and colleagues' extinction-risk modelling assumes that the distribution of potentially suitable environments for species will remain fixed, despite growing evidence that many of these distributions are already shifting, or are likely to shift over time, owing to climate change[5]. Research assessing the combined effects of land use and climate change on biodiversity suggests that not considering climate-change effects might lead to a severe underestimation of extinction risk[6].

The authors' modelling also assumes that all habitat currently provided by intact ecosystems will remain intact. But, given current trends in ecosystem degradation worldwide[7], it seems probable that the area of habitat available for species will ultimately be determined not only by gains made through restoration, but also by the interplay of such gains with losses occurring elsewhere in the extent and integrity of ecosystems[8]. The magnitude and spatial configuration of future losses will, in turn, be determined by ongoing interactions between socio-economic drivers of demand for converted lands, and actions aimed at either reducing the demand itself, or ameliorating the effect of this demand by protecting key areas of intact habitat from conversion[9].

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The role of such interactions in shaping ultimate outcomes underscores the need to take these interactions into account when defining, implementing and assessing progress in achieving global targets[10]. The post-2020 global biodiversity framework (see go.nature.com/36fqq44), currently being developed for adoption by the parties to the Convention on Biological Diversity, offers a timely opportunity to address this need by explicitly defining interlinkages between any agreed ecosystem protection and restoration targets and the framework's over-arching biodiversity goals.

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