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Agroforestry: a refuge for tropical biodiversity?

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As rates of deforestation continue to rise in many parts of the tropics, the international conservation community is faced with the challenge of finding approaches which can reduce deforestation and provide rural livelihoods in addition to conserving biodiversity. Much of modern-day conservation is motivated by a desire to conserve 'pristine nature' in protected areas, while there is growing recognition of the long-term human involvement in forest dynamics and of the importance of conservation outside protected areas. Agroforestry – intentional management of shade trees with agricultural crops – has the potential for providing habitats outside formally protected land, connecting nature reserves and alleviating resource-use pressure on conservation areas. Here we examine the role of agroforestry systems in maintaining species diversity and conclude that these systems can play an important role in biodiversity conservation in human-dominated landscapes.

Biodiversity conservation in the tropics

In tropical regions, extensive conversion of forests and agricultural intensification are typically identified as the most prominent drivers of land-use change and biodiversity loss [1,2]. Rates of deforestation in some parts of the tropics are estimated to have increased since the beginning of the 21st century compared to those in the 1990s [3]. Moreover, land-use pressure is compounded by the fact that some of the world's poorest people live in the tropics. It is estimated that up to 86% of the population in some tropical countries lives below the poverty line [4]. In addition, the population growth rate in these regions is substantially higher than the population growth rate of the world as a whole [5]. Therefore, any approach that aims to mitigate tropical deforestation and protect biodiversity should address the livelihoods and needs of local communities.

Agroforestry – intentional management of shade trees with agricultural crops – has emerged as one of the most promising approaches to reducing deforestation in the tropics while enhancing rural livelihoods [6]. Furthermore, it has been suggested that agroforestry systems can alleviate the resource-use pressure on protected areas, enhancing habitats for some wild species and increasing the connectivity of landscape components, thereby making conservation more effective [7]. However, the extent to which agroforestry might provide a viable option for biodiversity management outside formally protected areas remains seriously under-researched (but see Ref. [8]).

Here we review evidence from studies across the tropics where species richness and composition of agroforestry systems are compared with that of neighbouring forest reserves. We treat this evidence from two perspectives. First, we highlight the changing concept of 'pristine nature' by arguing that people have played a key role in shaping many of the so-called pristine forests of today and emphasise that future approaches to conservation need to consider agroforestry. Second, we recognise the so-called matrix effect on species diversity in landscape mosaics with native tree cover, and suggest that agroforestry systems can provide corridors that connect distant reserves. Based on the evidence from the literature, we ask whether agroforestry systems can offer a useful tool for biodiversity conservation and conclude that they can play an important role by providing habitat for many species in increasingly human-dominated landscapes.

Conservation in human-dominated landscapes

Many landscapes that are considered 'pristine' forests today have, in fact, been under some form of cultivation in the past [9]. Cultivation techniques included not only the planting of trees but also soil-management strategies. For example, evidence has recently emerged that the ancient Maya manipulated and cultivated the landscape of the Yalahau region in the northeast corner of the Yucatan Peninsula in Mexico using algae from wetlands to enrich upland garden plots, and cultivated trees within their communities [10]. Similarly, there is substantial evidence to indicate that the fertile Terra Preta soils were developed by pre-Columbian native populations in central Amazonia through the addition of large amounts of charred residues, organic waste, excrement and bones [11]. A variety of agroforestry crops are known to have been cultivated by prehistoric populations in the tropics [12,13]. These include Brazil nut trees *Bertholletia excelsa* cultivated in forest groves by the Kayapo Indians of the Brazilian Amazon before European colonisation [14], the cultivation of *Boswellia papyrifera* (the tree that yields frankincense) over 2500 years ago in Africa [15] and banana cultivation in the heart of the African rain forest at least 3000 years ago [16]. The hunter-gatherer communities in Nkang, southern Cameroon are also believed to have cultivated bananas around 3000 years ago in addition to keeping livestock [17]. Similarly, people inhabiting the lower montane rain forests of the highlands of Papua New Guinea are

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believed to have maintained banana plantations around 6500 years ago [17].

There is a substantial lobby within modern-day conservation that promotes protection of the largest possible tracts of pristine landscapes [18]. Although large tracts of forest habitat are necessary for conservation of, for example, megafauna that have large home ranges, such habitats are rarely as pristine as they are typically represented [9]. In fact, it has long been known that people have had a significant influence on landscape development in tropical regions. There is ample archaeological evidence of prehistoric human-induced environmental change, often indicating degradation of natural landscapes [19–21]. Recent work in applied palaeoecology is adding to a gradual shift in perception that many of today's so-called natural landscapes were, in fact, shaped by prehistoric people [22]. Therefore, many areas conceptualised as pristine forests might have regenerated from agricultural fallows in the recent past. Long-term palaeoecological records provide realistic estimates of the time it takes for a forest to regenerate after abandonment from cultivation. For example, evidence of cultivation by humans around 700 years ago has been reported from vast stretches of so-called pristine rain forests in southern Nigeria today [23]. Several other examples have shown cycles of use, forest regeneration and re-use of land by humans (see Ref. [24] and references therein). This work emphasises the message that people are part of nature and that the biodiversity found today is the result of past human activities, as well as a combination of other ecological and climatic processes [25]. A substantial body of knowledge suggesting that today's pristine forests might have been yesterday's agricultural fallows is, by necessity, changing concepts and approaches to biodiversity conservation [25–28].

Today, in some humid tropical landscapes, trees have such a prominent place in farming systems that the difference between forests, old fallows and extensively managed tree-crop plantations is not always apparent. Coffee plantations in many tropical regions, for example, are grown under shade of native tree species, making these plantations resemble neighbouring forests in their structure [29] (Figure 1). Such plantations provide habitat for many species outside protected reserves in otherwise highly human-dominated landscapes [7]. This role of agroforestry plantations in biodiversity conservation is often overlooked. Much emphasis is placed on 'fencing in' forests within strictly protected reserves and nature conservation is largely regarded as being focused almost exclusively on formally protected areas [30]. Although there is no doubt that protected areas do contribute hugely to preserving large parts of the biodiversity on Earth, such areas often fail to cover the entire diversity of ecological habitats and species and, as crucially, strict protection of such areas is often resented by local people [31]. In a recent debate over the future of tropical forest species, it has been suggested that although some forest specialists need 'intact' forest habitat, the bulk of tropical species will be forced to persist in degraded and secondary habitats outside forest reserves in the future (see Ref. [32] and references therein). Therefore, the need for biodiversity conservation in human-dominated landscapes in the tropics is greater today than ever.

Agroforest refuges for biodiversity

Recent research in tropical fragmented landscapes suggests that small, isolated fragments, typically less than 100 ha in area (much of which is forest edge), are dominated by common and invasive species and are poor in rare and endemic species [33]. Agroforests are often very small

Figure 1. An example of a coffee plantation grown under the shade of native trees. In this coffee plantation in Kodagu, Western Ghats, India, a layer of coffee bushes is seen in the understorey and a canopy of native trees is seen above this layer. Such plantations of shade-grown coffee in many tropical regions have canopy structure similar to that of secondary forests. The shade of native trees provides habitat for many forest-dwelling species in otherwise highly human-dominated landscapes.

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