Review

Abandonment of agricultural land: an overview of drivers and consequences

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Abstract

Agricultural activities and their complex effects on nature conservation, and the services that ecosystems deliver to humans are controversial. We present an overview of land abandonment, its driving forces and its consequences for landscape, biodiversity and humans. A descriptive meta-analysis of independently published studies highlighted the fact that the abandonment of agricultural land is a phenomenon mostly driven by socio-economic factors such as immigration into areas where new economic opportunities are offered to rural people. Ecological drivers such as elevation and land mismanagement leading to soil erosion are of secondary importance. We identified the major problems related to abandonment of agricultural land and quantified their relative importance. In order of decreasing importance, they were biodiversity loss, increase of fire frequency and intensity, soil erosion and desertification, loss of cultural and/or aesthetic values, reduction of landscape diversity and reduction of water provision. The impacts of these problems were not equally relevant in all regions of the world. The abandonment of agricultural land may also benefit humans. The benefits include passive revegetation and active reforestation, water regulation, soil recovery, nutrient cycling and increased biodiversity and wilderness. In a world that is becoming less natural and more intensively exploited by humans, we suggest that (1) farmland must be viewed in a context of multi-functionality to take advantage of ecosystem goods and services, (2) at the global scale, the abandonment of agricultural land is mostly positive for humans and (3) there is a need for the implementation of policies based on the payments for environmental services that encourage human societies to reconcile agricultural use, nature conservation and ecological restoration.

Keywords: Biodiversity, Economy, Environmental services, Land-use change, Multi-functionality, Revegetation, Soil

Introduction

Agricultural activities and their complex effects on nature conservation, and the services that ecosystems provide for humans are controversial [1]. Widespread destruction of natural vegetation, mostly forests and prairies, to provide agricultural land has led to major environmental problems around the world since long ago. For instance, the Mayan civilization caused severe deforestation in Central America during its peak in the eighth–ninth centuries [2, 3]. Today, croplands and pastures have become the largest terrestrial biome, accounting for ca. 40% of the planet's land surface [4, 5]. This area will increase in the immediate future, coupled with continued deforestation [6], which has occurred at an estimated global rate of 130 000 km^2 per year over the last five years [7].

The agricultural frontier is constantly advancing. Cropland area in the world increased from $15.84 \times 10^6\,km^2$ in 1983 to $16.79 \times 10^6\,km^2$ in 2003, whereas pastureland changed from 32.62×10^6 to $34.33 \times 10^6\,km^2$ during the same period (data extracted from World Resources Institute http://earthtrends.wri.org/). Additionally, in recent history, farming practices have been intensified and increasing amounts of water, fuel, fertilizers, pesticides and herbicides are used worldwide to augment food and fibre production. Thus, the proportion of irrigated cropland (an indicator of agriculture intensification) has increased from 13.8% in 1983 to 16.5% in 2003. Globally, degraded land due to agricultural activities has been estimated at about 12 400 000 km^2 [8], and ranges between 10–20% in the dry regions of the planet [9] (see also LADA – land degradation in drylands at http://lada.virtualcentre.org). The ultimate drawbacks of agriculture and livestock rearing include loss of biodiversity, soil erosion, mobilization of stored carbon and soil nutrients and loss of usable water resources [6, 10].

On the other hand, some agricultural and agroforestry systems that shape cultural landscapes have been recognized for their conservation relevance, including biodiversity, habitat and aesthetic values [11, 12]. This conservation relevance will be addressed further in this review. For example, four out of seven terrestrial ecosystems included in the European Union Habitat Directive are under agricultural use, including temperate heath and scrub, matorral, grasslands and wooded pastures. These valuable ecosystems would be lost if agricultural use is abandoned. Importantly, increased farmland and agricultural intensification can occur alongside extensive farmland abandonment [13], and agricultural intensification has been identified as a driver of this abandonment [14, 15]. The abandonment of agricultural land represents a change of land use, and land cover/use changes are a complex phenomenon. For example, changes in ecosystem goods and services that result from land use change may feed back on the drivers of land use change [16].

In this review, we present an overview of land abandonment, its driving forces and its consequences on landscapes, biodiversity and humans. Firstly, we review the drivers of abandonment of agricultural land worldwide. To address this issue, we analysed independently published studies in a directed literature search. Next, we identified the effects – negative and positive – that emerge from this abandonment, and quantify their relative importance by using target keywords in a literature search. Finally, we discuss the perspectives that abandonment provides.

Drivers of Abandonment

The scientific literature reports three major types of drivers of agricultural land abandonment. The first type refers to ecological drivers, albeit under different names (sometimes called geo-bio-physical, physiographic, or abiotic drivers). They include factors such as elevation, geological substrate, slope, aspect, fertility, soil depth, soil erosion, climate, and climate change when they constrain agricultural production. Soil erosion can often be regarded as a consequence of overexploitation (i.e. the real driver) as it is in many cases the precondition for soil erosion. The second type refers to socio-economic drivers. They include market incentives, migration and rural depopulation, technology, industrialization, land-tenure systems and security, farm characteristics, farmer age, accessibility (e.g. roads) and proximity to cities. Usually, some of these drivers are mediators of large-scale or macro-driving forces of change, representing, ultimately, new economic opportunities. Beyond specific agrarian policies such as the European Common Agricultural Policy [17–19] and global trade liberalization [20], socio-economic drivers are sometimes intermingled with profound political (e.g. post-Soviet market in Eastern European countries) [21, 22] and cultural changes (e.g. traditions in India [23]). The third type of driver is unadapted agricultural systems and land mismanagement, leading to soil degradation, frequent flooding, overexploitation and productivity loss [24–27].

To identify the relative importance of the major driver types, we performed an electronic search in CAB Direct database of scientific literature under target keywords in either the title or abstract of the reference study. The search under the keywords 'land abandonment' and 'drivers' provided very few references. Searching for 'land' and 'change' resulted in 45 studies dealing with causes of agricultural land abandonment, and this was considered a representative sample in order to reach conclusions about the studied phenomenon. Our examination of these studies identified ten studies reporting ecological drivers and 33 studies reporting socio-economic drivers, whereas just eight studies considered mismanagement as the driver of abandonment (Table 1). Some of these studies mentioned two drivers at the same time. Based upon these results, we conclude that abandonment of agricultural land is a global phenomenon mostly driven by rural–urban migration in areas where new economic opportunities are offered to rural people [28], whereas ecological and mismanagement drivers are of secondary importance. Socio-economic, ecological and mismanagement drivers impinge on the abandonment of agricultural land. For instance, agricultural land whose production is limited by ecological factors such as fertility or precipitation is more prone to be abandoned if socio-economic factors act [29–31].

Since the previous analysis pointed to relevant socio-economic drivers, we next examined the relationships between changes in the amount of cropland and socio-economic indicators across countries under specific hypotheses derived from our literature review. We correlated the changes in the proportion of a country's total area used as cropland between 1983 and 2003 with changes in human population density, per capita gross domestic product and contribution of agriculture to economy. We did not include outlier data in these analyses (countries with changes >300% in population density, >800% in *per capita* GDP and >100% in the proportion of cropland). The source of the raw

Table 1 Summary of the identified drivers of abandonment of agricultural land and where they occur according to 45 independent studies (referenced in Appendix 1)

Identified driver	Biome	Region	Source
Ecological			
Elevation	Temperate mountain, tropical forest	Northern Spain, Honduras	Nagendra *et al*. 2003, Mottet *et al*. 2006
Slope	Temperate mountain, Mediterranean	Northern Spain, Greece, Swiss Mountains	Bakker *et al*. 2005, Mottet *et al*. 2006, Gellrich and Zimmermann 2007, Tasser *et al*. 2007
Soil depth	Mediterranean, wetlands and riparian forests	Greece, Wisconsin, Swiss Mountains	Bürgi and Turner 2002, Bakker *et al*. 2005, Gellrich and Zimmermann 2007
Erosion	Mediterranean	Greece	Bakker *et al*. 2005
Climate	Mediterranean, tropical ecosystems	Southeastern Spain, tropics	Lambin *et al*. 2003, Gisbert *et al*. 2005
Fertility, WHC	Temperate grassland, wetlands and riparian forests	Europe, Wisconsin, China	Yang and Li 2000, Bürgi and Turner 2002, Hodgson *et al*. 2005
Socio-economic			
Migration, rural depopulation	Dry shrubland, Mediterranean, tropical forest, temperate mountain, temperate forest, various	Central Mexico, Spain, Western Europe, Puerto Rico, Italian Alps, Southeast Poland, Ireland, Europe	Cawley 1994, Romero-Calcerrada and Perry 2004, Aide *et al*. 1995, Douglas *et al*. 1996, Lasanta *et al*. 2001, Angelstam *et al*. 2003, Grau *et al*. 2003, Coelho *et al*. 2004, Laiolo *et al*. 2004, Gisbert *et al*. 2005, López *et al*. 2006, Plieninger 2006, Busch 2006
New economic opportunities (tourism, industrialization, housing, etc.)	Tropical forest, tropical coast, Mediterranean, wetlands and riparian forests	Puerto Rico, Tanzania, Brazil, tropics, Spain, Wisconsin, Swiss Mountains	Aide *et al*. 1995, Gössling 2001, Bürgi and Turner 2002, Futemma and Brondízio 2003, Lambin *et al*. 2003, Grau *et al*. 2003, Romero-Calcerrada and Perry 2004, Gellrich *et al*. 2007
Land-tenure system	Temperate mountain, temperate forest	Northern Spain, Denmark	Kristensen *et al*. 2004, Mottet *et al*. 2006
Accessibility by road, proximity to town or city	Temperate mountain, tropical forest	Northern Spain, Brazil, Panama, Northern Italy, Peru, Swiss Mountains	Wiegers *et al*. 1999, Simmons *et al*. 2002, Tasser and Tappeiner 2002, Mottet *et al*. 2006, Gellrich, *et al*. 2006
Market incentives	Tropical forest, temperate grassland	Brazil, Panama, Eastern Europe, Peru	Wiegers *et al*. 1999, MacDonald *et al*. 2000, Simmons *et al*. 2002, Cremene *et al*. 2005
Agrarian policy	Mediterranean, temperate grassland, temperate forest, wetlands and riparian forests, various	Spain, Europe, Denmark, Central Italy, Wisconsin, Ex-USSR	Caraveli *et al*. 2000, MacDonald *et al*. 2000, Oñate *et al*. 2000, Hedlund 2002, Gisbert *et al*. 2002, Bürgi and Turner 2002, Holzel *et al*. 2002, Romero-Calcerrada and Perry 2004, Scozzafava and de Sanctis 2006, Busch 2006, Plieninger 2006
Input and output prices	Various	Europe	Strijker 2005, Verburg *et al*. 2006
Farmer age	Temperate forest, Mediterranean, various	Denmark, Spain, Europe	Kristensen *et al*. 2004, Romero-Calcerrada and Perry 2004, Busch 2006
Mismanagement			
Induced desertification, over-exploitation	Semi-arid shrubland, tropical forests, Mediterranean, temperate ecosystems	Northern China, tropics, Southern Spain, China, Europe, Northern Spain	Ruiz-Flaño *et al*. 1992, Douglas *et al*. 1996, Parrotta *et al*. 1997, Yang and Li 2000, Lambin *et al*. 2003, Robinson *et al*. 2003, Andréassian 2004, WenZhi *et al*. 2005, Sun *et al*. 2006

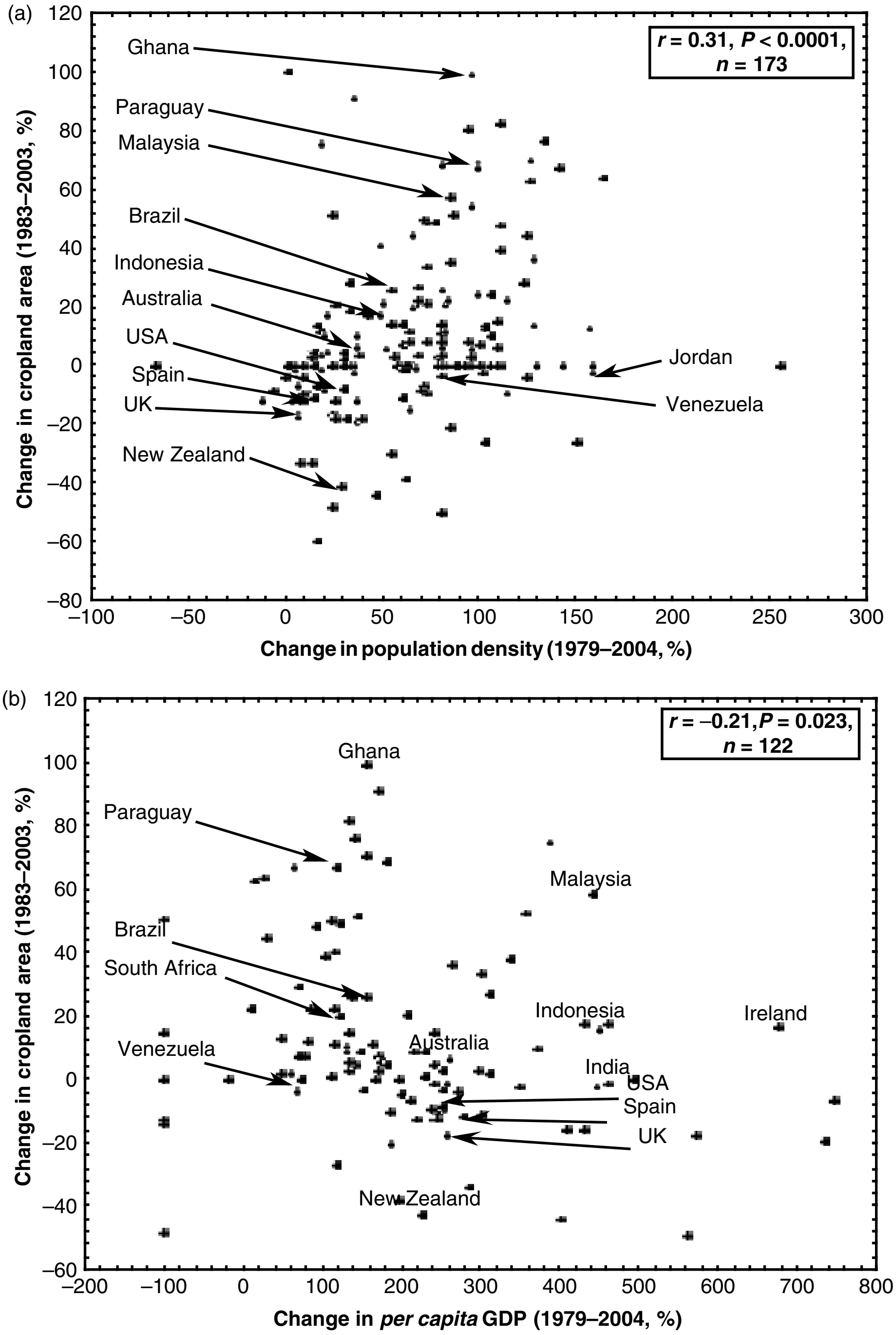

Figure 1 Relationships between changes in the proportion of the cropland area of a country (years 1983–2003) and changes in (a) population density and (b) per capita GDP. Negative values for the vertical axis mean a reduction in cropland area, whereas positive values for this axis mean an increase in cropland area. The figure highlights a few representative countries from different regions of the world and with different economic development

data was: http://earthtrends.wri.org [32]. We used STATISTICA 6.0 for analyses.

We hypothesized the following relationships: (1) population growth is expected to induce an increase in the proportion of agricultural land, as more food and other primary products are demanded by people. (2) The increase in per capita gross domestic product – related to new economic opportunities such as industrialization – and changes in the proportion of agricultural land should be negatively related. And (3) changes in the proportion of agricultural land and the contribution of agriculture to economy are expected to be positively correlated. Our results support these hypotheses (Figure 1; correlation between change in cropland area and the contribution of

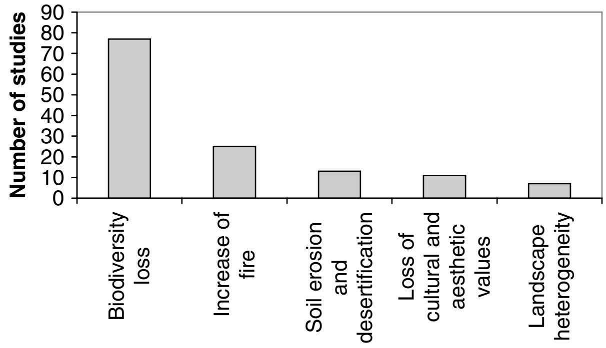

Figure 2 Number of studies that identify problems linked to the abandonment of agricultural land classified into five broad categories

agriculture to economy was r=0.31, P=0.004, n=81). We attribute the low correlation obtained for Figure 1b to the fact that GDP only includes activities which fall within the market economy and excludes factors such as small-scale farmers' economies [33].

Identified Problems of Abandonment

There is general agreement that agricultural intensification produces land degradation and reduces the quantity and quality of the services that ecosystems provide to humankind, including overall loss of biodiversity [34], declining populations of particular species [35] and increased erosion [36, 37]. However, the abandonment of agriculture brings about positive, as well as negative consequences. These consequences are not always relevant in all parts of the world, or only relevant at small scales.

Even in arable landscapes with a long history of human intervention, environmental problems have accelerated in the last few decades. The effects of these changes are usually externalized, having a greater impact for society as a whole than for the farms on which they take place [38]. We have identified five main problems linked to the abandonment of agricultural land, namely: (1) reduction of landscape heterogeneity and promotion of vegetation homogenisation, often associated with increased fire frequency, (2) soil erosion and desertification, (3) reduction of water stocks, (4) biodiversity loss and reduced population of adapted species and (5) loss of cultural and aesthetic values. The results obtained by our directed literature search in the CAB Direct database based upon target keywords to quantify the relative importance of these problems are summarized in Figure 2.

Reduction of Landscape Heterogeneity and Increased Fire Frequency

A search under the keywords 'abandonment AND (landscape heterogeneity OR landscape diversity)' found this phenomenon highlighted in seven studies (Figure 2). Although agriculture has often promoted the complete destruction of ecologically valuable habitats, agricultural practices have sometimes established highly diversified landscapes in many regions of the world, with a mosaic of land patches at different successional stages, from cultivated fields to closed forest. Agricultural land represents open spaces under secondary succession that are colonized by pioneer vegetation if abandoned. When abandonment is simultaneous for large extensions of farmland, it leads to vegetation homogenization [39] and a reduction in landscape heterogeneity [40]. Reduced landscape heterogeneity increases the spread of disturbances [41]. Higher fire frequency and intensity are the main effects of disturbance propagation.

Increased fire frequency is a consequence of vegetation homogenization triggered by secondary succession [42]. A search under the keywords 'abandonment AND fire' pointed to this phenomenon in 25 studies (Figure 2). All studies but five were located in the Mediterranean biome. In fire-prone areas (dry environments, but not the humid temperate zones and the humid tropics), land abandonment may interact with fire to alter landscape properties and eventually fire risk and its occurrence in extension and intensity through an increase in fuel loads [43–45]. In turn, fire introduces a source of landscape heterogeneity, but it may not be enough to counterbalance the homogeneity trend associated with agricultural abandonment [46]. Border effects and the combination of past landscape pattern and the poor dispersal abilities of forest species may allow shrublands to persist in some places after land abandonment, and shrublands burn more readily than forests [47]. Fire on abandoned land often leads to a further decline in biodiversity, as it enhances the growth of fire adapted plant species. In the Mediterranean basin, the climate is predicted to be warmer and drier. Sometimes, an increase in fire frequency due to land and climate change represents a threat not only through direct impacts on ecosystems, but also by promoting invasive plant species that have the potential to induce feed-forward processes [44]. The preservation of traditional exploitation systems, such as tended herds of goats or sheep, or free-ranging domestic animals (e.g. cows and horses) that consume large amounts of fuel biomass, constitutes an efficient tool for fire prevention [48].

Soil Erosion

A search under the keywords 'abandonment AND (soil erosion OR desertification)' identified 13 studies that reported increased erosion due to abandonment (Figure 2). Soil erosion is a problem linked to land abandonment in some parts of the world, but not everywhere. For instance, 11 of the 13 studies mentioned refer to dry environments, whereas erosion occurs, at most, at very small scales in humid-temperate areas such as Central or Northern Europe. Soil evolution after abandonment is linked to plant colonization and establishment abilities (i.e. vegetation resilience), and to subsequent land uses. Under spontaneous plant colonization, hilly areas with terraced fields have erosion problems when: (a) overgrazing prevents plant growth [49], compacts and removes topsoil [50] or promotes vegetation burning [51, 52]; (b) plant colonization is limited by lack of propagules (i.e. dispersal elements such as seeds) or by climate constraints, as in drylands [53, 54]; and (c) conservation structures such as terraces and drainage ditches break down due to lack of maintenance, and runoff from fields upslope from the terrace occurs [55, 56]. Soil erosion and restrained vegetation succession feedback positively [57]. Soil degradation through erosion, sedimentation, or salinization as a consequence of inappropriate agricultural practices has been reported as a driver of cropland abandonment in several studies (Table 1).

Reduction of Water Provision

This problem is most accentuated in dry regions than in humid regions. When abandoned agricultural land gains vegetation cover, some hydrological changes occur at the watershed scale. Reforestation may result in a decrease in water yield, with a reduction of low flows but a very small reduction of flood peaks [58]. Runoff reduction is explained because both interception of precipitation and transpiration from forests are likely to be higher than those from crops or pastures [59, 60]. Rain interception is higher in forests because leaf area index is higher and an increase of water vapour exchange from their aerodynamic leaf surfaces [61]. In dry climates, transpiration from forests is likely to be higher because of the generally increased rooting depth of trees and their access to soil water [62]. A search under the keywords 'abandonment AND water' identified just one study that reported a reduction of water provision due to abandonment [63].

In China, Sun *et al.* [64] estimated, by applying a hydrological model, a water yield reduction ranging between ca. 50% in the semiarid Loess Plateau region and ca. 30% in the tropical southern region as a consequence of massive afforestation of bare lands, grasslands and croplands. However, this reduction is unlikely to occur because large cropland areas are needed to meet food demands in rural areas. Similarly, historic flow records of several Spanish rivers in the last 50 years show an average reduction of ca. 0.4% per year. About one-third of these observed reductions was not explained by an increase in water consumption for irrigation or climate variability, and were attributed to an increase in evapotranspiration from headwaters [65]. This was caused by and increase in forest cover on large areas formerly used for marginal agriculture and grazing, that were abandoned during the second half of the twentieth century, and especially in mountain areas [66].

Biodiversity Loss and Reduced Abundance of Adapted Species

A search under the keywords 'abandonment AND (biodiversity OR decline)' identified 77 studies that report biodiversity loss and/or decline of a particular species or group of species. They are by far the most cited negative effects of farmland abandonment in the scientific literature (Figure 2). Impacts linked to these effects are different for different species, taxonomic groups and ecosystem types.

Extensive livestock production has been historically linked to local, traditional breeds. A major consequence of land abandonment – particularly in marginal areas – and/or of farmland intensification is the depletion of this unique biodiversity [67, 68]. Similarly, the abandonment of pastoral practices has had some negative consequences, such as the penetration of invasive species (herbaceous, shrubby and arboreal) and an increase of unaltered litter on the ground, which leads to the worsening of the pastoral features [69]. The spread of humankind worldwide over the last 12 000 years, thereby increasing domestic animal biodiversity via adaptation to diverse environmental situations, has resulted in about 6000 livestock and poultry breeds. During the last 50 years of the twentieth century, about 20% of these breeds have become extinct, and many of the remainder are at risk [70].

Beyond domesticated plant and animal species, land abandonment has a negative impact on wildlife in landscapes with a long history of management such as Central and Northern Europe, the Mediterranean basin and the Near East. At the landscape or regional level, habitat diversity (i.e. landscape heterogeneity) is positively related to species richness, since more resource opportunities are offered to a wider range of organisms. For instance, many plant and animal communities are embedded in mosaic landscapes that include semi-natural grasslands, meadows and cropland. The abandonment of farmland and its detrimental effects on landscape heterogeneity results in the loss of plants [71, 72], birds [71, 73] and invertebrates [74, 75]. At the local level, the major impacts are related to the interruption of management in species-rich habitats, for certain groups of species. These include meadows, semi-natural grasslands, grazed forests, steppe-like habitats and extensive croplands that benefit plant, invertebrate and bird species adapted to open areas [76–78]. Besides habitat loss, the processes leading to local extinctions include dominance and subsequent competitive exclusion [79], invasion of exotic plants [80], litter accumulation [81] and increased predation [82].

Loss of Cultural and Aesthetic Value

A search under the keywords 'abandonment AND (cultural OR aesthetic)' identified seven studies that point to this type of negative consequences of abandonment of agricultural land (Figure 2). Many cultural landscapes have historical, cultural, recreational, scenic and aesthetic importance [83–85]. For example, the loss of the authentic European pre-industrial village, characterized by a fine-grained structure of arable land, woods and grasslands, is a threat to cultural heritage in many rural landscapes [86]. People's perception and opinion of the consequences of rural abandonment is very variable. In the southwestern Alps, local people regard the effects of abandonment as very negative, whereas visitors appreciate the return to wilderness, although they regret the cultural losses associated with abandonment [40]. However, some studies have demonstrated that tourists appreciate managed agricultural landscapes much more than abandoned ones, because the absence of management results in inhabitable spaces [40, 50]. Aesthetic aspects score highly in tourist preferences [87]. Thus, abandonment may impede additional income from alternative sources such as tourism to local human communities in rural areas [88].

Opportunities Related to Abandonment

The abandonment of agricultural land may also have a variety of positive consequences and raise opportunities, including revegetation and forest plantations, water retention and soil recovery along with nutrient cycling, and an increase in biodiversity. As for the problems identified in relation to land abandonment, their consequences are not equally relevant in all parts of the world.

Passive Revegetation and Forest Plantations

Passive revegetation is secondary succession, and involves the colonization of abandoned land (e.g. old-fields) by whatever plants and animals can disperse from surrounding habitats and subsequently establish, survive and grow. This means it has a highly stochastic outcome [90]. It integrates natural conditions with plant cover, and results in shrubland, woodland, or forest depending on local climate and soil conditions [39]. It results in a general increase in the density and distribution of biomass [89]. It may be rapid in highly productive environments such as the tropics and temperate humid areas [91], but is usually very slow in environments with low primary productivity such as the Mediterranean and other dry regions of the world [92]. Key constraints for fast regeneration are dispersal limitations [93], abiotic limitations such as low water availability for plants [94] and biotic limitations, such as competition from herbaceous vegetation [95].

Natural woodland regeneration restores more land and at lower cost than tree plantations. Throughout the world, the former has occurred over an estimated 45 000 km^2 per year during the last five years, whereas plantations have restored 28 000 km^2 of deforested land per year [7]. However, these figures vary considerably across regions. Many tropical ecosystems can recover rapidly with little or no intervention if previous land uses have not severely degraded the soil. Rapid ecosystem recovery following cropland abandonment and rural–urban migration has been documented in forested and non-forested ecosystems in many regions of the world [9, 28, 96–99]. In Europe, the idea of returning unproductive land to wilderness is considered worthy and attractive by conservationist groups, despite cultural prejudices [100].

Around 7% of the world forests are semi-natural forests, i.e. composed of native species that have been planted, sown, or are under assisted regeneration. Forest plantations consisting basically of introduced, exotic species expand over 140 million ha, 3.8% of the total forest area in the world [7]. Few countries, for example China and Chile, have regained more forest land through tree plantations than through passive restoration. The European Common Agricultural Policy has subsidized the transformation of agricultural land into forest plantations since the 1990s [18]. This policy mainly pursued the reduction of excessive agricultural production. However, the outcome (reforested agricultural land, e.g. 684 847 ha in Spain during 1994–2006) provides almost equivalent benefits to natural forest regrowth, including carbon sequestration and increased soil fertility. Forest plantations, particularly if they are extensive, may accentuate all the problems related to land abandonment that were described in the previous section.

Water Retention, Soil Recovery and Nutrient Cycling

There are a number of benefits obtained from revegetation of abandoned agricultural land. These include hydrological regulation, soil recovery and erosion mitigation, increased fertility, fungal biomass and decomposer activity, higher water quality and carbon sequestration.

Successional vegetation development leads to higher evapotranspiration and infiltration rates, and therefore to reduced runoff and an increase in water holding capacity (sponge effect) [101]. There are also associated climate effects such as surface cooling [102]. Additionally, in the case of cloud forests, secondary succession increases precipitation by stripping water from the atmosphere [103].

Soil evolution after land abandonment is a complex phenomenon. When plants are able to colonize old-fields and secondary succession progresses, soil erosion and sediment exportation are reduced due to a better natural regulation of runoff [104, 105] coupled with the regeneration of natural soil fertility and higher water quality [63]. Conversion to forest leads to a decrease in albedo and an increase in leaf area index, roughness length and rooting depth. Changes in these parameters can modify near-surface energy fluxes, which can influence temperature and humidity and hence mineralization of organic matter. This includes a greater concentration of organic matter and nutrients such as N and P [106, 107], as well as the recovery of fungal biomass and microbial activity [108, 109].

Soil properties improve when afforestation practices after land abandonment are successful. In tropical environments, changes in soil moisture content enable germination of seeds and growth [27], although soils in forests with no history of cultivation have greater contents of C and P than secondary growth forests [110]. In temperate environments, the planting of loblolly pine (*Pinus taeda*) following agricultural abandonment slowed erosion and contributed to storage of belowground C [106].

Land-use and land-cover changes have impacts on carbon regulation. The total amount of carbon stored in the terrestrial biosphere implies transfer and long-term storage of atmospheric CO_2 [111, 112]. Permanence is the probability that stored carbon is not immediately reemitted into the atmosphere; it requires conditions that create carbon sinks in the form of plant biomass or soil organic matter [113]. On average, one km^2 of forest can store 16 110 metric tonnes of carbon [7]. At the present world deforestation rate (130 000 km^2 $year^{-1}$), 2094×10^6 metric tonnes of stored carbon are being lost every year. The reforestation rate (active and passive) is estimated to be creating the conditions for the gradual storage of 1176×10^6 metric tonnes of carbon every year. For example, a reduction of agricultural land and increased afforestation have positively affected the net terrestrial carbon sink in Europe [10].

Biodiversity Increase

The abandonment of agricultural land may decrease as well as increase landscape heterogeneity, and therefore habitat diversity. As abandonment promotes the population decline of species adapted to open spaces, it favours the populations and diversity of species characteristic of woody vegetation habitats, namely shrubland and forest [73, 91, 114, 115] and of soil fauna [116]. If woody vegetation habitats are species-rich, e.g. forests in the tropics, abandonment leads to a high increase in biodiversity compared with farmland [114, 117]. Our literature search identified 39 studies that report increases in biodiversity as a consequence of abandonment. Some studies have found that, within landscape mosaics with patches at various stages of succession and management types, each stage and type harboured the maximum species richness for one taxonomic group or type of species [73, 74, 78, 118]. Other studies have found positive correlations between time since abandonment and species richness of plants and invertebrates [77, 119].

Perspectives and Concluding Remarks

The conversion of natural ecosystems to human land-uses seems to have ensured our food supplies at a global scale. In spite of that, worldwide poverty – and occasionally hunger in some regions – remain a consequence of the unequal distribution of welfare, war conflicts, and extreme environmental events such as drought. However, food security has damaged the regulation function of ecosystems. Whereas the provision of environmental services such as crops and livestock production have increased, hydrological and climate regulation, soil retention, and greenhouse gas mitigation have decreased as a consequence of overall degradation of ecosystem services by 60% in the last 50 years [120].

The restoration of ecosystem health has mostly been focused at land abandonment and subsequent natural succession [26]. In areas where provision functions have been interrupted there are perspectives to re-establish areas of higher environmental regulation functionality through shrubland, woodland and forest ecosystems. Among terrestrial ecosystems, forest ecosystems and wetlands stand out for the highly valuable ecosystem services they provide [121], and should be of priority for restoration. Whereas wetland restoration is difficult, passive revegetation has the potential to provide large areas or at least patches of wilderness in multifunctional landscapes at low cost. In the year 2000, world CO_2 emissions were estimated at 31.6×10^9 metric tonnes [32]. Returning carbon to the land could account for a reduction of atmospheric carbon estimated at 70 ppm of CO_2 by 2100, and can play an important role in decreasing atmospheric carbon [113]. The increase of carbon sinks through woodland regeneration and soil restoration could be guaranteed on abandoned land since it is less likely to be returned to agricultural use.

When passive revegetation is difficult, then active revegetation (usually reforestation) is needed if the goal is to recover the vegetation that preceded crops and pastures and its benefits. The main drawbacks of active reforestation are high costs, lack of naturalness if reforestation is based on exotic tree plantations, and loss of cultural and aesthetic values in old agricultural landscapes. However, mixed models such as woodlots, forest islands, and the 'woodland islet approach' [122] may reconcile agricultural use, nature conservation and forest restoration. After land abandonment, the extensive reforestation approach should be replaced or at least complemented by small, dense, diverse, strategically placed, and wisely managed reforested patches or woodland blocks. These patches would actually be islands of functional ecosystems in a sea of intensively used or abandoned land, thus being compatible with other land uses (e.g. livestock grazing or crop production) and passive restoration in their vicinity. These islands would act as 'sources and traps' of propagules of different species of plants and animals, since many organisms would find refuge and food, although this effect would largely depend on island size. These biodiversity reservoirs could function as nuclei for passive restoration of large extensions around the world. Such experiences need to be started rapidly and their lessons shared and replicated widely [123].

However, abandonment in some parts of the world may also include the problems previously described, including soil erosion, fire frequency increase and local biodiversity loss. These mainly occur in extensively deforested and dry climate areas of the world. Importantly, the same consequence of land abandonment (e.g. reforestation) may result in negative effects (e.g. reduction of landscape heterogeneity, reduction of water provision, loss of species characteristic of open spaces and loss of aesthetic values), as well as positive effects (e.g. mitigation of soil erosion, carbon sequestration, increase of habitat diversity and increase of species characteristic of woody vegetation). Management practices aimed at nature conservation and active restoration approaches are therefore needed to avoid further land degradation and loss of environmental services under these circumstances. The conservation of biodiversity and heterogeneity in landscapes under historical human intervention must rely on the maintenance of traditional extensive land-uses such as agroforestry, agro-silvo-pastoral systems, extensive grazing and extensive cropland [118, 124].

We recommend the implementation of government policies of subsidies for environmental services that encourage society to conciliate agricultural use and nature conservation [125]. The land that becomes 'surplus' with respect to food production requirements may have a balancing effect on the production of other ecosystem services, for example through extensification [10]. There is a need for a strategic arrangement of managed and natural ecosystems, so the services of natural ecosystems are available across landscape mosaic [5]. To stop land abandonment due to socio-economic pressure, farmers that use traditional and extensive practices should be rewarded for their role in maintaining such land use schemes. These exploitation systems would also preserve important cultural and aesthetic values that offer possibilities for the development of rural tourism. Rural tourism may revive rural landscapes that have suffered from agricultural abandonment and provide income for local populations, thus helping to maintain their cultural traditions [126, 127].

Generalizations in the field of land abandonment – especially when they are made on a global level – are difficult. The decision about more (artificially or naturally) reforested areas on the one hand, and the maintenance of traditional agro-silvo-pastoral land uses on the other should always be made on the basis of local or regional studies. However, we consider that, at the global scale, land abandonment is good for humans mostly because it triggers the recovery of natural vegetation, of which 40% has already been lost. This is particularly viable in resilient ecosystems with adequate post-abandonment management, whereas in low-resilience ecosystems the regain of environmental services is more difficult and needs specific restoration activities. Subsidy systems in developed countries have focused on both agro-environmental services and forest regeneration though subsidizing the abandonment of marginal agricultural areas [128, 129]. Robinson *et al.* [63] calculated that 15–20 Mha of farmed areas could be potentially afforested in the context of the Common Agricultural Policy reforms to reduce agricultural overproduction in Europe. Unfortunately, poverty in developing countries and scarce financial support from developed countries make difficult the implementation of worldwide strategies that allow the sustainability of both agricultural production and ecosystem services.

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