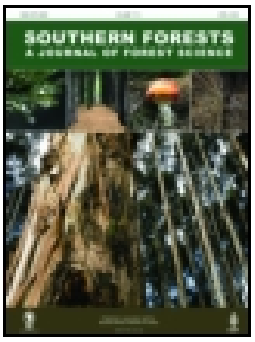

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# Deforestation since independence: a quantitative assessment of four decades of land-cover change in Malawi

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**Land cover has changed rapidly across the tropics over the past century; however, detailed historical information describing the extent and possible drivers of such change is widely lacking. Here, we constructed a history of land-cover change at the district level in Malawi over a 37-year period from 1972 to 2009, the immediate post-colonial phase. Overall, there was a loss of 12 760 km² (36%) of original forested area but also 11 161 km² of new forest establishment, resulting in a relatively modest overall net loss of 1 599 km² (5%). We correlated changes in deforestation and forest establishment with changes in socio-economic variables derived from spatially explicit data from the same time period. Deforestation was positively correlated with (in order of influence) changes in male school attendance, sex ratio, population density, hospital bed numbers, protected areas and dependency rate, but negatively correlated with changes in cattle density; forest establishment broadly showed the inverse relationships with the same variables. Although direct drivers of deforestation are well known for Malawi and much of Africa, the significance of socio-economic variables within this study can help to understand the underlying social pressures behind such drivers. In particular, development, population pressure and demographic factors are important predictors of deforestation rate within our study area.**

**Keywords:** afforestation, Africa, deforestation, drivers, land-use change, reforestation, rural, urban

## Introduction

Humans have been deforesting and over-exploiting forests for millennia, but it is only relatively recently that the rate of deforestation (defined here as the conversion of forest to non-forest land covers) has been so widespread. Of particular concern is the rapid deforestation of tropical forests, one of the world's most biologically diverse ecosystems (Lepers et al. 2005). Sub-Saharan Africa, which is home to the second-largest expanse of tropical forest after the Amazon, has been rapidly deforested in recent years (Baccini et al. 2012). For example, a recent estimate of deforestation in sub-Saharan Africa shows a yearly average deforestation rate of 0.7% accounting for a loss of around 3 million ha every year (Brink and Eva 2009).

The proximate drivers of tropical deforestation are the human activities that most directly result in deforestation. Proximate drivers are well documented and similar across much of sub-Saharan Africa, including agricultural expansion, wood extraction, and expansion of infrastructure (Geist and Lambin 2002). However, an increased demand for agricultural land or wood extraction may be a response to numerous socio-economic pressures – for example, the degree to which forest resources are utilised has been found to be influenced by education, housing type, occupation and socio-economic status (Feder 1997). These underlying relationships of deforestation are less frequently documented but may vary considerably between regions (Lambin and Geist 2003; Fisher and Shively 2005; Kamanga et al. 2009).

The aim of this study was to quantify changes in forest area across Malawi between 1972 and 2009, and to subsequently investigate potential relationships between changes in land cover and socio-economic variables at a district level across the entire country over this period.

### *Study area*

This study focused on Malawi, a landlocked country in south-eastern Africa which gained independence from Britain in 1964. Malawi is one of the 10 most densely populated countries in Africa, with a population that has tripled in size since independence to over 15 million resulting in a population density of 158 individuals km$^{-2}$ (FAO 2013). The combination of a high population density and over 50% of the population being described as below the poverty line (World Bank 2013) undoubtedly puts pressure on the available natural resources in Malawi. Previous estimates suggest substantial deforestation in Malawi, from 45% of land area in 1972 to 25.3% in 1990 (a loss of 18 572 km²; Satellitbild 1993), followed by an additional loss of 6 690 km² by 2008 (MARGE 2009). However, these estimates have not been peer-reviewed and were produced using differing methodologies that may not be fully compatible (Satellitbild 1993; MARGE 2009). Therefore, these estimates could be substantially improved upon (FRA 2010).

In the nineteenth century, the arrival of British settlers to Malawi ('Nyasaland' at the time) introduced agricultural systems and cash cropping, particularly for tobacco (Feder 1997). Agriculture remains the dominant economic activity, involving 84% of the workforce (Malawi Government 2010) and 59% of the total land area (FAO 2013), and is commonly cited as a significant cause of deforestation in Malawi (Kamanga et al. 2009; Davies et al. 2010; Palamuleni et al. 2011). Brink and Eva (2009) estimated an expansion of agriculture across sub-Saharan Africa of 57% between 1975 and 2000, at the expense of forested land.

The reliance upon fuelwood or charcoal for domestic fuel in Malawi is another commonly cited direct cause of deforestation (Davies et al. 2010). This is not dissimilar across much of sub-Saharan Africa, where 90% of the energy demand is met by burning biomass (Bailis et al. 2005). In rural areas of Malawi, 97% of the population is thought to rely on fuelwood as an energy source (Bandyopadhyay et al. 2011). Prolonged and intense fuelwood demand may result in land-cover change through successive waves of forest degradation (Abbot and Homewood 1999; Asner et al. 2009).

Finally, the commercial use of forests is documented as influencing deforestation rates (Feder 1997). Malawian timber is cheaper in international trade than many other sub-Saharan countries, which promotes rapid deforestation (Malawi Government 2010) and the impact of activities such as tobacco curing involves burning huge amounts of biomass (Fisher 2004).

## Methods

We georeferenced and digitised historical maps describing land cover and potential socio-economic drivers in the immediate post-colonial period using ArcGIS 10.1. Due to historical data deficiency, this limited our study to a single historical land-cover map and 10 socio-economic drivers: cattle density, child-woman ratio, dependency rate, distance to railways, distance to roads, hospital beds, male school attendance, population density, protected areas, and sex ratio (Table 1). The maps were georeferenced to the modern international border for Malawi and transformed using the adjust transformation with root mean square errors approaching zero. Once corresponding recent data and maps were sourced, post-processing on land-cover maps and the data for the 10 socioeconomic variables was performed following Willcock et al. (2016) before statistical analysis, ensuring internal consistency and like-for-like comparisons (e.g. imperial units used in older maps were converted to metric units). Thus, any differences in land cover detected are unlikely to result from changes in the definition of forest (Putz and Redford 2010; Willcock et al. 2016); see Supplementary Appendix S1 for further details. The spatial data on forest and mosaic land (defined as a mixture of cropland, forest, woodland, grassland, scrubland and other natural vegetation) cover were aggregated at the district level, the highest resolution at which most data are available (Hietel et al. 2007). The change of each variable over time was then calculated by subtracting the historical value from the modern value.

Prior to statistical modelling, Likoma, a district comprised of islands situated in Lake Malawi, was excluded as there

**Table 1:** Summary of the data used in the study

| Data | Description (see Supplementary Appendix S1 for further details) | Broader indicator | Historical data | | Modern data | |
|---|---|---|---|---|---|---|
| | | | Year of estimate | Source | Year of estimate | Source |
| Cattle density | The average density of cattle per km² | Agricultural intensity | 1968 | Agnew and Stubbs (1972) | 2005 | FAO (2009) |
| Child-woman ratio | The ratio of children under 5 to females aged 15–49 | Demography | 1966 | | 2008 | NSO (2008) |
| Dependency rate | The ratio of those aged 10–14 and >65 to people aged 15–64 | Demography | | | | |
| Distance to railways | The average Euclidean distance to railways (km) | Infrastructure | 1969 | | 2013 | OSM (2013) |
| Distance to roads | The average Euclidean distance to roads (km) | Infrastructure | | | | |
| Hospital beds | The number of hospital beds per district | Development (health) | | | | MASDAP (2013) |
| International Malawi boundary | The international border of Malawi | International Malawi boundary | – | – | | |
| Land cover | The land cover harmonised into six uniform land cover classes: forest, mosaic cropland and vegetation, cropland, swamp, urban areas, and water bodies | Land cover | 1972 | Agnew and Stubbs (1972) | 2009 | European Space Agency (2009) |
| Male school attendance | The percentage school attendance for males aged 10–14 | Development (education) | 1966 | | 2008 | NSO (2008) |
| Population density | The density of people per km² | Population pressure | | | | |
| Protected areas | The area of land under legal protection (km) | Protected areas | | | 2013 | MASDAP (2013) |
| Sex ratio | The ratio of the number of males to every 1 000 females | Demography | | | 2008 | NSO (2008) |

was no historical land-cover data and therefore the change in forest land cover could not be calculated. In addition, for districts with no past forest area, a value of 1 km² was substituted to enable a calculation of percentage change. Furthermore, where both the past and recent forest area values were zero, a percentage change of zero was given.

### *Statistical analysis*

Two separate statistical relationships were investigated, the correlation of socioeconomic variables with both deforestation and forest establishment. Although the drivers of deforestation and afforestation could be the same variables but with inverse relationships, it is possible separate drivers could be involved in one and not the other. Additional models, where all of the city districts (Blantyre City, Lilongwe City, Mzuzu City and Zomba City) were excluded, were also created to allow for the investigation of potentially differing relationships between socio-economic variables and land-cover change in rural and urban districts.

All statistical relationships were performed in R ×64 3.0.1 (R Development Core Team 2010) using multiple linear regressions, transforming the scaled data using cubed root functions to ensure normality. The most appropriate model was chosen by forward and reverse stepwise selection using the Akaike information criterion (AIC) (Bozdogan 1987).

## Results

### *Changes in forest area*

Between 1972 and 2009, the area of forest cleared totalled 12 760 km², a reduction of 36% of the original forested area (Figure 1). However, due to the simultaneous establishment of 11 161 km² of forest in other areas, the net loss of forest was 1 599 km²; a reduction of only 5% of the total forest area from the 1972 baseline.

The overall loss of forest area varied spatially, with northern and central regions showing an overall reduction (−1 124 km² and −1,666 km², respectively) but the southern region having an overall gain in forest area (+1 192 km²; Table 2; Supplementary Appendix S2). The greatest decline in forest area was in the districts of Nkhotakota (−595 km²; −19%), Karonga (−579 km²; −28%) and Chitipa (−565 km²; −20%). By contrast, the districts of Balaka (−48%; −437 km²), Ntcheu (−45%; −378.27 km²) and Karonga (−28%; −579 km²) experienced the greatest forest loss per unit area.

In 56% of districts there was an overall gain in forested area (Table 2; Supplementary Appendix S2). The districts with the largest overall gain were Manchinga (+402 km²; +36%), Mulanje (+385km²; +98%) and Mzimba (+344 km²; +11%). The three districts with the largest percentage gain in forested area were Zomba City (+550%, +18 km²), Lilongwe City (+405%, +4 km²) and Mzuzu City (+300%, +44 km²). The small areas of forest in these city districts in 1972 meant even relatively small changes resulted in large percentage changes.

### *Changes in mosaic land cover*

Throughout the period studied, mosaic land cover had a net gain of 2 804 km² (+5%). However, in terms of original mosaic land in 1960, there was a loss of 20%

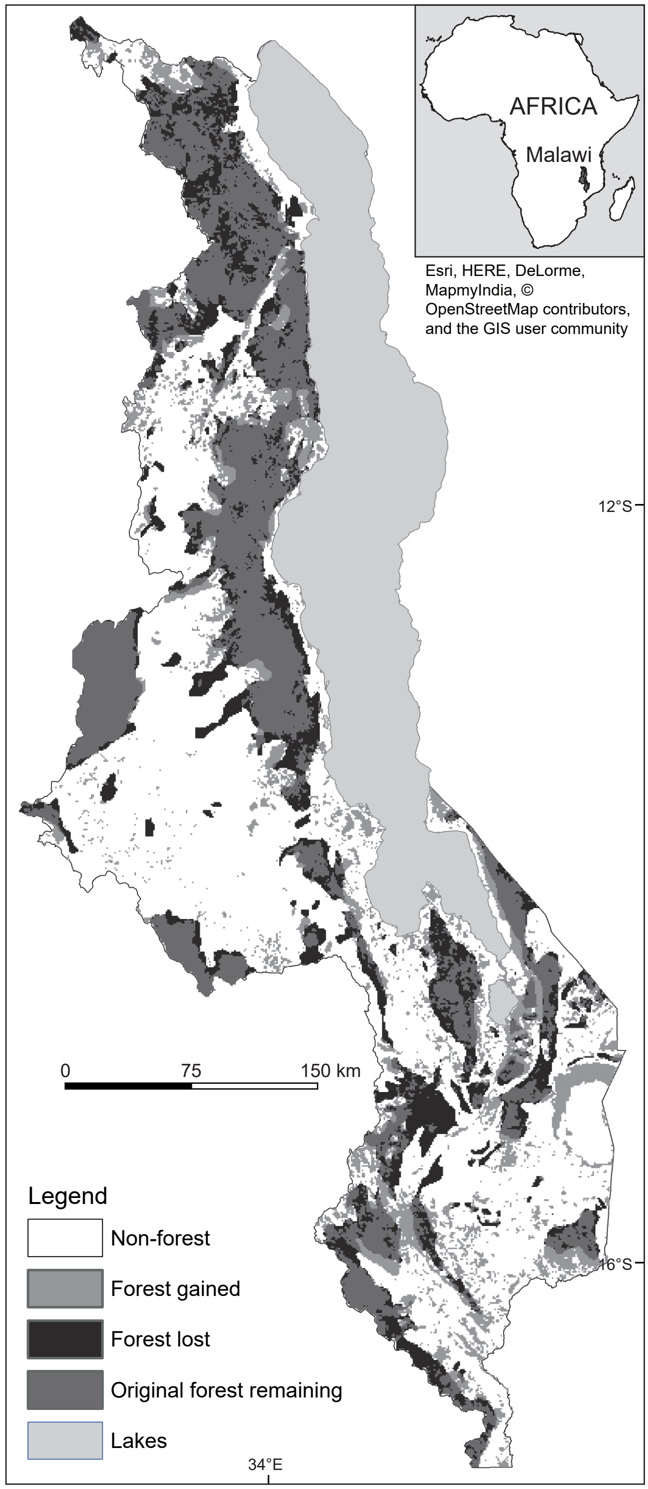


**Figure 1:** Change in forest area in Malawi between 1972 (Agnew and Stubbs 1972) and 2009 (European Space Agency 2009)

(−10 703 km²), of which 72% became forest. This was offset by the gain in 13 508 km² of newly classified mosaic land cover, which resulted in the overall net gain across Malawi from 1972 to 2009 (Table 2).

The largest overall gain was seen in the central region (+1,583 km²) and then followed by the northern region

**Table 2:** Changes in forest area between 1972 and 2009 in each district of Malawi. City districts are shown in bold

| Region | District | Forest change (km²) | Percentage forest change (%) | Mosaic land cover change (km²) | Percentage mosaic land cover change (%) |
|---|---|---|---|---|---|
| Northern Region | Chitipa | −565 | –20 | 622 | 55 |
| | Karonga | –579 | –28 | 523 | 44 |
| | Likoma | No data | No data | No data | No data |
| | Mzimba | 344 | 11 | –239 | –3 |
| | **Mzuzu City** | **44** | **300** | **−47** | **−39** |
| | Nkhata Bay | 184 | 6 | –147 | –19 |
| | Rumphi | –554 | –15 | 608 | 85 |
| Central Region | Dedza | –181 | –15 | 154 | 6 |
| | Dowa | –6 | –4 | 6 | 0 |
| | Kasungu | –462 | –14 | 487 | 11 |
| | Lilongwe | –133 | –14 | 136 | 3 |
| | **Lilongwe City** | **4** | **405** | **−113** | **−29** |
| | Mchinji | –62 | –16 | 92 | 3 |
| | Nkhotakota | –595 | –19 | 565 | 57 |
| | Ntcheu | –378 | –45 | 396 | 17 |
| | Ntchisi | 31 | 9 | –31 | –2 |
| | Salima | 116 | 30 | –108 | –7 |
| Southern Region | Balaka | –437 | –48 | 489 | 43 |
| | Blantyre | 23 | 7 | –23 | –2 |
| | **Blantyre City** | **24** | **97** | **−113** | **−54** |
| | Chikwawa | –53 | –3 | 217 | 9 |
| | Chiradzulu | –4 | –7 | 4 | 1 |
| | Manchinga | 402 | 36 | 303 | 18 |
| | Mangochi | 104 | 4 | –57 | –2 |
| | Mulanje | 385 | 98 | –422 | –27 |
| | Mwanza | 92 | 30 | –87 | –20 |
| | Neno | –75 | –10 | 82 | 10 |
| | Nsanje | 204 | 39 | –41 | –4 |
| | Phalombe | 28 | 16 | –7 | –1 |
| | Thyolo | 300 | 245 | –343 | –22 |
| | Zomba | 181 | 57 | –92 | –5 |
| | **Zomba City** | **18** | **550** | **−18** | **−48** |

(+1,330 km²). However, the southern region experienced a relatively small net loss of −109 km². The districts of Chitipa (+54%, +622 km²), Rumphi (+85%, +608 km²), Nkhotakota (+57%, +565 km²) and Karonga (+44%, +523 km²) experienced the largest net gains in mosaic land cover and were also the districts with the largest percentage gains. These districts were also those where deforestation were greatest. In every district that had an overall loss in forest, there was an overall gain in mosaic land cover.

Even though there was a net gain across the whole country, only half of the 32 districts experienced a gain in mosaic land cover. The districts of Mulanje (−27%, −422 km²), Thyolo (−22%, −343 km²) and Mzimba (−3%, −239 km²) were those with the greatest loss in mosaic land cover. Similarly to the districts with large percentage changes for forest establishment, the city districts were those with the greatest percentage changes for a loss in mosaic land cover. These were Blantyre City (−54%, −113 km²), Zomba City (−48%, −18 km²), Mzuzu City (−39%, −47 km²) and Lilongwe City (−29%, −113 km²).

### *Correlates of deforestation*

The deforestation model ($n = 14$, $F$-value = 19.18, $p < 0.01$) had an adjusted $R^2$ value of 0.91, indicating that most variance in deforestation between 1972 and 2009 could be explained by the socio-economic variables included in this study (Table 3). In order of influence, the variables included within the model were the changes in male school attendance, sex ratio, population density, number of hospital beds, dependency rate, protected areas and cattle density (Table 3). Changes in population density ($p < 0.01$), hospital beds ($p < 0.01$), sex ratio ($p < 0.001$) and male school attendance ($p < 0.001$) were positively correlated with deforestation. Cattle density, although not significant within the model ($p > 0.200$), was the only variable to be negatively correlated with deforestation.

### *Correlates of forest establishment*

The best fit model for forest establishment included both city and rural districts ($n = 17$, $F$-value = 6.665, $p < 0.01$) and had an adjusted $R^2$ value of 0.71. The variables included in the model, in order of influence, were changes in male school attendance, sex ratio, population density, dependency rate, distance to railways, child-woman ratio and number of hospital beds (Table 3). The changes in hospital beds ($p > 0.100$), dependency rate ($p > 0.100$) and male school attendance ($p > 0.200$) were positively correlated with forest establishment, whereas all other

**Table 3:** Summary of the regression models relating changes in forest cover to socio-economic variables

| Broader indicator | Explanatory variable | Deforestation | | Forest establishment (including city districts) | | Forest establishment (excluding city districts) | |
|---|---|---|---|---|---|---|---|
| | | Coefficient estimate | *p*-value | Coefficient estimate | *p*-value | Coefficient estimate | *p*-value |
| Agricultural intensity | Cattle density | −0.114 | 0.291 | – | – | 4.194 | 0.148 |
| Demography | Child-woman ratio | – | – | −1.481 | 0.228 | −1.065 | – |
| | Dependency rate | 0.384 | 0.023* | 2.065 | 0.136 | 2.028 | 0.232 |
| | Sex ratio | 1.974 | 0.000*** | −3.388 | 0.014* | −1.986 | 0.095 |
| Development (education) | Male school attendance | 4.227 | 0.000*** | 3.501 | 0.200 | −9.417 | 0.301 |
| Development (health) | Hospital beds | 0.527 | 0.001** | 0.878 | 0.131 | 0.669 | 0.281 |
| Infrastructure | Distance to railways | – | – | −1.815 | 0.009** | −0.802 | 0.350 |
| | Distance to roads | – | – | – | – | 1.020 | 0.343 |
| Population pressure | Population density | 1.112 | 0.008** | −2.577 | 0.047* | 1.550 | 0.245 |
| Protected areas | Protected areas | 0.337 | 0.013* | – | – | – | – |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

variables (changes in sex ratio [$p < 0.05$], population density [$p < 0.05$], distance to railways [$p < 0.01$] and child-woman ratio [$p > 0.100$]) were negatively correlated.

On removal of the city districts from the analysis, the model was largely unchanged, including identical variables, except for the addition of changes in distance to roads and cattle density (Table 3). Of the variables included within both forest establishment models, the relationships were in the same direction except for population density, which now showed a positive relationship, and changes in male school attendance, which showed a negative relationship. Unlike the model including the city districts, none of the variables were identified as significant ($p > 0.05$) and the adjusted $R^2$ value was much lower at 0.52. The removal of city districts from the deforestation model was not necessary as none of the city districts showed any deforestation.

## Discussion

### *Change in forest area*

Our results show that Malawi has experienced a deforestation rate of around 1% (345 km$^2$) per annum between 1971 and 2008, of which most (98%) was replaced by mosaic land cover. This is at the lower end of the 1–2.8% estimate from the *Malawi State of Environment and Outlook Report* (Malawi Government 2010), in accordance with previous estimates of 1.8% by Hudak and Wessman (2000) and 1.4% by Hansen et al. (2013). Lower deforestation rates are likely due to an under-representation of forest within the historical land cover; a finer resolution in the recent map enabled smaller patches of forest (<300 m$^2$) to be identified. Due to the lack of data from intervening years in this study, any changes in the rate of deforestation throughout the time period are unable to be inferred. Some authors have noted, however, that the rate of deforestation in Malawi may be declining (Hudak and Wessman 2000; Davies et al. 2010).

Despite the high rate of deforestation, the rate of forest establishment is also rapid, an observation shared by Hyde and Seve (1993). In this study, the overall net loss of forest was only 5% between 1972 and 2009 due to the 12 760 km$^2$ original forest loss being offset by 11 161 km$^2$ of forest establishment. However, as discussed in Willcock et al. (2016), it is impossible to distinguish afforestation, forest regeneration and reforestation. Just under half of the districts experienced overall deforestation (14 of 32 districts), which showed deforestation is not the dominant trend across the districts of Malawi. Similarly, in Angola, not all districts experienced the levels of deforestation that national figures would suggest (Cabral et al. 2011). In Tanzania, both continual forest establishment and continual deforestation were found at the village level depending on how traditional the village practices were (Strömquist and Backéus 2009).

Effort put into forest establishment have been successful in Malawi, particularly in the southern region, which experienced a net gain in forest. The *Malawi State of Environment and Outlook Report* (Malawi Government 2010) outlined a number of reforestation initiatives, including piloting a programme of payment in return for tree planting and the ‘Community-based Forest Management’ policy in 2003 where village committees were encouraged to promote forest conservation, management and tree planting within the village’s forested areas. The planned introduction in 1964 of 40 km$^2$ of forest annually until 1977 as part of the Vipya pulpwood project (Chapman and White 1970), the presence of several hundred tree nurseries to encourage farmers to use the seedlings (Walker 2004), and public awareness schemes such as a national tree planting day (Walker 2004) are other examples throughout the period studied. Hyde and Seve (1993) quantified forest establishment, suggesting government plantations added 30 km$^2$ y$^{-1}$ by 1985 and private smallholders added 11 km$^2$ y$^{-1}$ by 1990. However, although there has been much forest establishment, it is unlikely the new forested areas would have the same levels of biodiversity as remaining original forests (Mwase et al. 2007).

### *Correlates of forest area change*

Whilst we are able to report the land-cover change trends that have occurred in Malawi between 1972 and 2009 with some certainty, the statistical correlations of the forest area change with socio-economic variables is unable to support strong cause and effect conclusions. Below, we briefly consider some of the possible cause–effect relationships identified from our results (see Supplementary Appendix S3 for more details).

One of the most influential correlates of deforestation was sex ratio ($p < 0.001$), where the positive correlation suggested that as the ratio of men to women increased, deforestation increased. Men tend to be the dominant gender involved in the collection of commercial wood (Abbot and Homewood 1999), an often destructive process involving the removal of entire trees for activities such as illegal charcoal production (Fisher 2004). Men are more likely to have more substantial tools for wood collection, which would increase the likelihood of deforestation; 42% had axes compared with 13% of women (Abbot and Homewood 1999). Of the individuals collecting fuelwood in Malawi, 84% are thought to be women (Bandyopadhyay et al. 2011). Women tend to collect dead wood and small branches, which are easy to gather, lighter to carry and contribute more to forest degradation than deforestation (Gbadegesin 1996).

Population density was another correlate within the deforestation model ($p < 0.01$). The positive relationship suggests that the greater the increase in population density, the greater deforestation, which is consistent with *a priori* expectations, as when the density of a population increases, the demand for agricultural land increases. This relationship is firmly established within the forest transition theory globally (Rudel et al. 2005). In Malawi, the influx of 800 000 refugees from Mozambique in the 1980s led to the clearing of large areas of land for cultivation in the border districts, a line clearly visible from aerial photographs at the time (Potts 2006). Since independence, there has been a gradual migration of people to the northern and central districts in search of cultivatable land (Potts 2006). It is these areas that have also experienced the greatest amount of deforestation since independence.

Male school attendance ($p < 0.001$) and the number of hospital beds ($p < 0.01$) were two other positively correlated significant variables included within the deforestation model. The greater the increase in the percentage of males attending school or the number of hospital beds, the more forest lost. Both healthcare and education are key developmental indicators (World Bank 2013). Since independence in 1964, the government has sought to balance development across the country (Kalipeni 1997). During the colonial period, the development of the central and northern regions of Malawi was often ignored as the majority of the population and commercial activities occupied the southern region (Kalipeni 1997; Potts 2006). Initially, the capital was moved to Lilongwe to be more centrally located (Potts 1985) and improvements and extensions were made to road and rail links (Kalipeni 1997). By 1987 there had been the establishment of 10 ‘growth centres’ to act as vehicles to spread development throughout the country, which included, among an extensive list, the building of schools and health centres in each place (Kalipeni 1997). The increasing population and subsequent deforestation occurring at the same time as increasing development, particularly in the northern and central regions, is perhaps why the positive relationship between deforestation and male school attendance or the number of hospital beds in this model exists.

Generally, it is harder to separate the correlates of forest establishment, as it is the effect of three separate processes (afforestation, reforestation and forest regeneration), which cannot be disaggregated without further study (Willcock et al. 2016). Broadly, the correlates of forest establishment were identified as the inverse of the relationships observed with deforestation. For example, more forest establishment was found in areas that showed a reduction in population density ($p < 0.05$), perhaps as a result of land abandonment allowing for recovery of the natural forest. However, some correlations, for example distance to railways ($p < 0.01$), were unique to forest establishment (see Supplementary Appendix S3 for more details).

## Conclusion

In Malawi, there has been significant deforestation (12 760 $km^2$; 36%) over a 37-year period from 1972 to 2009. However, much of this was balanced by significant forest establishment over the same time period (11 161 $km^2$), resulting in a net loss of 5% of forested area. Broadly, deforestation and forest establishment show similar but inverse relationships with socio-economic variables. Specifically, development, population pressure and demographic factors are important predictors of forest area change within our study area.

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