Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use

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Restoration initiatives seek to address widespread deforestation and forest degradation, but face substantial problems. "Passive restoration", whereby abandoned agricultural land undergoes secondary succession, is often slow, owing to biotic and abiotic limitations. "Active restoration", chiefly accomplished by planting trees, can be very expensive if large areas are to be restored. We suggest "woodland islets" as an alternative way to achieve ecological restoration in extensive agricultural landscapes, particularly in low-productivity environments. This approach involves the planting of many small, dense blocks of native trees to enhance biodiversity and provide a range of ecosystem services. If the surrounding land is abandoned, the islets act as sources of woodland species and seed, which can accelerate woodland development. Alternatively, if the surrounding area is used for cultivation or pasture, the islets will increase the conservation value of the land and offer the potential for income generation. Here, we review existing approaches to woodland restoration and evaluate the relative strengths and weaknesses of the woodland islets approach.

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In the debate over how to balance conservation and exploitation of ecosystems, no human activity is as controversial as agriculture (Green *et al*. 2005; Matson and Vitousek 2006). From the boreal regions to the tropics, widespread deforestation, often for the purpose of conversion to agricultural land, has resulted in major environmental problems, compromising ecosystem services. These problems include loss of biodiversity, soil erosion, mobilization of stored carbon and soil nutrients, depletion of usable water resources due to run-off, contamination of waterways, and lowering of water tables (Schröeter *et al*. 2005). Today, croplands and pastures have become the largest single terrestrial biome, accounting for ~ 40% of the planet's land surface (Foley *et al*. 2005). This area is likely to expand in the immediate future, resulting in continued deforestation, which has occurred at an estimated global rate of 130 000 km^2 per year for the past 5 years (FAO 2006).

Traditional agriculture typically restricts natural vegetation to valleys and saline, infertile areas, and on steep hillsides, rocky outcrops, shallow soils, property boundaries, and track edges. More recently, farming practices in many areas have intensified, and increasing amounts of water, fuel, fertilizers, pesticides, and herbicides are used worldwide to increase food and fiber production (Figure 1). Intensification of land use has brought remnant areas of natural vegetation into mainstream agriculture and many such areas have been lost or severely degraded as a result. Globally, degradation of land as a consequence of agricultural activities is estimated at about 12 400 000 km^2, and ranges between 10–20% in the dryland areas of the planet (Lepers *et al*. 2005; see also LADA 2007).

Patterns of land-use change are complex. Agricultural intensification and deforestation to create farmland can occur alongside extensive farmland abandonment, which, in turn, can lead to succession back to forest (Rey Benayas 2005). Agricultural abandonment is a global phenomenon and is usually a result of rural–urban migra-

In a nutshell:

- Agriculture is often in conflict with other environmental services that natural or cultural landscapes provide to humans
- This is the "agriculture and conservation paradox", and can be addressed by ecological restoration
- Natural regeneration of woodland restores more land at lower cost than active planting of forests, but is often slow because seed dispersal is limited and adverse environmental conditions constrain tree establishment
- The "woodland islets" approach uses local-scale management interventions to support natural regeneration over larger areas
- This could reduce costs compared to extensive reforestation, increase conservation value of agricultural land, enhance provision of ecosystem services, increase income, and improve social and educational resources

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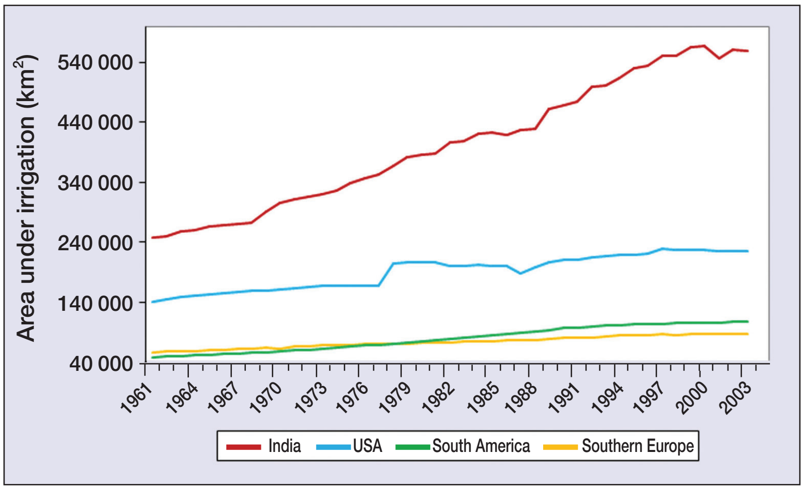

Figure 1. *Increased intensity of land use in arid and semi-arid zones, indicated by increases in the area of agricultural land under irrigation since the 1960s. In these examples, the area of irrigated land doubled, on average, over the time period shown. Data from FAOSTAT (http://faostat.fao.org/).*

tion, driven by economic and political forces (Aide and Grau 2005). Some agricultural and agroforestry systems within cultural landscapes (human-modified environments that include cultural and natural resources) are recognized for the conservation merit of their biodiversity, habitat, and aesthetic values (Kleijn *et al.* 2006). For instance, a majority of the terrestrial ecosystems deemed of particular conservation value in the European Union Habitat Directive have been created or modified by agriculture (Rey Benayas *et al.* 2007). Agricultural intensification can have a negative impact on these values, but so can agricultural abandonment. It seems that agriculture, woodland, and biological conservation are in permanent and irreconcilable conflict – a problem we call the "agriculture and conservation paradox". This creates a dilemma in woodland restoration projects that can only be resolved by considering the relative values associated with woodland versus agricultural ecosystems.

Existing approaches to woodland restoration

The principal method used to combat loss of natural and semi-natural vegetation and associated communities is ecosystem restoration. Until now, ecological restoration of woodland has been based upon two contrasting approaches: natural colonization by shrubs and trees and secondary succession ("passive restoration"), or the artificial establishment of trees ("active restoration"). Both approaches face unique challenges.

Causes of land abandonment include declining farmland productivity, voluntary or involuntary emigration from rural areas, diversion of labor toward the industrial and service sectors, reduced subsidies for cultivation of crops, and changes in agricultural subsidy set-aside programs (Rey Benayas 2005). Passive restoration involves the colonization of abandoned agricultural land (ie old fields) by whatever plants and animals can disperse from surrounding habitats and subsequently establish, survive, and flourish. Passive restoration therefore has a highly stochastic outcome (Bullock *et al.* 2002). Key constraints on the speed of regeneration are: (1) dispersal limitation, because seed sources are remote and dispersal vectors may be rare (Bullock *et al.* 2002); (2) abiotic limitation, such as low water availability, extreme temperatures, poor soil structure, and low nutrient availability (Rey Benayas 1998; López-Barrera *et al.* 2006); and (3) biotic limitation, such as competition from herbaceous vegetation and grazing (Rey Benayas *et al.* 2005).

Active restoration involves management techniques such as planting, weeding, burning, and thinning, all of which are aimed at producing a forest with a particular composition or structure. A wide variety of approaches have been used to restore degraded forest areas (Table 1). These methods may be preferred when passive approaches are too slow or too risky, due, for example, to positive feedback from soil erosion and vegetation loss (Mansourian *et al.* 2005).

Direct seeding (hand-broadcast or mechanical) is a relatively inexpensive establishment technique, but requires large amounts of seed, and the failure rate is generally high. Where seed is limiting, establishment of tree seedlings may be preferred (Lamb and Gilmour 2003). Rapid revegetation of degraded areas is most easily achieved by intensive planting of a large number of tree species (Lamb and Gilmour 2003). This approach is especially suitable for areas needing rapid restoration, or where natural recolonization will be slow due to isolation from intact forest remnants. The growth rate of plants in such dense plantings can be low, however, and this approach is comparatively expensive (Mansourian *et al.* 2005). It is also possible to hasten natural recovery of degraded forest

Table 1. Summary of the most commonly used approaches for active restoration of forest and woodlands

Approach	*Example*	*Reference*
Enrichment planting	Sri Lanka	Ashton *et al.* (1997)
Direct seeding	South–central USA	Allen (1997)
Scattered tree plantings	Amazonia	Nepstad *et al.* (1991)
Dense, low-diversity plantings	North Queensland, Australia	Goosem and Tucker (1995)
Dense, multi-species plantings	Scotland	Newton *et al.* (2001)
Monoculture plantations	Eastern Australia	Kanowski *et al.* (2003)
Mixed species plantations	China	Wenhua (2004)
Agroforestry	Taungya system in Indonesia	Kobayashi (2004)

Notes: Examples adapted from Lamb and Gilmour (2003) and Mansourian *et al.* (2005).

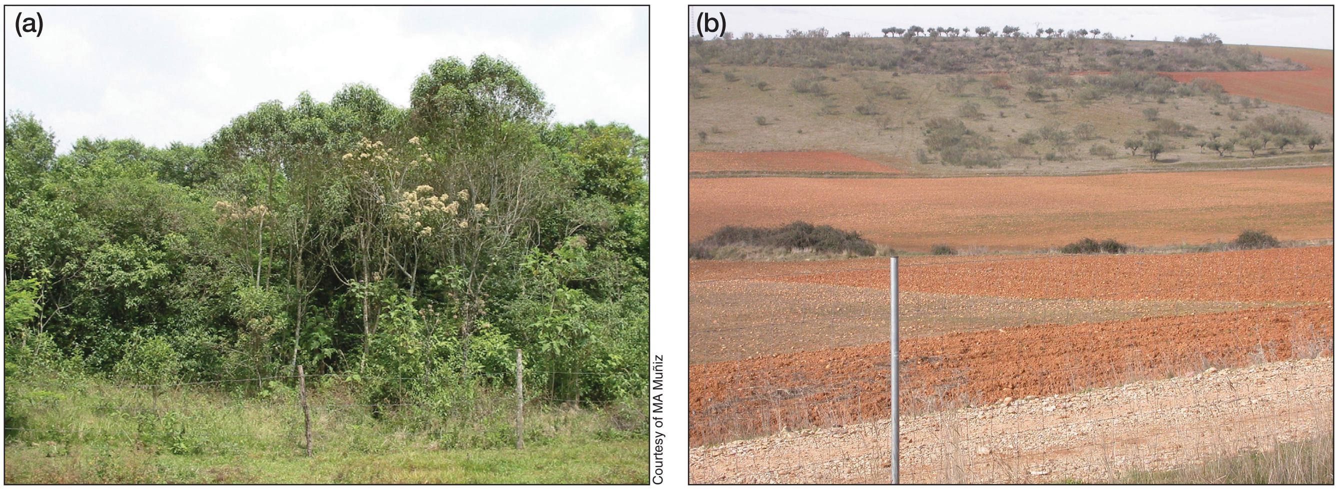

Figure 2. *(a) Secondary forest of a cloud-forest domain in Veracruz, Mexico, 9 years after abandonment of a ranch. (b) Secondary shrubland (on the hillside) in Guadalajara, Spain, 20 years after abandonment of arable land.*

stands by enrichment planting, which involves establishing new trees under an existing forest canopy.

Tree establishment can also be encouraged by attracting seed- or fruit-dispersing fauna into the area undergoing restoration (eg by providing perches for birds, shrub cover for small mammals, or by planting rows of trees to trap wind-dispersed seed; Lamb and Gilmour 2003). This approach is also relatively inexpensive, but without mitigation of abiotic and biotic limitations, establishment and growth rates will be low.

Passive restoration versus active restoration

Natural regeneration currently restores more forest cover in areas that have been deforested than do tree plantations, and probably at lower cost. In the past 5 years, natural forest regeneration has occurred over an estimated area of 45 000 km^2 per year worldwide, whereas plantations have been established on 28 000 km^2 of deforested land per year (FAO 2006). However, these figures vary considerably across regions. Regeneration is usually very slow in environments with low primary productivity, such as in the Mediterranean and other dry regions of the world (Vallejo *et al.* 2006), but many tropical and humid temperate ecosystems can recover rapidly with little or no intervention when the soil has not been severely degraded by previous land use (Figure 2). For example, in Puerto Rico, forest cover increased from < 10% to > 40% of the island in about 60 years, following the abandonment of agricultural and grazing lands (Grau *et al.* 2003). Similar patterns of ecosystem recovery following cropland abandonment and rural–urban migration have been documented in forested and non-forested ecosystems in many regions of the world (Aide and Grau 2005; Lepers *et al.* 2005; FAO 2006; Vallejo *et al.* 2006; González-Espinosa *et al.* 2007).

Active methods of tree establishment are widely used to support commercial plantation forestry and to establish trees on farms to benefit rural communities (eg by providing fuel and fodder and mitigating the effects of wind erosion). Examples of the latter include shelter belts, buffer strips, woodlots, orchards, and agroforestry systems in which woody perennials are deliberately combined with agricultural crops and/or animals (Mansourian *et al.* 2005). These afforestation approaches may also contribute to the ecological restoration of forest landscapes by providing a habitat for wildlife (Erdmann 2005). However, modification of traditional management approaches will often be required to maximize habitat suitability for wildlife (Newton and Humphrey 1997).

On a global scale, only a few countries, such as China and Chile, have established larger forest areas through tree plantations than through passive restoration during the period of 2000–2005 (FAO 2006). The vast majority of tree plantations have been established for commercial timber-producing purposes, which have limited value for biodiversity. In addition, this increase in forest cover has often been at the expense of other land cover of higher biodiversity value.

■ The new "woodland islets" approach

We suggest a different concept for restoration of forest ecosystems on agricultural land, which uses small-scale, active restoration as a driver for passive restoration over much larger areas. This could increase the economic feasibility of large-scale restoration projects and facilitate the involvement of local communities in the restoration process.

"Woodland islets" can be planted to restore woodlands in extensive agricultural landscapes where no natural remnants of native vegetation exist. Whereas passive restoration leaves reforestation to chance, and active restoration usually requires a large input of resources, woodland islets represent an intermediate degree of intervention. They enable secondary succession by establishing small colonization foci, while using a fraction of the resources required for large-scale reforestation. In addition, this approach maintains flexibility of land use, which is critical in agricultural landscapes, where

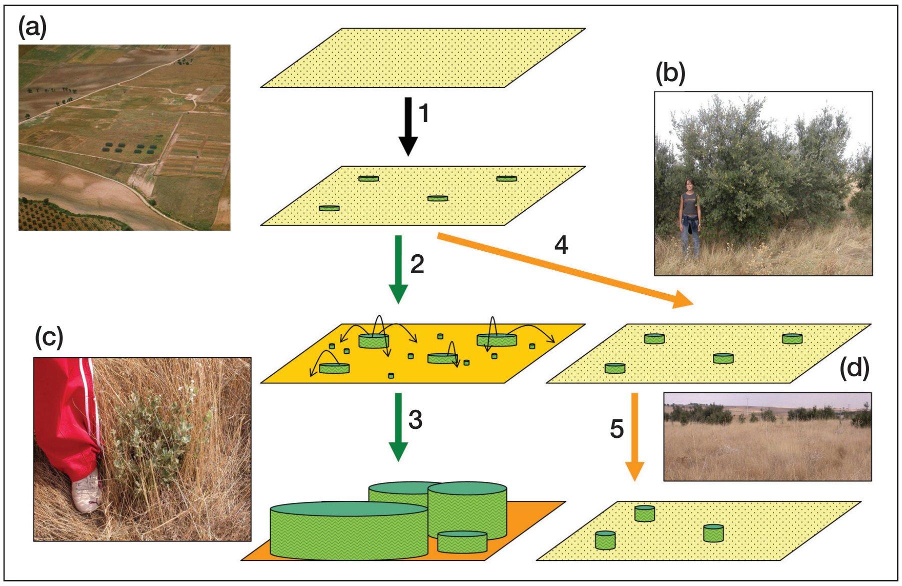

Figure 3. *Schematic diagram of the "woodland islets" approach, illustrated with the 15-year experimental site at La Higueruela Experimental Farm (Toledo, Spain). A denuded agricultural landscape is planted with a few (here, four) small (eg 100-m^2) woodland islets (1 and a). Targeted management of the islets allows the trees to establish, grow and reach sexual maturity rapidly (b). If the cropland is then abandoned, the islets can expand and export seeds (and other organisms established in them) to the surrounding land (2 and c – a holm oak seedling). The islets eventually coalesce to form closed woodland (3). Alternatively, the surrounding land remains in same or other uses (eg cultivation or pasture, d) while the islets remain as small patches of native woodland community as the trees grow taller (4). Because they are small, some islets may disappear through stochastic events (5).*

exploitation of the territory is subject to a number of changing economic and policy drivers (Antle *et al.* 2001). A number of small (some tens or a few hundreds of m^2), densely-planted (eg one introduced seedling per 2 m^2), and sparse (some tens or hundreds of m apart) blocks of native trees are planted on agricultural land, occupying only a small fraction of the area of target land to be restored (eg < 1% of a field; Figure 3). This provides a means of reconciling competing demands for agriculture, conservation, and woodland restoration at the landscape scale (Panel 1).

Panel 1. The range of potential benefits provided by the "woodland islets" approach for restoration in agricultural landscapes; individual benefits are not necessarily exclusive, but in combination result in an integrated set of ecological, economic, and social benefits

- High survival and growth rates of planted trees through management
- Reduced cost of management because it is concentrated in small areas
- Maintenance of the conservation values of extensive agricultural landscapes
- Provision of ecosystem services, including carbon sequestration and increased soil fertility
- Provision of suitable habitat for a variety of organisms, including some woodland specialists
- Increased heterogeneity of uniform landscapes and connectivity among forest remnants
- Provision of a source of propagules, which greatly accelerates woodland development if the surrounding land is abandoned
- Provision of economic benefits through farming or other livelihood activities, such as livestock production and hunting undertaken on the remaining land
- Addition to farm income by increasing game and crop production
- Provision of social benefits, such as labor for local communities, educational resources, technical training, public amenity, and ecotourism

Ecological, social, and economic benefits of the islets approach

The planting of woodland islets could enhance a range of processes relating to biodiversity restoration, ecosystem services, agriculture, and rural societies and economies. Critically, while individual processes (eg carbon sequestration) may be achieved more efficiently by other means, islets could provide an integrated set of ecological, social, and economic services. We detail the various benefits below and illustrate them with reference to a case study (Panel 2).

Reduced cost

Management interventions to overcome abiotic limitations can include fertilizer inputs, irrigation, and artificial shading, while weed eradication and protection from herbivores can mitigate biotic limitations (Rey Benayas *et al.* 2005). The cost of managing planted trees can be high (Lamb *et al.* 2005), but because the area planted is small, intensive management can be more concentrated than in an extensive reforestation program, and so total costs are greatly reduced. However, cost per unit of woodland established may not necessarily be lower.

Provision of woodland habitat

The islets would provide habitat for a range of woodland species, including microbes, fungi, plants, invertebrates, and vertebrates. Even small patches or individual trees can provide the required microclimate, food, and protection from predators for some (although not all) woodland specialists (Lovei *et al.* 2006; Manning *et al.* 2006). Colonization of woodland patches is enhanced by directed dispersal of relevant species: animals deliberately seek out such patches in a hostile landscape and seeds may be deposited by animal dispersers or trapped while being blown by wind (Sekercioglu 2006; Zahwai and Augspurger 2006). Furthermore,

Panel 2. The "La Higueruela" case study (Toledo, Spain)

We have been conducting an experiment on former cropland, where we introduced holm oak (*Quercus ilex rotundifolia*) seedlings into 16 100-m^2 plots in 1993. *Q ilex* is a late successional, slow-growing tree. The introduced seedlings were subjected to four replicated combinations of summer irrigation (presence or absence) and artificial shading (presence or absence; Rey Benayas 1998). Because management is expensive and can only be applied for a limited period of time in the field, shading and irrigation were stopped in 1996. The experiment is often revisited to evaluate (1) the survival, growth, and reproduction of the young trees, (2) soil fertility, and (3) diversity of various taxonomic groups. We also compare these functional and structural properties with the surrounding abandoned cropland, which has been under passive restoration for 15 years.

Thirteen years after the experiment began, 56% of the oak seedlings in control plots and >87% in managed plots have survived. Management accelerated growth and development; 6 years after the end of management, 2% of the trees in control plots produced acorns, compared to 11–16% in managed plots (Rey Benayas and Camacho 2004). Now, canopy openness ranges between 69% in control plots and 45–49% in managed plots and the trees average 5.4 cm in diameter at breast height and 177.2 cm in height, and produce, on average, 51.3 g of acorns per individual (Figure 4).

In the surrounding land, only eight woody plants have established after 15 years of abandonment. Two are *Retama sphaerocarpa*, a pioneer Mediterranean shrub, but the six others are holm oak seedlings that have colonized from the woodland islets. Without introduced woodland islets, no tree seedlings would have been able to establish in the abandoned cropland.

Overall, soil in the woodland islets is more fertile than in the adjacent abandoned field. Organic matter concentration and inorganic N average 0.94% and 3 μg g^{-1}, respectively, in woodland islets, and 0.78% and 2.24 μg g^{-1}, respectively, in the abandoned field. We have also found positive effects of the woodland islets on herb diversity, owing to the heterogeneity that they create at the landscape scale (Figure 5).

Figure 4. A woodland islet developed on abandoned cropland in a Mediterranean landscape 13 years after the introduction of Quercus ilex *seedlings at a density of 50 individuals per 100 m^2.*

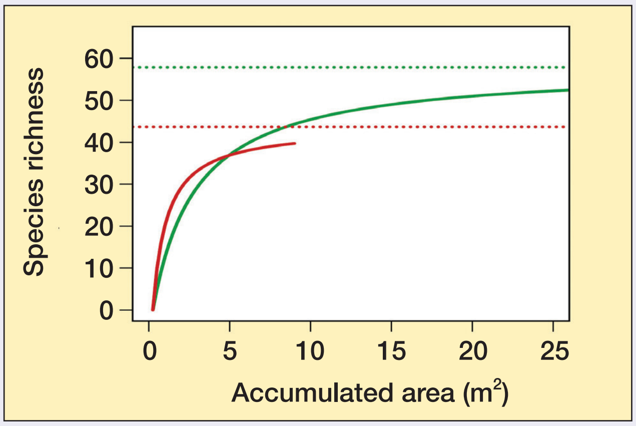

Figure 5. The woodland islet approach increases heterogeneity and therefore biodiversity. Expected herb diversity based on accumulation curves at the landscape level – represented by the flat, asymptotic lines – after 13 years of cropland abandonment in two scenarios: secondary succession alone (red and dotted line) and secondary succession with established woodland islets (green and dashed line). The woodland islet scenario includes 16 species (38%) more than the secondary succession scenario.

the high density of planting may facilitate the establishment of woodland plants in otherwise exposed conditions (Padilla and Pugnaire 2006). The islets can also function as habitat at a landscape scale; woodland patches have higher species diversity when in close proximity to other patches, sustaining metapopulations and providing local resources such as food and shelter for relatively mobile species (Tylianakis *et al.* 2006).

Provision of ecosystem services

As demonstrated by agroforestry initiatives, small areas of trees and shrubs in agricultural landscapes can provide valuable services to the farmer. These include sources of natural enemies of pests, pollinators of crop plants, wind shelter for crops and livestock, and fodder for livestock (Bodin *et al.* 2006). More broadly, woodlands can enhance certain ecosystem services compared to croplands and agricultural grasslands. These include carbon sequestration, soil fertility, protection from erosion, and water retention (Bunker *et al.* 2005). Even individual trees provide these services, albeit to a lesser extent (Manning *et al.* 2006) than do small woodland patches (Carreiro and Tripler 2005; Breshears 2006).

Acceleration of secondary succession

Woodland patches act as sources of seed and dispersing animals that can colonize adjacent habitats (Muñiz *et al.* 2006). If the surrounding land is abandoned, colonists from the islets can accelerate woodland development, because dispersal of various woodland organisms will continue over many years. If establishment is limited to the non-wood habitat, amelioration of conditions at the edge of the islet may be a critical process (López-Barrera *et al.* 2006). Patterns of early succession to forest after abandonment may also depend on the species of trees introduced in the woodland patches (Slocum 2001).

Income generation and social benefits

A critical aspect of woodland islets is that the use of the remaining, unforested land by human communities can remain flexible. If the land has not been abandoned, and therefore does not undergo succession, the area surrounding the islets can be farmed or devoted to other activities that generate income. This addresses the needs of local communities for a range of land uses, while total reforestation deprives farmers of agricultural resources and can be in conflict with their traditional livelihood options (Morenga *et al.* 2001; Tyynelä *et al.* 2002). The islets approach, on the other hand, can contribute to comprehensive management schemes that lead to improved productivity and an increase in farmers' income (Guobin 1999).

Tree planting schemes can be important for local communities (Lamb *et al.* 2005) and can generate substantial and measurable environmental and economic benefits for countries (Ferretti and Miranda de Britez 2006). The area planted with trees has social value, providing employment opportunities and an educational resource (Nawir and Santoso 2005). The newly wooded area can be used for the benefit of the local community. The woodland blocks could be created by local young people, who would gain technical training and education about conservation (eg training placements; Gold *et al.* 2006). The social benefits will vary, depending on the economic status and land-use traditions of countries and local communities.

Related approaches

The woodland islets idea is similar to other approaches involving planting small areas of trees on farms (eg creation of woodlots, hedges or shelterbelts, and agroforestry systems; Nair *et al.* 2005). These practices provide ecological benefits and support farm production. A critical difference of the woodland islets approach is that its spatial configuration provides additional ecological benefits, as well as socioeconomic flexibility, owing to the variety of uses to which the non-planted land can be devoted. While the small areas of planted trees on farms also confer benefits other than enhanced production, such benefits are the primary objective of the woodland islets approach. Provision of this variety of benefits depends on combining wooded areas and agricultural land in close proximity. The balance between woodland cover and agricultural land can remain dynamic over time, managed in response to the needs of the farmer. A key distinction is the landscape emphasis on a planned planting of islets to maximize benefits for biodiversity, and the potential to allow the islets to form foci for larger-scale reforestation of intervening land. Furthermore, if the surrounding land is to be farmed, its management can be designed to make use of the ecosystem services provided by the islets.

Unresolved questions

Although the potential environmental benefits of forests, woodland patches, and isolated trees have been widely documented by previous research, the woodland islet method is novel and largely untested. We must therefore be clear about potential problems.

The provision of ecosystem services by woodlands is, in some cases, dependent on woodland size. Since the islets would be small, they will experience the problems associated with small woodland patch size, such as strong edge effects, colonization by generalist species, lack of specialists, and vulnerability to local extinction of populations (Bender *et al.* 1998). The isolation of the islets could lead to founder effects and inbreeding risk (Honnay *et al.* 2005), or they may act as reservoirs of agricultural pests such as rabbits and rodents, and of weed species, so that the ground flora could be dominated by agricultural weeds rather than native species. They could also cause crop losses in their immediate vicinity through competition for water and soil nutrients, particularly in semi-arid environments. However, it is clear that small woodland patches or even isolated trees can maintain some of the ecological communities and functions of larger forested areas (Carreiro and Tripler 2005; Breshears 2006; Manning *et al.* 2006). Spread from these islet foci, as well as establishment and coalescence of forest over larger areas, will be dependent on dispersal distances, fecundity, and growth rates of key tree species, as well as the surrounding pattern of land management and barriers to seedling establishment. We have little information about how rapidly such reforestation might take place; in the case of an experiment in Mediterranean abandoned cropland (Panel 2), seedling establishment was low. However, tree spread and invasion rates could be high if driven by a few highly dispersive species with high fecundity (Clark *et al.* 1999). Data about these processes could be used in spatial models (Baskent and Keles 2005) to test and optimize islet planting scenarios.

Conclusions

The problems with existing methods for restoring woodlands in agricultural landscapes should not give rise to pessimism, but instead should inspire researchers to devise innovative solutions. The proposed woodland islets approach reconciles agriculture and ecological restoration (Panel 1). A realistic view of conservation must acknowledge the conservation value of the agricultural matrix in forest landscapes. A focus on the matrix is required if we are to solve the current biodiversity crisis, and that matrix is usually an agro-ecosystem of some sort (Vandermeer and Perfecto 2007). The woodland islet method suggested here should be viewed as an addition to existing approaches rather than as a replacement. Its application will be most useful in agricultural landscapes where: (1) establishment of shrubs and trees is difficult because, for example, no remnants of natural vegetation exist, productivity is low, or herbivore pressure is high; (2) the agricultural land holds value for economic production or conservation in its own right; and (3) it is likely that some agricultural land may be abandoned in the future, when the archipelagoes of woodland islets in agricultural seas will offer a nucleus for restoration of native communities over a broader area.

The complexity of the interface between human communities and ecological sustainability demands that we move beyond our traditional disciplines. The field of ecological restoration provides illustrations of the necessity and merits of interdisciplinary approaches to real-world problems (Gold *et al.* 2006). The implementation of any new approach requires the support of policy makers, managers, and land owners. There are also costs that must be met, and the woodland islets approach must be financially attractive. Incentive schemes from international, national, and regional agencies, environmental education, and technical assistance would make this goal attainable (Plieninger *et al.* 2004). Beyond external subsidies and environmental education, the potential addition to farm income provided by increasing crop, livestock, and game production should be a further incentive to farmers. Our proposed approach, based upon sound ecological research, may bring economic, social, and educational benefits. We therefore recommend that this concept be the subject of additional long-term field experiments in other study areas.

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