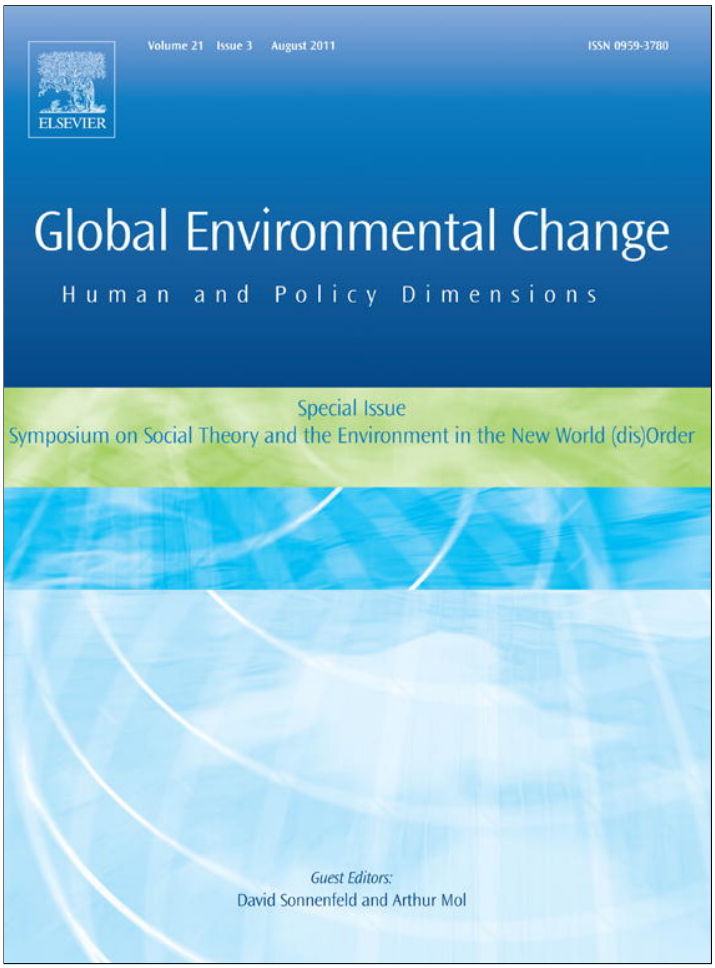
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# Exploring some of the myths of land use change: Can rural to urban migration drive declines in biodiversity?

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ABSTRACT

Forest transition theory describes a reversal in land-use trends for a given area, from a period of net forest area loss, to a period of net forest area gain. Some assume that such forest gain necessarily equates with biodiversity conservation. We question this assumption, based on research conducted in Oaxaca, Mexico. In Oaxaca's northern highlands, low intensity forest use and rotational (*milpa*) agriculture have led to pronounced spatial heterogeneity in forest structure and composition, and created a high-biodiversity forest–agriculture mosaic. In the Zapotec community of San Juan Evangelista Analco and the Chinantec community of Santiago Comaltepec, as across much of Oaxaca, fewer people are farming; farmers are cultivating less land, working closer to settlements, and growing fewer crop varieties. Widespread agricultural abandonment has initiated unprecedented changes in ecological succession, patch size, and edge effects, which we speculate will be having an impact on the biodiversity of the landscape mosaic. Our work suggests that the decline of land use activity may result in a gradual loss of the forest–agriculture mosaic, leading to localised declines in biodiversity, despite (or because of) extensive forest resurgence. These findings support the view that indigenous cultures in Oaxaca and Mexico should not be seen as an environmental constraint but rather as an agent of landscape renewal that allows for both cultural and biological diversity to flourish, a reality that national and international conservation bodies need to more fully recognise and incorporate into policy.

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## 1. Introduction

More than a decade ago, Lambin et al. (2001) published an influential and highly cited article in this journal that discussed changes in land cover and land use, in an effort to promote an "enhanced understanding of the causes of change" and dispel popular myths that are "[over] simplifications of cause–consequence relationships". They identified four main classes of land change, one of which was 'urbanization'. The present paper discusses a particular aspect of the urbanization process that has received scant attention to date: namely, how rural landscapes are impacted in environmental terms when transformed by out-migration.

Out-migration, itself a product of economic and cultural drivers, is of course one of many factors affecting land use change (Hassan et al., 2005; Lambin et al., 2001; Zimmerer, 2010). In the Mexican context, Eakin (2006) for example has addressed three of these drivers (climatic, economic and institutional change) in terms of risk that people face, and in terms of their vulnerability/resilience (Eakin and Wehbe, 2009) and building adaptive capacity to deal with change (Eakin and Lemos, 2010). As well, out-migration does not only impact land use but also community institutions (Robson and Berkes, 2011) among others. Here we focus on the impact of out-migration on land use and land cover. Apart from a handful of studies (e.g. Gray, 2009; Moran-Taylor and Taylor, 2010), most work on the relationship between migration and resource-use dynamics in Latin America has tended to focus on areas of in-migration and population growth rather than the abandonment of traditional rural livelihoods (e.g. Carr et al., 2009).

Our findings come from Oaxaca, arguably the most biologically and culturally diverse state in Mexico (Boege, 2008; García-Mendoza et al., 2004). Maintaining long-standing land-based customs while interacting with the demands and inequities of the global economy is proving a very real challenge to villages in this part of the world. Data from household surveys, semi-structured interviews and territorial mapping exercises help to identify the impacts that out-migration has had on farming, forest use and other environmental practices. With extensive agricultural abandonment driving changes to the agricultural–forest mosaic, the qualitative evidence we collected locally is supplemented by empirical quantitative evidence from elsewhere in Oaxaca and Mexico to speculate on the consequences for biodiversity in areas where a mix of small-scale productive activities has traditionally led to high environmental variability along steep altitudinal gradients (Perales et al., 2003; Robson, 2007).

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By examining the biodiversity consequences of agricultural abandonment, beyond an obvious increase in forest cover, the paper adds much needed detail, as flagged by Lambin et al. (2001) and others (Massey et al., 2010; Warner, 2009), on processes of environmental change through ongoing rural depopulation. We question the assumption (and thereby the myth) that depopulation necessarily aids the provision of ecosystem services and the conservation of biodiversity (Grau and Aide, 2007). Rather, our findings are consistent with del Castillo and Blanco-Macias (2007) who argued that rural landscapes in southern Mexico, composed of a mixture of forests of different ages and croplands, most commonly exhibit "a maximum diversity in situations in which agriculture is neither very frequent nor very uncommon in both time and space" (2007, p. 174). Such a hypothesis provides an important alternative perspective to the body of literature on forest transitions in Mexico and other tropical country contexts (Klooster, 2003; Kull et al., 2007; Rudel et al., 2005), as well as contributing to an emergent land change science (Turner et al., 2007). It strengthens the claim that the specific characteristics of forest transitions will vary depending upon the underlying socio-economic and environmental conditions, and how local resource management regimes are impacted by, and able to respond to the uncertainties of globalisation, transnationalism and 'modernisation' processes. We conclude the paper by stressing the need for continued research in this area and for new policy orientations.

## 2. People, area and study methods

### 2.1. Study region and communities

The state of Oaxaca, Mexico (Fig. 1) is located at the confluence of the neo-arctic and neo-tropical biogeographic regions, and marks the point where the country's two main mountain chains (Sierra Madre Occidental and Sierra Madre Oriental) meet. This has created a uniquely complex physiographic landscape, where high peaks punctuate deep canyons and valleys, and a varied mix of topographic, geological and climatic conditions is reflected in the presence of multiple forest ecosystems (Martin, 1993).

Research was conducted among indigenous communities in Oaxaca's *Sierra Norte* (northern highlands), also known as the *Sierra de Juárez*, a region where flora and fauna associated with temperate mountainous regions mix with species typical of more humid, tropical climes. The region constitutes a priority conservation area




**Fig. 1.** State of Oaxaca, southern Mexico.

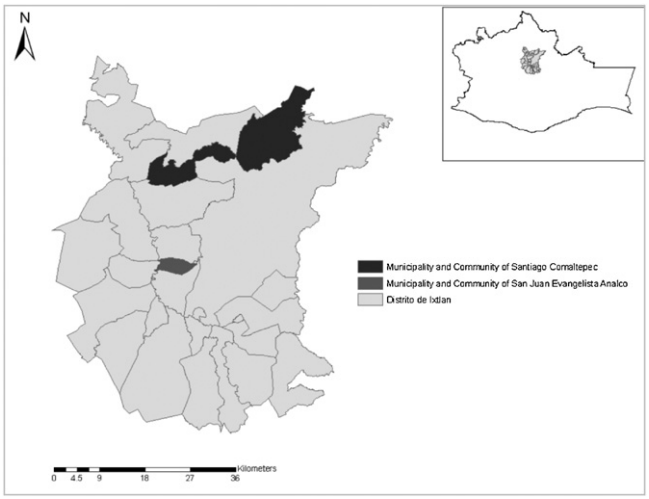



**Fig. 2.** Location of the two study communities.

at the national level (CONABIO-CONANP, 2007). Zapotec, Chinantec and Mixe indigenous communities control these diverse forestlands, which cover approximately 400,000 ha across approximately 70 communal areas. Data come from two of these communities; the Zapotec of San Juan Evangelista Analco (Analco) and the Chinantec of Santiago Comaltepec (Comaltepec), both located in the District of Ixtlan (Fig. 2). While Analco consists of a single locality, the community of Comaltepec is represented by three permanent settlements: the head village of Santiago Comaltepec (resident population some 800+) located in the dry, temperate zone (mixed pine-oak forests) of the community's territory; La Esperanza (pop. 150), located in the humid-temperate (montane cloud forest) zone; and, San Martin Soyolapam (pop. 80), located in the eastern lowland tropical zone (tropical evergreen forest). Both communities are also municipalities, allowing for an important closeness to form between civic and communal governance.

In terms of productive occupations, both Comaltepec and Analco are still best described as *campesino* communities, with farming and work around the home accounting for the majority of adult residents. Others earn an income as builders, labourers, teachers, with just a handful working as professionals in regional urban centres. Household income is low, with most families in both Comaltepec (89%) and Analco (92%) receiving the equivalent of the Mexican minimum wage or less from their productive activities. Additional sources of household income are migrant remittances, government social welfare programs such as *Oportunidades*,[1] *Procampo*[2] and *70 y más* (old age pension), or a combination of the two. It should be noted, however, that remittances are lower on average than they were 5 or 10 years ago, with over a third (38%) of migrant households in Comaltepec and more than half (58%) in Analco receiving little or no support during the period 2007–2008 (Robson, 2010).

### 2.2. Study methods

We believe that a community case study approach offers an excellent way to examine the impact of change on social-

[1] Government policies for rural areas now focus on large-scale antipoverty programs such as 'Oportunidades', which began in 1997 as PROGRESA, and is now Mexico's "flagship welfare program" (Fox, 2007). In 2008, *Oportunidades* supported 250 individuals in Comaltepec and 85 in Analco, with monthly income from $550 to over $3000 pesos per recipient.

[2] In late 1993, the federal government created PROCAMPO as a system of direct cash payments to maize, bean, wheat, rice, soya, cotton and sorghum producers, from $1160 to $1300 pesos per hectare, up to a maximum of 5 ha (http://www.aserca.gob.mx/artman/publish/article_183.asp).

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**Table 1**
Study community selection criteria.

| Community | Out-migration rate (Martinez Romero 2005) | Territorial size (ha) | Forest type | Conservation value (FSC classification) |
|---|---|---|---|---|
| Comaltepec | High | 18,366 | Tropical dry/dry oak/mixed pine-oak/cloud forest/tropical evergreen | High conservation value forests |
| Analco | High | 1658 | Tropical dry/dry oak/mixed pine-oak | High conservation value forests |

ecological systems and to investigate how societies respond to such impacts. Such case studies enable researchers to delve into the contextual conditions that surround each community under investigation – providing the freedom to gather different types of evidence, focus on multiple sources of data, and benefit from the prior development of theoretical propositions (Yin, 2003). The selection of Analco and Comaltepec as our two study communities was based on a range of geographical, bio-cultural and ecological criteria tied to the central premise of this paper (Table 1).

Interdisciplinary research is needed to understand the complex processes that link migration and the environment in sending communities, and the methods chosen for data collection reflected this. Households were surveyed (one-third of households in Analco and one-fifth of households in Comaltepec) by means of a concentric sampling technique that ensured representation across central, intermediate and peripheral urban zones; an appropriate method given the socio-economic divisions that exist in Oaxacan highland settlements (with poorer households generally located on the edge of villages). Respondents were asked specific questions about the area of land under cultivation today compared to 10 and 20 years ago, crop varieties grown today compared to 10 and 20 years ago, contemporary vs. traditional cropping systems, and other ways in which migration had possibly impacted farming and other resource practices locally. These data were then supplemented by over 80 semi-structured and unstructured interviews with a wide range of community members (resident and non-resident), including land users, and multiple discussions with the municipal and communal authorities. Again, lines of questioning centred on the factors that lie behind agricultural change.

These surveys and interviews were also used to determine the nature and principle characteristics of out-migration (national vs. international flows, degree of permanency, push and pull factors), with demographic data for the two municipalities sourced from INEGI census and population counts (1930–2005), and supplemented by available local village census data (2000–2008).

Ecological and land use data were collected through forest sampling and transects in tropical dry, dry oak, mixed pine-oak and cloud forests, and territorial walking tours across extensive areas of current and former farmed lands (more details in Robson, 2010). Specifically, forest sampling work and forest transects became important methods to provide a rapid assessment of local vegetation diversity and overall forest condition across ecological zones. Sampling followed IFRI[3] guidelines, with a combination of factors–including elevation, steepness of slope, aspect, and proximity to roads and agricultural areas – taken into account to ensure as representative a sample set as possible. Where forest sampling was not possible, we walked 1200 m transects with local guides, noting, at 150 m intervals, forest structure, indicators of conservation, and evidence of forest use. Knowledgeable local guides supplemented field observations with information on resource practice in these areas.

[3] The methodology of the International Forest Resources and Institutions (IFRI) Research Program (http://sitemaker.umich.edu/ifri/home) allows researchers to explore the complex relationships between communities and their forest resources, based on rapid rural appraisal, forest sampling and traditional interview methods.

Walking tours were used as a specific method for mapping areas of agricultural abandonment and new forest growth. Based upon prior discussions with land users and the communal authorities, we identified areas around each village that were no longer used for farming and had been left for pasture or natural regeneration. Local land users would accompany us on these walking tours, where abandoned plots would be marked by GPS and a history of land use (year of, and reason for abandonment) as well as current status and condition (use and vegetation type) noted. This information was supported by photographic evidence.

## 3. Findings

### 3.1. Multi-functional cultural landscapes

As a consequence of high environmental variability, traditional lifestyles in both communities have been based on access to a diversity of ecological zones, and adaptation to environmental extremes. Here, as in most parts of the northern Sierra, local land use systems are interrelated with multiple aspects of the natural environment (as an example, Fig. 3 shows the profile of land use across Comaltepec's communal territory), with the distribution of vegetation types, climates and soils determining people's choice of where to settle, where to farm, what to farm, and where to hunt or gather. In this way, various threads weave together to form a complex tapestry of local environmental practice (Martin, 1993; Robson, 2010).

Comaltepec (since 1993) and Analco (since 2005) have developed Community Land Planning (CLP) processes to reflect such multifunctional land use and improve management of their territorial resources. These plans reflect the presence of mixed systems that both respond to contemporary issues and livelihood needs, while retaining historic sacred relations and traditional practices (Robson and Berkes, 2010).

### 3.2. Out-migration and changing land use practices

Migration has become a way of life in both these communities, with out-migration rates climbing steadily since the 1970s. Although rough terrain and increasingly unpredictable weather patterns complicate a subsistence-based agricultural livelihood, the principal push-and-pull factors that lie behind the decision to migrate have been economic and cultural rather than environmental in nature (Robson, 2010). While urban centres in Mexico were favoured by the first waves of migrants, the United States has become the destination of choice since the mid-1980s. The demographic impacts have been striking. There has been a dramatic fall in resident populations, with a 60% and 55% decline reported in Analco and Comaltepec, respectively, for the period 1980–2008. The loss of community members of a productive age has had a major impact on the age–sex structure of those left behind, with top heavy population pyramids for 2008 showing few young people and a slimming in the number of adults aged 21–45 years (Robson, 2010).

As individuals and families from both communitries have become increasingly engaged with national and international markets for wage labour, their relationship with farming and other

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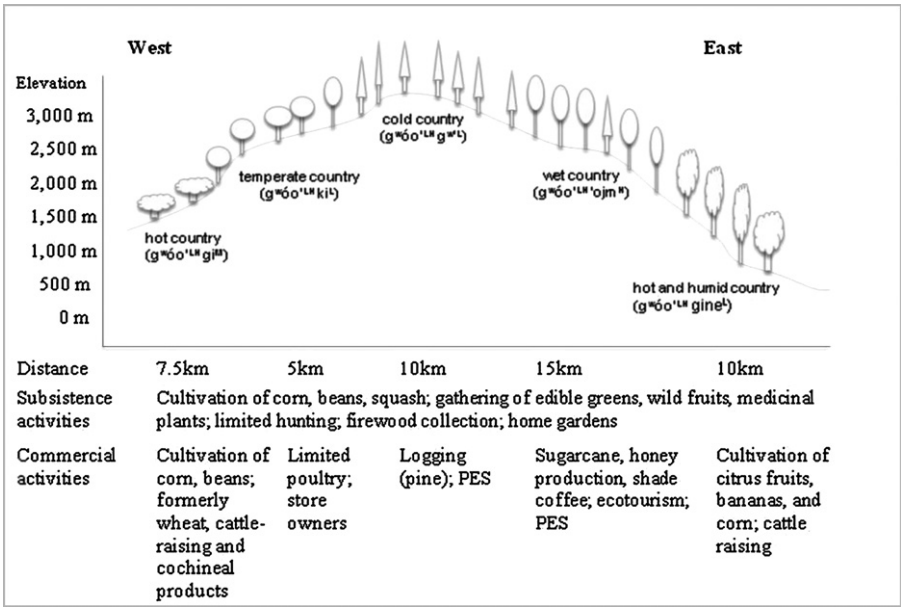



**Fig. 3.** Cropping zones tied to variation in climate, soil and vegetation, Comaltepec (adapted from Martin, 1993). Local names in Chinantec are provided in brackets.

**Table 2**
Percentage of farming households and area under cultivation.

| Village/Community | % Of households that still farm | % Of households that no longer farm | Average area under cultivation in 2008 (ha per farming household) | Average area under cultivation in mid-1990s (ha per farming household) |
|---|---|---|---|---|
| Santiago Comaltepec | 76 | 24 | 1.04 | 2.1 |
| La Esperanza | 89 | 11 | 2.33 | 2.72 |
| San Martin Soyolapam | 90 | 10 | 1.7 | 1.9 |
| Comaltepec | 85 | 15 | 1.69 | 2.24 |
| Analco | 85 | 15 | 0.89 | 2.2 |

land-based practices has changed. Table 2 shows the percentage of households in each community that continue to farm. Survey and interview data show how, over the past 30 years, more and more households have turned their back on agriculture, choosing to depend on off-farm activities to cover their basic needs. In Santiago Comaltepec, for example, approximately one-quarter of households have stopped farming altogether. The data that best illustrate the drop-off in farming concern the decrease in average area under cultivation per farming household (Table 2, columns 3 and 4), with those still farming in the two head villages of Analco and Santiago Comaltepec now working less than half the area they were just 15 years previously.

Although there are differences between the two communities, overall production has declined as family members move away from their villages and the pool of available labour dwindles. In both communities, the labour required to work a hectare or less of *milpa* or another subsistence crop has traditionally been provided from within the family. Working more land than that, or harvesting cash crops such as coffee and sugarcane that demand a higher labour input, normally requires surplus cash to hire local workers (*mozos*) during key moments in the agricultural calendar. Table 3 shows that a majority of households in both communities now depend wholly on intra-family labour.

Even if households have the money to hire workers, it is getting more and more difficult to find this kind of help, simply because there are so few people remaining in the village. Farming households are thus largely dependent on the labour of family members to get their fields ploughed, sown and harvested, independent of whether they have the money to hire outside help or not. With household size dwindling through rural out-migration, there has been an obvious reduction in the relative importance of subsistence farming, which is best illustrated by looking at how families cover their basic food needs (Table 4).

**Table 3**
Use of intra-family labour resources vs. hired help.

| Village/Community | % Of farming households that depend totally on intra-family labour resources | % Of farming households that use combination of family labour and hired help (*mozos*) |
|---|---|---|
| Santiago Comaltepec | 69 | 31 |
| La Esperanza | 56 | 44 |
| San Martin Soyolapam | 62 | 38 |
| Comaltepec | 62 | 38 |
| Analco | 82 | 18 |

**Table 4**
Principal source of food for households in Comaltepec and Analco (2007–2008).

| Source | Proportion (%) of total (per household) Comaltepec | Proportion (%) of total (per household) Analco |
|---|---|---|
| Food grown locally by the family | 32 | 43 |
| Food grown locally but not by the family | 2 | 9 |
| Food bought from a local market (but not grown in the community) | 65 | 38 |
| Food acquired through trade | 0 | 6 |
| Food acquired as a gift or form of support | 0 | 3 |
| Other (specify): Government programs | 1 | 1 |

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**Table 5**
Crops no longer widely grown in each village.

| Community/Village | Principle crops grown locally (during 2008 agricultural year) | Crops no longer widely grown |
|---|---|---|
| Santiago Comaltepec | Maize (yellow, white), beans, squash, miltomate, pea | Wheat, barley, potato, apple, pear, black corn, mottled corn, white corn varieties, temperate fruits |
| La Esperanza | Maize (white, mottled), beans, sugarcane, banana | Black corn, coffee, mamey, avocado |
| San Martin Soyolapam | Maize (white, yellow, mottled), beans, banana | Coffee |
| Analco | Maize (yellow, white), beans, squash, mustard, cilantro, pea | Wheat, potato, black and mottled corn, white corn varieties, temperate fruits |

In Comaltepec, for example, households are now sourcing approximately two-thirds of their staple food needs from the community food store and other local markets, rather than through their own farming activities or those of their neighbours. In Analco, the figures are similar, although compared to Comaltepec there is a greater relative dependence on farming for meeting local needs. Despite this, a sizeable proportion of Analqueño households (30%) buy a proportion of their food from neighbours, while the vast majority (92%) purchase at least some of their food from the local market or community store. Interview data show that this is directly linked to the decline in area under cultivation, with many households no longer growing enough corn, beans and other staples to last the family throughout the year and thus having to supplement domestic production with store-bought food.

In addition to fewer families farming, most of whom now work a smaller acreage, another key change concerns the reduced territorial mobility of community members and a shift towards a more sedentary lifestyle. This is most apparent in Comaltepec, where families have customarily undertaken a form of agricultural transhumance that involves the seasonal movement of people from their residential base in the head village of Santiago Comaltepec to *rancherías* (ranches) located in *tierra caliente* (hot land) or more commonly in humid zones on the windward side of the Sierra Madre range. Over the past 30–40 years, there has been a steady reduction in the numbers dividing their time between dry and humid territorial zones, with many ranches (a number of which had been permanently settled at one time or another) now abandoned.

In Analco, the community's territory is much smaller, and changes in territorial mobility are less obvious. Nevertheless, here too the vast majority of *campesinos* now carry out their land-based activities within a 30 min walk of the village. The main area of permanent rain-fed agriculture is shrinking in size each year. Specifically, farmers are no longer working lands on the community's higher slopes (*tierra fria*, or cold land) (above 2300 m) or in the drier zone (*tierra caliente*, or hot land) to the west of the village (1700–1900 m). Considered a transition zone where dry pine-oak forest begins to give way to tropical dry forest mixed with cactus shrub (*matorral*), this area provides excellent climatic and soil conditions for certain varieties of bean, as well as the ubiquitous *milpa*. Forty years ago, large swaths of hillsides were under heavy cultivation. In 2008, just one family had a ranch in the area. Neighbouring plots were abandoned in the 1970s and 1980s, as farmers and their families migrated to the cities, or because farmers began to take advantage of a reduced overall demand for land to cultivate plots closer to the village.

The constriction of farmed zones has gone hand in hand with changes to the type and diversity of crops being grown in both communities (Table 5). On higher slopes above the head village of Santiago Comaltepec and the community of Analco, crops such as potato, and black and mottled corn varieties, are conspicuous by their absence from local dinner tables. They are rarely grown now because so few farmers are maintaining plots at elevations (>2300 m) that provide the cooler conditions such crops require. Similarly, cereals such as wheat and barley (for making bread), along with some older bean and maize varieties, which were traditionally grown in the drier, warmer lands (<1800 m) found to the west of the head villages are no longer cultivated. While traditional cereal, corn and bean varieties have lost favour, survey and interview data show that an increasing number of farmers in the two head villages have switched focus to 'green' crops (pea, mustard, cilantro, *miltomate*) that they can sell at the regional Monday market in nearby Ixtlan.

On the humid side of Comaltepec's territory, the most obvious crop to have lost favour is shade-grown coffee, cultivated extensively in the 1970s and 1980s, as has also happened in Central America (Tucker, 2008). No more than one-fifth of respondent households in La Esperanza continue to maintain shade-coffee systems, while the number of families from Santiago Comaltepec that still cultivate groves on the humid side of the mountains can be counted on two hands. Depressed coffee prices and labour shortages have forced many family producers to abandon their *cafetales* (coffee groves). The fall in prices and high out-migration rates are clearly connected, with the low profitability of the region's most visible cash crop becoming one more reason why people have packed their bags and headed to the cities. Although the last few years have seen the coffee market recover, local growers say prices are still too low to offset the labour costs when migration is present. As the coffee groves have disappeared, so too have the other multi-crop agro-forestry systems that use native tree species for providing shade and maintaining soil fertility.

A decline in farming activities mirrors a decline in resource (forest-based) practice generally. Respondents to the general household survey were asked if "*the time dedicated to collecting forage, firewood, timber and other forest products had increased or decreased over the past ten years*". The results are shown in Table 6.

In both Analco and Comaltepec, close to half of households spent less time in the forest collecting timber and non-timber forest products (NTFPs). The reasons for this were multiple, and included: (i) a smaller household size that reduced the demand for firewood and other NTFPs; (ii) the advanced age of many heads of household, with many less able and willing to carry out non-

**Table 6**
Time spent collecting forage, firewood and non-timber forest products (NTFPs).

| Community | % Of households spending *more* time | % Of households spending *less* time | % Of households spending *same* amount of time |
|---|---|---|---|
| Analco | 27 | 46 | 27 |
| Comaltepec | 23 | 54 | 23 |

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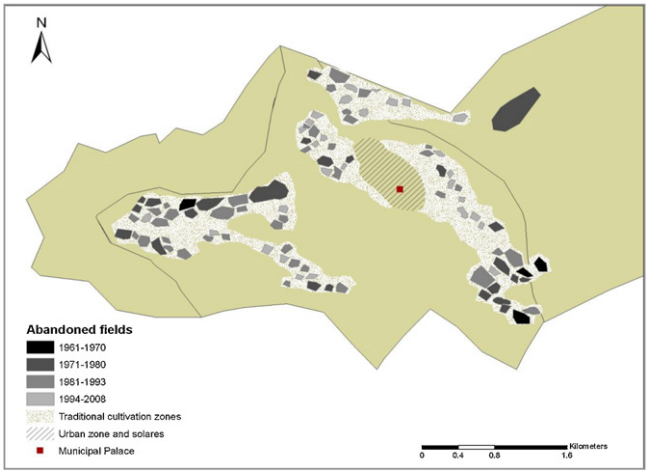



**Fig. 4.** Pattern of agricultural abandonment around Santiago Comaltepec (1960––2008). Coloured area refers to forested areas not used for cultivation due largely to abrupt topography. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

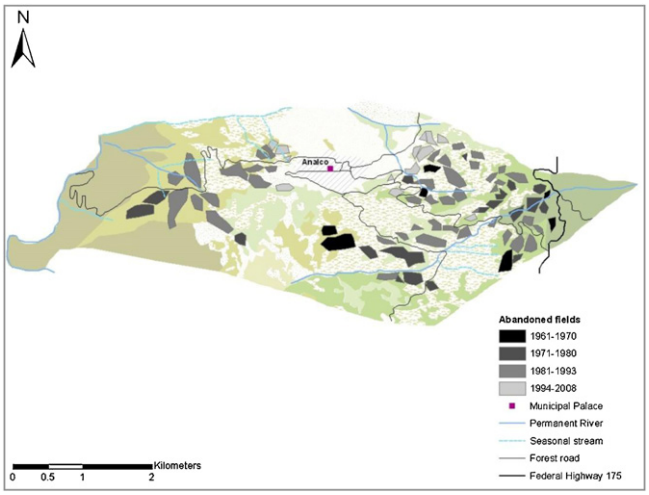



**Fig. 5.** Pattern of agricultural abandonment across territory of Analco (1960-2008). Coloured areas refer to extensions and patches of forest of different types.

essential chores; (iii) a preference for modern materials in new house builds; and (iv) the increased use of gas as a substitute for firewood. The other significant factor contributing to a reduction in consumption of timber products is that their collection is easier for those families who still farm, and thus with ready (daily) access to the stands of oak, *madrono* or *limoncillo* found close to the fields where they work. Similarly, the harvesting of NTFPs such as mushrooms, medicinal herbs and wild fruits is normally undertaken opportunistically as farmers and their family members use the network of forest trails that take them to and from their agricultural plots.

Lastly, in addition to farming outside the village centre, the majority of households in Analco and Comaltepec have customarily planted in their yards and adjacent gardens (*solares*) fruit trees (apricot, cherry, apple, and pear) and small amounts of corn, beans, 'chepil' (*Crotalaria longirostrata*), among other species. In Analco, households have used these spaces to maintain local varieties of mottled, purple, yellow and white corn, which are no longer cultivated in other parts of the community (Robson, 2010). On the humid side of the Sierra, in La Esperanza and San Martin Soyolapam, home gardens are arguably even more significant, acting as the in situ seed bank for an incredible range of crops, including: tepejilote palm (*Chamaedorea tepejilote*), corn (local varieties), avocado (native variety), tomato (native varieties), papaya, coffee, grapefruit, tamarind, vanilla (local variety), mango, chilli, banana, plantain, and coconut, among other tropical fruits. In both communities, survey and interview data pointed to a decline in the number of households maintaining home gardens, and one that clearly mirrors the fall in the number of households whom continue to farm.

### 3.3. Mapping and photographing land use change and forest encroachment

In both study communities, shifting resource practices are driving environmental change through a general abandonment of agricultural areas, reduced pressure on the resource base, and a subsequent process of natural forest regeneration in old corn and bean fields. Since the onset of marked levels of out-migration in the 1960s and 1970s, resident farmers have, in an almost systematic fashion, abandoned those plots furthest from their homes in favour of more accessible farmland less than an hour's walk from the village centre and closest to roads with vehicle access (farmer interviews). Figs. 4 and 5 clearly show the general distribution of agricultural zones that were abandoned during the periods 1960–1970, 1971–1980, 1981–1993, and those that have been reclaimed by new vegetative growth, or left for pasture, over the past 15 years (1994–2008).[4]

Qualitative evidence through interviews with farmers and other land users shows that agricultural abandonment has led to clear changes in the ratio of forested to non-forested areas, with photographic evidence (Plates 1–6) highlighting processes of ecological succession from grassland communities to secondary forests of varying maturity in old fields and terraces. In temperate-cold and temperate-dry zones, new stands of pine (as a pioneer species) have colonised old corn and bean fields. On the windward side of the range, far fewer areas of cloud forest are being opened up for long-fallow agriculture, or thinned out for the establishment of small-scale shade coffee and banana plantations.

In Comaltepec and Analco, interviews with farmers suggest that as much as 60% of the communities' agricultural lands have been abandoned over the past 30–40 years (Robson, 2010). Around the head village of Santiago Comaltepec, the general consensus among interviewees was that only 20–30% of original agricultural areas are currently in use. While forest encroachment has taken hold most obviously in traditional cultivation zones located furthest away from permanent settlements and/or access roads, abandonment is now affecting areas that lie closer to village centres, such that forest growth is now evident in some areas for the first time in living memory. Only in San Martin Soyolapam is forest encroachment in some zones tempered by ongoing clearance in others. Improved market access for beef and the introduction of a more productive grass for pasture has encouraged local ranchers to increase their herd size and (pending approval from the communal authorities) clear further tracts of primary forest to open up more and larger *potreros* (grazing pens).

## 4. Biodiversity implications of land use change supported by findings from elsewhere in southern Mexico

While a trend of agricultural abandonment and forest resurgence fits the general theory of 'forest transition' (Mather, 1992) previously reported within the context of Latin America and

[4] It is important to note that, while the location of fields and their date of abandonment are wholly accurate, the size and shape of the polygons are estimations based upon field observation and the detailed knowledge of the local land users who acted as our guides.

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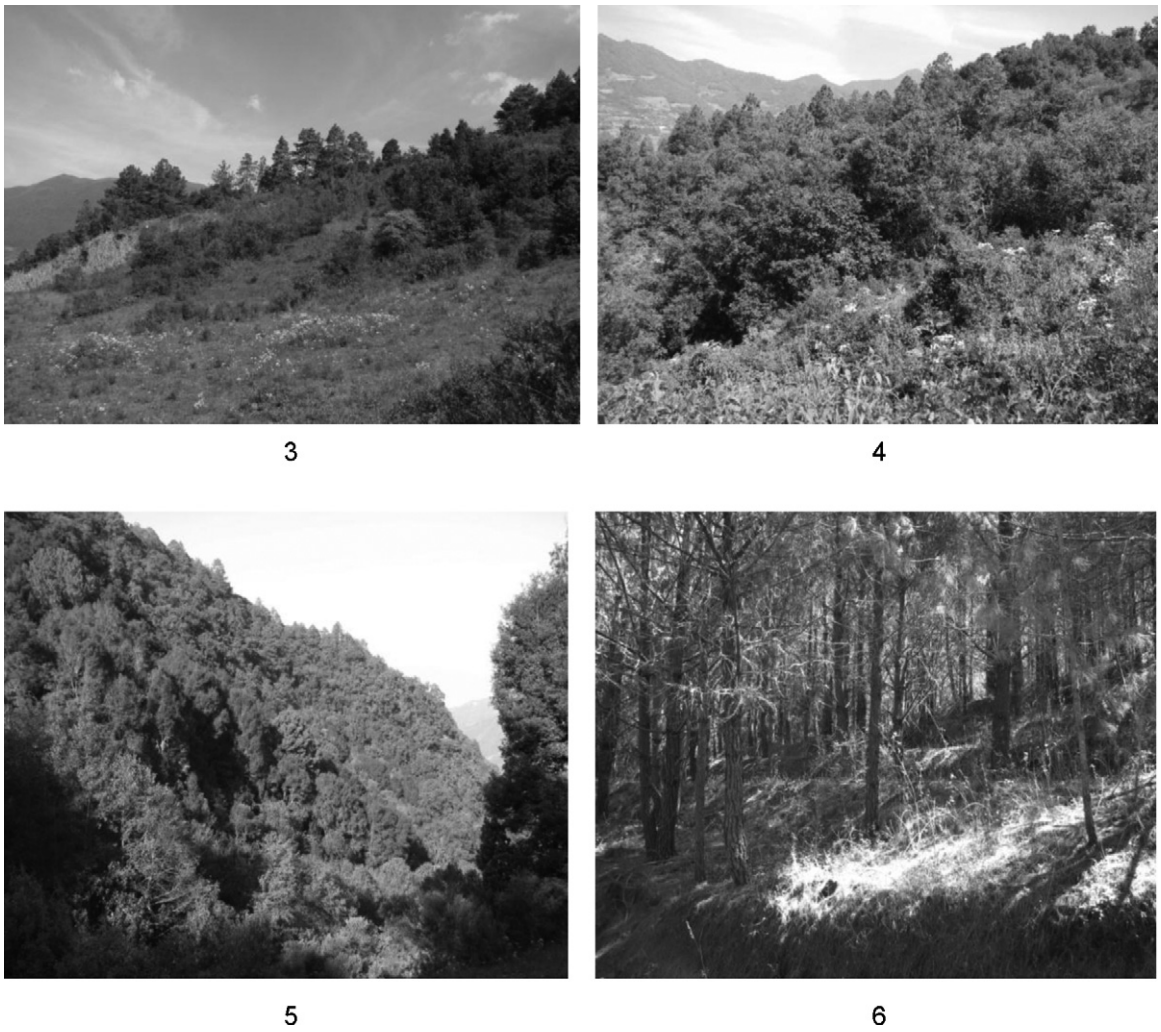




**Plates 1 and 2.** (**1**) Pine as pioneer species in areas of dry oak-pine forest. (**2**) New pine growth in plot abandoned in 2003, Santiago Comaltepec.

Mexico (Klooster, 2003; Rudel et al., 2005), there is still uncertainty about the type and particular characteristics of forest transitions that will occur under differing socio-economic and environmental conditions. For one, it is unclear what impact these changes have for biodiversity beyond an obvious increase in forest cover.

Although a substantial research literature exists relating to deforestation processes (Fahrig, 2003), edge effect (Ries et al., 2004), forest dynamics and succession (Shugart, 1998), among other principles and processes of landscape ecology (Turner et al., 2001), the impacts of human activity on forest biodiversity remain poorly defined. In Mexico, tropical and temperate montane forests



**Plates 3–6.** (**3**) New growth on cornfields abandoned 5 years previously. (**4**) Forest growth on plot abandoned 12 years previously. (**5**) Maturing secondary forest, 18 years after abandonment. (**6**) Secondary forest (pine) on former corn fields abandoned in the early 1980s.

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are widely recognised as centres of high diversity and endemism for many different groups of organisms (Challenger, 1998), yet little is known about how flora and fauna respond to human disturbance at different intensities. In the Sierra Norte, traditional land use has always driven secondary succession with impacts on forest composition, structure and regeneration through practices such as long fallow rotational agriculture, ground fires, lopping of hardwoods for fuel wood, pine for timber, and sporadic cattle grazing. Recent progress in landscape ecology and its application to conservation management has highlighted the importance of assessing threats to these processes at both a forest patch and forest landscape scale (Newton, 2007).

Although this study did not generate empirical quantitative data on changes in biodiversity in Analco and Comaltepec, it is possible to use a mix of qualitative evidence and general field observations, together with quantitative studies from other parts of Oaxaca and southern Mexico. Such a mix of information enables us to hypothesise that reduced land and resource use is likely to: (i) interrupt processes of ecological succession and disturbance in the agricultural–forest mosaic; (ii) reduce edge effects and cause changes in patch size; and, (iii) drive declines in agro-forestry systems and home gardens. All of these changes may impact (negatively or positively) different elements of biodiversity, and the processes that generate and maintain that biodiversity.

### 4.1. Ecological succession and disturbance

Away from more remote areas of 'untouched' natural forest, historical patterns of disturbance in both Analco and Comaltepec, and the Sierra Norte generally, have been far more subtle than the catastrophic clearances evident in other parts of Mexico (Challenger, 1998), helping to create a mix of primary and secondary forest characterised by relatively small perimeter/forest patch area ratios. While extensive areas have been cleared in and around Metates and San Martin Soyolapam (mainly for cattle ranching), in most other zones, disturbance has been more localised and small-scale, helping to keep sizeable tracts of primary forest intact.

The spatial heterogeneity created by these patterns of low to moderate disturbance has been identified as one of the factors that may permit the coexistence of a high number of species (Tilman, 1982). Such patterns of disturbance may also enhance diversity at the genetic level by allowing shifts in selection regimes. The development of multiple vegetation and forest types through secondary succession is a particularly important process in landscapes subjected to long-fallow agriculture. Around La Esperanza, areas of cloud forest are cleared by tree felling, drying of the plant material and burning. Maize is cultivated for 3–5 years, after which cultivation moves to another piece of land. A fallow period commences, allowing the development of secondary vegetation.

Fallow duration can vary widely but tends to decline as human population increases. In contrast to other parts of the country, a number of social factors in northern Oaxaca have allowed the recovery of secondary forest for periods of time sometimes longer than a century. First, population densities have historically been low and, second, shifts in the economic activities of land users have resulted in cornfields at higher altitudes being permanently or semi-permanently abandoned for decades. In particular, the introduction of small-scale shade coffee plantations in the 1970s and 1980s reduced pressures in areas above 1,300 m. Work by Rey-Benayas et al. (2007) suggests that secondary succession in areas of cloud forest involves relatively rapid changes in species richness, particularly during the first 40 years after abandonment. Species richness appears to depend on fallow time and on species composition, with local perspectives showing that successional processes in wet, humid country tends to result in diverse formations of secondary vegetation, with differences in dominant species, time of recovery and the size of the secondary forest a result of the microclimatic conditions that create a patchwork of ecological niches up and down the mountainside (Martin, 1993).

Such evidence suggests that it is the level and type of disturbance inflicted by long-fallow rotational agriculture and other farming activities that can contribute to enhancing biodiversity – a finding supported by del Castillo and Blanco-Macias (2007) work in other areas of northern Oaxaca. Abandoned fields provide conditions for succession, the establishment of pioneer species, and eventually secondary forest growth that exhibit a different mix of species to adjacent primary forest and thus higher plant diversity locally (Martin, 1993). At the landscape scale, the biodiversity benefit of having a mix of primary and secondary forests thus becomes apparent from the perspective of overall tree diversity, since the trees found in secondary forests are virtually absent in old growth and primary forests. As such, while large areas of primary forest exhibit much higher species richness (with several canopy layers), limited extensions of secondary forest play an important role in increasing overall diversity.

In addition to their biodiversity value, secondary forests also play important roles in watershed protection and help buffer mature forest fragments from edge effects, and increase the degree of connectivity between them. For example, in both study communities they constitute the key source of firewood and other non-timber forest products (NTFPs) for local resource users, again protecting primary forest from exploitation.

### 4.2. Edge effects and patch size

Edges may induce changes in the abundance and distribution of species, which in turn produce changes in species interactions, such as predation, herbivory, pollination and seed dispersal (López-Barrera et al., 2007). It has been stated that edge effects may have negative consequences for biodiversity as edges modify forest structure, tree regeneration and mortality (Harper et al., 2005). Nevertheless, the variety of results found in recent years and evidence from Mexico (Davidson-Hunt, 2003; López-Barrera et al., 2007) indicate that edge effects on biodiversity are not immediately obvious. In the study region, the reduction in cultivated areas has led to changes in the mosaic of forest patches, generally leading to fewer but larger patches. This has led to changes in forest edges, which have been shown in northern Oaxaca to have a weak but positive effect on tree diversity (Rey-Benayas et al., 2007). These same authors argue that such a positive response of tree diversity to forest edges is likely the result of traditional shifting cultivation, since agricultural systems employed in the region create a matrix dominated by semi-natural vegetation in various states of modification, which does not lead to dispersal barriers to most tree species; in contrast to the traditional concept of fragmentation. In this way, edges can allow many species to disperse and flourish, and affect both pioneers and late-successional species. After a gap is opened in the forest, pioneer species such as pine tend to colonise the forest edge. Although shade-tolerant late successional species have a lower chance of colonising these sites, observations in the field showed that mature trees growing near the edge may still persist (Robson, 2010).

Edges, therefore, may generate positive or negative conditions for forest biodiversity dependent upon what surrounds them. In cloud forest they may actually represent opportunities for forest regeneration and forest fragment expansion. Fog capture in these patches greatly influences biological diversity, as many species (ferns, bryophytes, for example) that depend on the water dripping from rich insect pollinator assemblages, have flower displays that are more attractive than in the forest interior (López-Barrera et al., 2007). Similar effects are likely occurring in edges of riparian

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vegetation strips, where birds are observed to deposit a large number and diversity of seeds (farmer interviews in La Esperanza). Habitat generalists are particularly well placed to exploit the opportunities presented by increased edges through low to moderate rates of forest fragmentation. In both study communities, the evidence provided by local land users suggests that the traditional mix of forested and open areas has provided for a complex, patchy landscape to which a number of species respond (Robson, 2009). In both dry and humid zones, many species frequent open areas where grains and wild and domesticated fruits are grown. In particular, a diversity of birds, butterflies and forest mammals are frequent visitors to these areas (Robson, unpublished field observations and interviews, 2007–2008; Robson, 2009, 2010).

Increasing forest cover through agricultural abandonment will impact this mosaic by reducing the edge contrast between forested and open areas. Such changes are likely to have an effect on wildlife habitat quality, ecological processes and ultimately both localised and landscape-level biodiversity. At a landscape scale, what we can see in northern Oaxaca are forest patches (along an altitudinal gradient) increasing in size and connectivity to form larger and larger forest patches (consistent with Watson, 2002). Although no empirical studies have been carried out in Analco, Comaltepec or a neighbouring community to understand the impact such change is having on different elements of wild biodiversity, the anecdotal evidence collected through interviews with local farmers and field observations suggest that fewer birds and mammals are now seen in agricultural areas as open areas reduce in number and size (Robson, 2009, 2010). While studies may come to show that the most affected species are generalists rather than specialists, one may hypothesise that the return to a heavily forested landscape, with the loss of landscape features associated with patches of cropland and pasture, may have a negative impact on the overall diversity for some key groups of species, such as birds and butterflies (Martinez et al., 2004; Navarro et al., 2004).

### 4.3. Impact on agro-forestry systems and home gardens

It is not only wild biodiversity that is impacted through land use change driven by out-migration and associated processes. Through varied crop selection – a result of both farmer experimentation and as a response to the high environmental variation found locally – both study communities and the region in general have long been home to high levels of agro-biodiversity (Boege, 2008; Robson, 2010) and maize races in particular (Gonzalez, 2001; Soleri et al., 2006). With agricultural abandonment taking place across the region, and remaining farmers beginning to favour pea, cilantro and other 'greens' over *milpa* and traditional multi-species cropping systems, this looks set to change. Indeed, our findings add credence to the view that a major threat facing agro-biodiversity in regions such as Oaxaca is the functional extinction of crop varieties through globalised rural transformation; perhaps more so than genetic pollution, which has dominated most of the debate over the past couple of decades.

Away from open areas, studies have also shown the biodiversity benefits of agricultural systems within forest zones (e.g. Schroth et al., 2004). In Oaxaca and the neighbouring state of Veracruz, research has highlighted how local agro-forestry systems that 'mimic' the structure of natural forest ecosystems (Challenger, 1998), can help maintain an impressive diversity of trees, birds, bats and beetles (Bandiera et al., 2005; Pineda et al., 2005). On the humid side of Comaltepec's territory, the agro-forestry systems that were used to grow coffee, avocado, mamey and vanilla, among other crops, have diminished in number across mountainous terrain between 1000 m and 1600 m; thus impacting another key reservoir of agricultural biodiversity.

Within the villages themselves, we can see a change in the small plots of land, or *home gardens*, which are cultivated relatively intensively by their owners, and act as a source of edible, medicinal, ornamental and other useful plants (Martin, 1993; Robson, 2010). Despite their bio-cultural importance, home gardens are becoming less prevalent as fewer families have the time, resources or need to maintain them – a trend that mirrors the wider decline in farming activities. This, again, will have a negative impact on levels of agricultural biodiversity locally, not least because these gardens are embedded in, and complement the functions of other aspects of the larger land use system. From studies conducted in northern Oaxaca, Aguilar-Stoen et al. (2008) has shown that home gardens are not static or discrete in space and time, but are continually transformed by farmers. The high levels of biodiversity harboured by these land-use units are "maintained and enriched by farmers' practices, particularly plant and seed exchange". Indeed, work has shown that plant diversity tends to be higher in home gardens where owners actively exchange plant material with their neighbours (Watson and Eyzaguirre, 2008). Maintaining diversity in this way is important since it can help to increase the resilience of local farming systems in the face of changing climatic, demographic and economic conditions. Consequently, the loss of home gardens may have far-reaching effects on the health of the socio-ecological system overall.

## 5. Discussion and conclusions

In responding to the call for an enhanced understanding of causes of change in land use (Lambin et al., 2001; Turner et al., 2007; Zimmerer, 2010), this paper points to the complex relationship that exists between out-migration and the transformation of rural landscapes. Contemporary societies in rural Oaxaca are developing present and future economies through courses of action that are only partly tied to customary lands and territorial resources. This paper shows that as individuals, families and collectives become more engaged with national and international markets for wage labour, the relationship between local people and their farming and forest-based practices changes. While the inequities of the global market economy limit the economic benefits that communities can accrue from resource-based practices and expertise, new opportunities have emerged based upon a range of 'off-farm' activities – a number of which are drawing people away from their home villages. In addition to the key role played by labour migration, globalisation also leads to changes in cultural attitudes, which can serve to encourage a more sedentary existence and reduce territorial mobility among residents and migrants alike.

The consequences of these demographic and cultural changes are multi-fold: (i) fewer people are farming; (ii) farmers are cultivating less land than before; (iii) farmers are working closer to permanent settlements; and, (iv) farmers are growing fewer crop varieties, with a shift away from traditional multi-species systems toward monocultures. As the numbers who farm decline, resource use and environmental practices are simplified. In place of customary land-based livelihoods, new communities of practice emerge through ongoing processes of cultural adaptation, where the embodiment of new skills and perceptions become the product of a changed learning environment (Lave and Wenger, 1991). The emergence of new socio-cultural practices drive changes to the forest landscape, with farming and domestic forest use giving way to a range of non-extractive activities. Our paper suggests that this may have significant (and perhaps unexpected) implications for biological diversity, ecosystem services, and ultimately the wellbeing of sending communities.

In many parts of Mexico, anthropogenic disturbance can be described as chronic, widespread and increasing in intensity

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(Challenger, 1998), with native forests subject to intense human pressures. In Oaxaca's northern highlands, however, forests have traditionally been subjected to low intensity logging and rotational (*milpa*) agriculture, which involve localised forest clearance to enable crop cultivation over a limited time period. Such activities had led to pronounced spatial heterogeneity in forest structure and composition, and created a forest–agricultural mosaic that comprised a complex mix of vegetation types and natural features. It is thus the close conjunction of agricultural activities as a source of disturbance, with adjacent secondary forests and old-growth forests that have contributed to high biodiversity at a landscape scale (Newton, 2007; Robson, 2007).

While both study communities are characterised by a mosaic of cornfields, secondary forests of different ages after abandonment, and large unbroken tracts of primary forest, the ratios between these different vegetation categories are now in a state of flux. Widespread agricultural abandonment has initiated a process of ecological succession on a scale unheard of previously. del Castillo and Blanco-Macias (2007) found that the relationship between agricultural disturbance and species diversity in southern Mexico is non-linear, with diversity displaying maximum values at intermediate intensities of disturbance. A landscape composed exclusively of old-growth forest, thus in the absence of long-fallow agriculture or other sources of disturbance, does not sustain most of the common species of young secondary forests. At the other extreme, a landscape with high deforestation rates would result in many species being threatened with extinction locally.

Although it is not possible to decisively demonstrate that changes in ecological succession, patch size and edge effects are having an overall negative impact on wild and agricultural biodiversity, there is a consistency between the quantitative evidence and analyses coming from other parts of Oaxaca and Mexico, and the qualitative findings that our study has generated through multiple interviews with farmers and other land users, supplemented by extensive transects and mapping exercises across community lands. Such a body of evidence allow us to: (i) question whether the depopulation of rural areas and subsequent forest resurgence can be assumed to increase the provision of ecosystem services and enhance biodiversity conservation locally; (ii) point to the need for specific research to show how land use change is impacting biological diversity; and, (iii) consider the important policy ramifications.

Future research would necessarily involve longitudinal studies to empirically determine how a changing landscape mosaic, through processes of agricultural abandonment and subsequent forest encroachment, is impacting the biological diversity of high value conservation regions such as the Sierra Norte. Indeed, this would likely be the case in any area where the right biophysical conditions to create high biodiversity go hand in hand with high cultural diversity (Robson, 2007, 2010). With a few exceptions (e.g. Alcorn and Toledo, 1998), there have been a paucity of work on the biodiversity benefits of Oaxacan land use systems. In this way, there is scope for the kind of work carried out by Newton and colleagues (2007) to be replicated elsewhere.

Also significant are the policy implications of the different scenarios that will emerge under continued demographic and cultural change in rural areas in Oaxaca and Mexico generally. Indeed, the lack of information on this topic poses a problem for practitioners and policy-makers who wish to support rural livelihoods in migrant-sending regions. The suggestion that large-scale agricultural abandonment could lead to declines in biodiversity, goes against the grain of conventional conservation thinking, and adds a layer of complexity to how we perceive forest transitions in tropical country contexts. By painting a picture of possible biodiversity decline that is associated with increasing (rather than decreasing) forest cover, and a reduction in contrast between forested and non-forested areas, our work questions one of the 'popular myths' of land use change (Lambin et al., 2001) by showing that the relationship between population and the environment is neither linear nor deterministic (after Curran, 2002). Indeed, the study supports a view that indigenous cultures in Oaxaca should not be seen as an environmental constraint but as an agent of landscape renewal and source of heterogeneity that generates biodiversity (Robson, 2010; Robson and Berkes, 2010). The fact that indigenous landscapes exist in Mexico that allow for both cultural and biological diversity to flourish (Boege, 2008) is something that national and international conservation bodies need to more fully recognise and incorporate into future policies and initiatives.

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