

Historical landscape repeat photography as a tool for land use change research

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Abstract

This study applies repeat photography – the comparison of historical and recent landscape photographs from the same camera point – to the case of highland Madagascar. First, it evaluates whether repeat photography is an efficient, effective, and useful method to identify region-wide trends in land use change. To do so, it proposes and applies a systematic methodology that addresses the significant obstacles of spatial bias and temporal inconsistency. When compared with the analysis of air photos and satellite images, the technique is found to provide useful high-resolution data and a deeper historical reach. If pursued opportunistically alongside other fieldwork, the method is efficient in time and cost; it can be a useful way to identify environmental trajectories worthy of further investigation, to corroborate other studies, and to illustrate changes. Second, the overall trends of 20th century land-use change in highland Madagascar are investigated. Results suggest that many parts of the central highlands – dominated 100 years ago by open grasslands – are now characterized by expanded and intensified agriculture, an increased presence of trees (fruit trees and exotic reforestation species), and general stability in soil erosion. These results complicate the view of Madagascar as an island suffering problematic environmental degradation, such as deforestation and erosion.

Keywords: *afforestation, environmental history, land use change, Madagascar, repeat photography*

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INTRODUCTION

The landscape of highland Madagascar has changed radically since the arrival of the first people over a millennium ago. By the time people began photographing the landscape in the late 1800s, what was once a mosaic of woodlands, riparian forests and savannas had become dominated by grasslands stretching as far as the eye could see. During the course of the 20th century, though still prominent, these grasslands receded as towns developed, and crop fields and farm trees increased.

This article presents and tests a method – repeat photography – to substantiate these trends. It has two goals. First, it seeks to identify the overall regional trends of 20th century land-use change in highland Madagascar, with particular attention to the extent and character of tree cover, crop fields, and soil erosion. Many of these details are lost in discussions of environmental change on the island, since they are overshadowed by attention to the rapid loss of the endemic forests both to the east and west of the highlands. In some cases, unfounded generalizations about pre-human forest cover – or about the processes of fire or erosion – cloud interpretations of highland environmental change (Kull 2000). A number of researchers investigate 20th century highland environmental transformations in specific case studies (Rakoto Ramiarantsoa 1995a, Kull 1998, Blanc-Pamard & Rakoto Ramiarantsoa 2000), but often the specificity of their case studies precludes region-wide conclusions.

Second, the article seeks to evaluate whether repeat photography is an efficient, effective, and useful method to identify region-wide trends in land use change. Repeat photography – where still photographs of a particular scene from the same ground-based camera point are taken at different points in time – can be a useful tool for monitoring landscape change. Geologists use fixed camera positions to document the ebb and flow of glaciers, ecologists investigate changing vegetation communities, architects analyze the changing faces of cities, and geographers examine the changing human impact on the landscape. However, the approach is frequently relegated to illustrative, supplemental, or pedagogical applications, and only occasionally considered a tool in its own right. It lends itself more to ideographic than to nomothetic approaches. For broad regional analyses, repeat photography is less spatially representative than alternatives such as airplane and satellite-based remote sensing. This article reviews recent contributions to the methodology and proposes and evaluates an approach using repeat photography that both addresses methodological shortcomings and helps to draw broader conclusions about regional landscape change.

REPEAT PHOTOGRAPHY

The anglophone literature on repeat photography is dominated by the western United States, where two pioneering projects documented vegetation changes over the past century. First, the US Geological Survey Desert Laboratory's 'Changing Mile' project in southern Arizona and Mexican Sonora investigated changing desert vegetation based on historical photographs from the late 1800s and early 1900s, re-photography in the 1960s (Hastings & Turner 1965), and again in the 1990s (Turner et al. 2003). Second, the US Forest Service has monitored Oregon's mountain ecosystems for a century (Skovlin & Ward 1995, Skovlin et al. 2001, Johnson 2003), inspired by 45 years of effort by Frederick Hall (2001, 2002). Both projects demonstrate the effects on vegetation communities of land uses such as grazing or woodcutting, management policies such as fire exclusion, and climate change.

America's western national parks are particularly well represented in repeat photography studies. Broad interest in the parks and their management combined with dramatic landscapes with open vistas (which inspire photography and simplify the search for original camera points) give results that lend themselves to both academic articles and coffee table books. Recent examples include the Grand Canyon (Baars et al. 1994, Webb 1996), Yosemite (Vale & Vale 1994; Gruell 2001, Stewart et al. 2002), Rocky Mountain National Park (Veblen & Lorenz 1991), and Glacier National Park (Butler & DeChano 2001).

Also in the American west, repeat photography has been applied to topics as varied as geomorphology (Graf 1987, Butler & Malanson 1990, 1993, Butler 1994, Webb 1996, Pérez 1998), volcanic geology (Topinka 1992), biogeography and forest ecology (Veblen & Lorenz 1991, Clay & Marsh 2001, Gruell 2001, Manier & Laven 2002), range management (Hall 2002, Keigley et al. 2002, Johnson 2003), and historical architectural studies (Ahlstrom 1992). A recent bibliography listed 175 sources on repeat photography in range and forest management in the American west (Hart & Laycock 1996); they build upon an earlier work that lists 450 sources, largely in the same region (Rogers et al. 1984).

As Rogers et al. (1984) note, over 90% of repeat photography studies focus on ecological or geomorphic change, whether due to anthropogenic or natural causes, especially in rangelands, forestlands, or 'wild' landscapes. The technique is less frequently applied to the study of more human-shaped landscapes, such as agricultural areas or settlements, even though it is aptly suited for such work. Two outstanding exceptions document change in America's heartland. First, Vale & Vale (1983) re-photograph of a 1950 picture book of scenes along the coast-to-coast US Highway 40, providing mini-essays of commentary for each photo pair on topics ranging from suburban development to historical mining activities (Stewart 1953). Second, Bromberg (2001) documents the changing landscapes, cities, villages, farms, and people of Wisconsin on the state's 150th anniversary with particularly evocative photography.

Outside America, repeat photography has been used to address questions of erosion and slope management in the Himalaya (Byers 1987, Ives 1987), treeline change in Sweden (Kullman 1988), and vegetation change in the South African Karoo (Hoffman & Cowling 1990). Glaciers have long been photographed as natural curiosities; repeat photography documents glacial advances and recessions around the world, from the Alps (Zängl & Hamberger 2004) to the Rwenzori in central Africa (Kaser & Osmaston 2002). Though the technique has much potential, it has only rarely been used in the tropics and subtropics, for example Australia (Pickard 2002) or Madagascar (Koechlin et al. 1974; Kull 2004).

Most relevant to this article is work on rural landscape change in Pakistan (Nüsser 2001), Mexico (Works & Hadley 2000), and Kenya (Tiffen et al. 1994). These three studies use repeat photography to show the impacts of population growth and economic change on landscapes, including expanding settlements, agricultural change (field expansion, intensification, division, or abandonment), and shifting tree cover. The first two studies use repeat photography as their central data collection method; the latter study uses judiciously selected repeat photos to confirm and illustrate findings of a broader research project.

Repeat photography studies vary widely not just by the topic of analysis, but also by the time frame or interval. At one end of the spectrum is the re-photographing of a historical photo after the passage of a century; at the other end is yearly or monthly photographic monitoring of a designated site (or, taken to the extreme, time-

lapse photography). Most of the above studies used photo intervals of multiple decades up to a century. Shorter interval photography has been used fruitfully to monitor system responses to disturbances such as floods, debris flows, grazing, or fires over a period of a few years (Ives 1987, Butler & Malanson 1993, Hall 2002, Keigley et al. 2002), or to demonstrate seasonal changes in vegetation cover (Kull 2002, Nüsser 2002). Such photography frequently focuses on smaller parts of the landscape, down to individual trees (Kullman 1988) or patches of grass (Hall 2002).

Repeat photography has both advantages and disadvantages (Pickard 2002). As opposed to aerial photography and satellite-based remote sensing, which provide comprehensive, unobstructed top-down views, re-photography has a less comprehensive and more biased cover of the landscape in question. The resulting oblique photographs are not orthogonal, wildly exaggerating nearer things in size, thus making areal quantification very difficult (though not impossible; see Clay & Marsh 2001 or Manier & Laven 2002 for quantitative approaches to repeat photo measurements).

On the other hand, systematic re-photography has advantages in terms of cost, time frame, and physical detail. *First*, repeat photography can be less costly than remotely sensed analyses, particularly if photos can be taken opportunistically during other fieldwork efforts. *Second*, since photography became widespread by the late 1800s, repeat photography can afford deeper historical records than aerial photography (which became common in the 1930s) and satellite remote sensing (Landsat 1 was launched in 1972). In addition, for present-day monitoring uses, the time frame is more flexible than aerial overflights or satellite passes. *Third*, the oblique perspective and larger scale of ground-based photography make landscape features easier to recognize and understand by audiences not trained in aerial photograph interpretation. It allows analysis of details, such as species composition, and avoids the generalizations inherent in remote sensing pixels. In sum, repeat photography is particularly useful when financial means are limited, a long historical reach is preferred, when frequent or spontaneous monitoring is necessary, and when detailed, small-scale, case-based information is desired (Turner et al. 2003).

The rest of this article puts re-photography to the test, proposing a systematic approach to assessing regional land use change through repeat photography, applying this method to 20th century land-use change in highland Madagascar, and evaluating the outcomes. As far as I am aware, this is the first published application of this technique to Madagascar – the only previous examples are single, illustrative photo pairs of the Andringitra waterfalls (Koechlin et al. 1974) and of the *tapia* woodlands (Kull 2004).

THE CASE STUDY

The highlands of Madagascar, which cover about one-fifth of the island (Fig. 1), are a good location to test the applicability of repeat photography for three reasons. First, the hilly relief of the highland landscape makes it photogenic and provides useful landmarks for recognizing photo locations. Elevated between 900 and 2700 m a.s.l., the landscape includes rolling hills, large plains, volcanic cones, granite inselbergs, tall mountain chains, and deeply incised valleys.

Second, as one of the most populous regions of the island, and seat of the capital Antananarivo, the highlands have been more frequently photographed than other regions. This region is home to over 6 million people. However, local population densities are quite varied, exceeding 200 people per km² in some

intensively cultivated valleys yet falling to below 10 people per km² in outlying zones.

Finally, the landscapes of the highlands have undergone many changes that re-photography might well serve to document. Building a better understanding of 20th century highland environmental change is important, given the way that questionable ideas about environmental change shape government policies and NGO actions (Kull 2000, 2004, Klein 2004). Indeed, the nature and extent of highland deforestation continues to be debated (Gade 1996, Lowry et al. 1997, Burney et al. 2004).

During the Holocene, the highlands were covered by a dynamic mosaic of vegetation, including riparian and montane forest, heathlands, open woodlands, savannah, and grasslands, maintained by lightning fires and now-extinct megafauna (Dewar 1984, Burney et al. 2004). Human arrival increased fire frequency and led to a dramatic expansion of grasslands. In the 19th century, burned and grazed grasslands were dominant, with irrigated rice in many valley bottoms. During the 20th century, land use intensified and now agriculture occupies most lowlands and many hillslopes, while pine, eucalyptus, and wattle woodlots cover some hills. Grassland, however, still dominates vast areas.

The 20th century highland forest cover change follows contrasting trends. Tree cover of some natural forests, particularly montane and riparian forest, has declined, such as the escarpment forests in Zafimaniry country (Coulaud 1973), or the Ambohitantely plateau forest (Langrand 2003 – though Ratsirarson et al. 2003 document conflicting trends). Other natural forests have remained relatively stable, including the human-modified *tapia* woodlands (Kull 2004), as well as parts of the western edges of the eastern rainforest (Green & Sussman 1990, 215, Note 14). On the other hand, cultivated and introduced tree cover, from fruit trees to forest plantation trees, such as pine, eucalyptus, and wattle, has increased, sometimes dramatically (Rakoto Ramiarantsoa 1995b, Bertrand 1999).

Changes in soil quality have been similarly complex. Many studies cite a widespread, slow, and incremental degradation of highland soils due to fire, overgrazing, and poor agricultural techniques (Le Bourdieu 1972, Randrianarijaona 1983, ONE/Instat 1994). Additional studies document the spread of dramatic *lavaka* gully erosion, which are attributed in one-quarter of cases to purely human causes (Wells & Andriamihaja 1993). Others, however, show how clever soil management by rural farmers has improved marginal lateritic soils through erosion benching and composting (Rakoto Ramiarantsoa 1995a). This study proposes to better illuminate these trends using a systematic approach to repeat photo analysis.

METHODOLOGY: THE PHOTO PAIRS

This section discusses the methods used to acquire and prepare repeat photo pairs. Both general principles and their application to this study of highland Madagascar are discussed. For other excellent and detailed discussions of repeat photography methodology, see Pickard (2002) and especially Hall (2001, 2002).

Acquiring historical photographs

Historical landscape photographs are available from a wide variety of sources; the only limit, perhaps, is the resourcefulness of the researcher (and permissions and copyright laws, if photos are to be reproduced). Archives, books, libraries, private

collections, and personal sources can all be treasure troves. In general, panoramic photos taken from good viewpoints are the most useful (Nüsser 2001).

This article highlights photographs obtained from the archives of the Norwegian Missionary Society (NMS) in Stavanger (www.mhs.no/article_193.shtml; www.usc.edu/isd/archives/arc/digarchives/mission; both accessed September 2005). Of particular interest were the black-and-white prints of photos taken by missionaries travelling the island between the 1880s and the 1940s, as well as a collection of colour slides by historian Paul Ottino in the 1960s and 1970s. By combining NMS photos with others from the FTM (National Geographic and Hydrographic Institute in Antananarivo), as well as from books (Humbert 1927, Saron 1953), colleagues, and friends, I have established a collection of 74 historical photos taken between 1895 and 1974.

Identifying photo locations

Perhaps the toughest task is finding the location where the original photographer stood. While an exact match is not always necessary to make general conclusions or to illustrate broader cultural change (Ahlstrom 1992, Bromberg 2001), it is absolutely necessary for more rigorous analysis or quantification (Manier & Laven 2002). Some historical photographs come with careful notation as to their location; others require a time-consuming work combining local knowledge, reading of historical documents, systematic searching, and, perhaps most of all, a 'geographic eye'. Even once one has found the general location it can be difficult to determine the exact camera position. It may be necessary to walk forward and back, left and right, for hundreds of metres to get the exact angle and distance. Fortunately, many photographers did not stray far from the edge of roads and paths, making this task easier; the scenes that caught the eye 100 years ago – of landmarks, of dramatic and picturesque views – often still catch the eye today. Over the past 10 years, I have located and re-photographed three-quarters of the photos in my collection (43 exact or near-exact matches and 13 rough matches).

Re-photographing

In addition to replicating the exact camera point, three additional factors must be considered in taking the most useful repeat photographs. First, the camera lens should cover a similar field of view. Many old photos were taken in a wider format, so a wide-angle lens is useful. Different lenses produce different apparent displacements of objects in space, so ideally a lens with similar characteristics to the original should be used. However, unless extremely precise on-photo measurements are required, this factor is not crucial. I used a SLR camera with 28 mm and 58 mm lenses, as well as a digital camera with a 8-24 mm zoom lens (equivalent to 38-114 mm in 35 mm camera format).

Second, in framing the photo, the photographer may need to consider alternative camera sites if trees or other obstacles obscure the original background (the change in the foreground should be noted as well).

Finally, attention to lighting and season can be important. Shadows differ based on time of day, time of year, and the weather. Vegetation cover changes in vigour and colour based on the season. Thus the environmental conditions of the original photo should be replicated as far as possible, given time and travel constraints.

Notes and coordinates

It is crucial to note the location and timing of photographs taken, not only to facilitate analysis, but also to allow for the potential of future monitoring of the same sites. Three types of location descriptors were usually noted in this study: place names, kilometre points along highways, and latitude–longitude coordinates using a handheld GPS unit.

Preparation and presentation

Computers significantly aid photo preparation and analysis. A variety of programs enable photographs to be manipulated, cropped, resized, and rotated in order to facilitate analysis. While algorithms could have been used in remote sensing programs to stretch images to overlay perfectly (Manier & Laven 2002), this was found to be unnecessary. I cropped and resized the scanned photographs using photo editing programs (e.g. Adobe Photoshop) or presentation programs (e.g. Microsoft PowerPoint). Then the photographs can be printed and compared side-by-side, or toggled back and forth between photos in successive slides of a slideshow (the latter technique was particularly useful). An alternative approach, aptly demonstrated by Nüsser (2001), is ‘visual image interpretation’, whereby the analyst transforms the photo pairs into detailed, stylized line drawings to facilitate quick visual comparison.

METHODOLOGY: ANALYSIS

This article examines whether repeat photography is an efficient, effective, and useful method to interpret regional land-use change. Much of the answer to this question arises out of the analytical methods employed. This section begins by reviewing the chief obstacles to reliable results. Then it proposes a systematic approach to compensate for these obstacles, and describes its application to the Malagasy case study.

Issues in analysis

The first obstacle to using repeat photography to assess regional land use change is difficulty with obtaining a spatially representative sample. Inherent spatial biases in photographed locations may invalidate conclusions made for the broader region. These biases reflect accessibility (historical or present), aesthetics, personal interests, or ideologies (Pickard 2002). For example, places along roads are frequently more often photographed, but they are also frequently more densely populated and more intensively used than the hinterland. This can lead to the possible exaggeration of region-wide land use intensification (Chambers 1983). Alternatively, a previous photographer may have been interested only in documenting farmers’ agricultural practices, thus photographing mainly those regions where terraced agricultural fields prevailed, to the detriment of vast zones of degraded hillslopes. Clearly, no collection of historical photos will be statistically representative, and such biases should be accounted for. This article proposes a few methods, in the section headed ‘Approach used’; other solutions include triangulation with other studies and with other forms of data collection.

A second obstacle is the lack of uniform photo dates and time spans. The analyst may be tempted to make broad statements about ‘then’ and ‘now’, assigning

an unwarranted uniformity to dates. For example, in the photos analyzed in this study, the ‘then’ photos span 80 years, and the ‘now’ photos span 10 years. One can, however, make conclusions about trends and their applicability across time periods; this article suggests a way to visually represent the results to account for temporal variability (Fig. 2).

Third, just as two spatial points are hardly conclusive for the entire region, changes between two moments in time do not necessarily confirm a trend. For example, a 1900 photograph of Ivohitra, the volcanic cone just outside the city of Antsirabe (Fig. 1), shows it to be covered in grass (Fig. 3). My 1996 re-photography documents a forest of pines around the base of the cone. From these, it might be concluded that there has been minor reforestation. However, an intervening photograph from *c.* 1946 shows the cone was fully covered with pines at that time. The story is clearly more complex than the 1900–1996 pair suggests.

Fourth, photo quality may impede analysis. Some photographs may be of poor quality which can lead to loss of information or, at worst, misinterpretation. In poorly preserved black and white photographs, a black smudge on a distant hill could equally be a forest, a cloud shadow, or a fire scar. The high contrast in black and white photography brings out different features than colour photography. Likewise, as mentioned above, photos taken at different seasons or times of day increase the possibility that differences in shadows or vegetation cover mask important changes or lead to erroneous conclusions.

Finally, there is the issue of measuring change. How should the changes seen in a pair of photos or in an entire collection of pairs be recorded? Many previous studies rely on largely qualitative descriptions. Some incorporate basic quantitative indicators (such as ‘while none of the background was cultivated in the first photo, 75% is cultivated in the second photo’). Such narrative description is very effective in accounting for complex trends of land use change and the particularities of individual photo sites. Some form of quantification, however, is often useful when assessing more than a few photographs. Approaches to quantification range from the simple use of categories (i.e. ‘more trees’, ‘less trees’, or ‘no change’), to counting the presence or absence of particular items such as vegetation species (Turner et al. 2003), to orthorectification, classification, and polygon measurements (Manier & Laven 2002). Sometimes, analysis of photos is combined with ancillary data that facilitate the measurement of change, such as a vegetation survey in the foreground (Hoffman & Cowling 1990). All of these approaches must account for the displacement caused by the oblique photo angle, where the cutting of a few foreground trees looks more dramatic than the razing of an entire forest in the distant background.

Approach used

In order to maximize efficiency and spatial representation, this study used a hybrid approach. While GIS or remote sensing technology could have been used to rectify, overlay and to measure change in photo pairs, rectification and image analysis was simply found not to be cost or time effective when compared to the skill of human eyes in dealing with visual comparisons. For instance, the poor quality of some older photos would make precise measurements difficult. Even if one were able to accurately and precisely determine the changes of a variable in a photo (e.g. a ‘35.7% decline in trees’), the added precision serves little in an aggregate study of a number of photographs covering different-sized and selective portions of the landscape. The eyeball estimate of ‘loss of nearly half of tree cover’ would suffice.

For each photo pair, I first made qualitative descriptions of observed changes in six categories: forests (both plantation woodlots and natural vegetation), village trees (fruit, shade, and ornamental), agriculture, erosion, and infrastructure (Table 1). These qualitative descriptions distinguish, as appropriate, between foreground, middle ground, and background; they employ, where relevant, approximate quantitative assessments such as ‘doubling of forest area’ or ‘3 new houses, 1 in ruins’. Besides giving the researcher close familiarity with all the photo pairs, such qualitative descriptions leave room for nuances that may be lost in later quantification and generalization.

Next, I tabulated trends across the six analytical categories and sub-categories. This involved reducing the qualitative descriptions into ordinal variables, such as ‘lots more’, ‘slightly more’, and ‘stable’. Making such eyeball estimates was not difficult and arguably more efficient than quantitative techniques, as the human mind can quickly make compensations for the distortions of obliqueness or changes in forest quality (‘more forest area but sparser tree cover’). Fig. 2 summarizes these results, using graphical means to indicate the temporal period of each data point to avoid some of the ‘then and now’ issues mentioned above.

The sample of photo sites is far from spatially representative for the highlands region as a whole. While widely distributed in 28 *commune rurale* (the basic administrative division) across 13 *fivondronana* (districts), the photo sites are clearly clustered in specific areas (Fig. 4). More accessible areas are better represented: many photos are clustered near the main roads. The photos emphasize sites of interest to Norwegian missionaries (locations of missions and routes between them in their main intervention zone around Antsirabe); to academic historians, geographers, and naturalists (research sites, interesting phenomena, national parks); and to tourists (spectacular or characteristic views). The 1960s and early 1970s photographs in my collection rely heavily on the work of anthropologist Paul Ottino (1998), whose slide collection at the NMS Archive reflects both an interest in intensively cultivated landscapes of steep rice terraces and more typical tourist excursion views, and on geographer Jean-Pierre Raison (1984), who studied agricultural change, intensification, and settlement in several case studies around the highlands, notably in the Ambositra area and near Tsiroanomandidy (Fig. 1).

To compensate for this spatial bias, the first task is to detail the possible impacts. Given the above information, in this study it is likely that photos over-represent populous areas that are well connected to regional markets, thus over-emphasizing processes of agricultural intensification. The second task, if possible, is to corroborate one’s results with other forms of evidence such as case studies, oral history, remote sensing, and other research. In this article this is done when discussing the results and in the conclusion.

In addition, certain methodological solutions can be used to correct for spatial bias. One such solution is to group results by sub-region. This gives equal analytical weight to 10 photo pairs in one sub-region as to a single photo pair in another sub-region, thus reducing biases linked to over-representation of one sub-region. For example, Table 2 summarizes the conclusions of photo pairs in the Malagasy highlands by *fivondronana* (district). Thus, if there is more than one photo site, each district’s result represents the *median* result (if five photo pairs in a district have, for example, the following results: ‘lots more’, ‘lots more’, ‘more’, ‘slightly more’, and ‘less’, then the combined result will be ‘more’).

A further technique for dealing with spatial biases and intra-regional variation is cartographic representation. Each photo pair has a fixed location on a map, and

symbols can be used to signal trends such as ‘fewer trees’, ‘afforestation by pines’, or ‘clear evidence of soil degradation’. The collection of symbols on a map – or a series of maps representing different time slices – then aid in determining regional trends, and delimiting zones of similar trends. Fig. 4 maps the results of this research in highland Madagascar.

RESULTS IN THE MALAGASY HIGHLANDS CASE STUDY

The 56 repeat photograph pairs from highland Madagascar demonstrate both dynamism and continuity in the selective samples of the 20th century landscape that they show. The older photo pairs, spanning 70 years to more than 100 years, document a dramatic change as the ubiquitous grass-covered hills became transformed by pine and eucalyptus afforestation and rain-fed crop field expansion. More recent photo pairs, spanning only 30–40 years, typically show changes that are more incremental, such as thickening woodlots and minor agricultural improvements. Valley-bottom rice fields have remained remarkably permanent features of the landscape. While these general trends hold, individual photos provide evidence for specific stories of change. The following sections present the results of the repeat photo analysis for different landscape elements.

Woodlot trees

Regardless of time period or region, the photo pairs demonstrate a clear increase in woodlot trees (Fig. 5). Only 10 photo pairs (18%) showed no woodlot trees at all, and six of these were within Andringitra National Park (Fig. 1). Of photo pairs with woodlot trees present either now or historically, 85% showed an increase in tree cover or numbers. Only four cases showed a decline. The most common tree genus was pine (identified in 68% of photo pairs), followed by eucalyptus (38%) and acacia (9%). While pines are present nearly everywhere, eucalypts are more prominent in Antananarivo province east and west of the capital. While the long-term trend is of afforestation, photo pairs from the 1960s to the present show a definite cycling of tree cover, in which some plots have been cut while new ones have been planted.

Several factors explain the success of pine and eucalyptus in the landscape. Government policy for the past century has persistently encouraged or required tree planting, with a view to conserving soils and increasing supplies of timber and wood fuel. For example, Articles 27 and 28 of the 1930 Forest Decree (*Journal Officiel de Madagascar* 1930) allow villages or individuals who plant trees on nominally state-controlled hills to claim the land as their own. In addition, most villages have a designated forest plantation area, where farmers planted trees during the obligatory tree planting exercises of the 1960s or where the Forest Service assigned tree planting as punishment for illegal pasture fires. In addition, the Forest Service established forest stations across the highlands to provide seedlings and undertake large-scale plantation forestry. Market incentives also promote tree planting. Urban residents in highland cities create a large demand for both charcoal for cooking and construction wood. As a result, regions such as Manjakandriana 30 km east of the capital have seen more than two-thirds of their hills covered with eucalyptus woodlots (Gade & Perkins-Belgram 1986, Rakoto Ramiarantsoa 1995b, Bertrand 1999). Now, the growth of woodlot trees has taken on its own momentum, as the presence of pine, eucalyptus, and acacia has reached a critical mass for spontaneous invasion and spread. Pines are invading some of the region’s natural woody vegetation, such as the

tapia forests of Ambositra and the approaches to Andringitra National Park, while acacia are spreading in cooler regions such as Ambatolampy (Kull 2004) (Fig. 1).

Village trees: fruit, decorative, and shade

There is a net increase of fruit, ornamental, and shade trees across all time periods and in most regions (Fig. 6). Such village trees are present in 71% of all photo pairs; cases of increase outnumber cases of decrease by four to one. The few cases of decline tend to be either localized events in the foreground of the pictures, or due to the declining importance (or abandonment) of historical monarchical ruling sites, such as Ambohimanga Rova 20 km north of the capital or Amboniazy Rova alongside Lake Itasy 15 km south-west of Miarinarivo.

Around the world, people plant trees near their homes, and a variety of shade, fruit, and ornamental trees can be found in Malagasy settlements. Older villages are graced by 'traditional' trees and shrubs such as nonoka (*Ficus pyrifolia*), ambiaty (*Vernonia appendiculata*), and landemy (*Anthocleista madagascariensis*) (Rakoto Ramiarantsoa 1995a). These are joined in many areas by introduced species. In the western, warmer fringes of the highlands, no village is complete without its mango trees; in the central highlands there are guavas, loquats, mulberries, persimmons, peaches, plums, bananas, and avocado, among others (Moggi & Deleporte 1994). Recent NGO-sponsored extension efforts ensure that a variety of seedlings are available to farmers.

In some cases, fruit trees are not just restricted to house gardens and hedges, but are planted in orchards. Different areas of the highlands specialize in different fruit, benefiting from their environmental endowments as well as local know-how and tradition. East of Antsirabe, numerous small apple orchards occur scattered throughout the landscape, as well as a large formerly state-run apple farm. The Andina valley, 10 km west of Ambositra, is renowned for oranges and mandarins. Such increases in fruit trees represent economically oriented agricultural strategies, often involving relatively significant capital outlays and complex social relations in production (Kull 1998).

Natural forest and woody vegetation

Endemic woody vegetation is present in less than one-third of the photo pairs, reflecting its scarcity in the highland region. While it may be scarce, analysis of the repeat photographs shows that in many areas endemic woody vegetation has been stable over the past century. This is in sharp contrast to the dramatic deforestation ravaging the eastern rainforest (Green & Sussman 1990) and parts of the western dry forests (Réau 2002). It should be noted, however, that 12 of the 19 photo pairs with natural woody vegetation occur in just two specific ecological zones, so generalization to all forms of native woody vegetation is not warranted.

Six photo pairs document parts of what is now Andringitra National Park, located in a granitic mountain range with montane forest and sub-alpine prairie at the southern end of the highlands. Formally declared a strict nature reserve in 1927, fire and grazing have been banned for most of its history, though enforcement was often incomplete. Ecologists hypothesize that reduced grazing and burning has allowed woody ericaceous brush to spread in the sub-alpine prairie; meanwhile, however, uncontrolled fires have opened clearings in the montane forest (Kull 2004). The photo pairs largely demonstrate stability, with one case of slight decline (shorter and more

open ericaceous brush at the foot of 2658 m Pic Boby) and one dramatic case of increase (growth of forest due to fire exclusion at the base of the Riandahy and Riambavy waterfalls) (Koechlin et al. 1974, 416–417).

Six other photo pairs show the tapia (*Upaca bojeri*) woodlands between Ambositra and Antsirabe, mostly documenting a slight thickening or infilling of the woodlands. These woodlands have been shaped by humans for centuries – through periodic fire, selective cutting, and protection – in order to ensure a supply of wild silk and fruit (Kull 2004).

The remaining incidences of native vegetation are scattered about the region. Two photo pairs show vegetation alongside important rivers (the Mania, where it crosses the main road 20 km north of Ambositra, and the Lily, at its dramatic waterfall 25 km west of Miarinarivo), without major changes. Another shows stability in the dry woodland scattered among the granite blocks at the foot of a massive inselberg west of Ambalavao. The most dramatic change occurs in the Middle West near Tsiroanomandidy. Here, due to an expansion of valley-bottom rice cultivation and wood harvesting, the riparian gallery forest has been thinned by c.50%. As farmers settle more remote regions and bring them under cultivation – whether at the western frontier or in regional uplands – it is these riparian forests and associated wetland plants that rapidly give way to incipient rice fields (Rakoto Ramiarantsoa 1995a).

Crop fields

The photo pairs document an expanding and intensifying agricultural system, as illustrated by Figs. 7 and 8. Crop field extent increased in 19 photo pairs, while it decreased slightly in two pairs, and 16 photo pairs showed no change (Fig. 2). Rain-fed crop fields are making inroads onto available hillsides in all regions. Change in irrigated rice paddy extent, however, appears less dramatic. New paddies appear in some of the western photo pairs (Tsiroanomandidy, Itasy) and in some of the photo pairs with the longest time spans. Once established, however, irrigated paddy fields – whether valley-bottom fields or hillside terraces – are remarkably stable.

In addition to expansion, the use of individual crop fields appears to be intensifying. One-fifth of the photo pairs with crop fields show signs of increased labour inputs such as benching, erosion bunds, and incipient terraces.

This agricultural expansion and intensification has been due to the demands of a growing urban and rural population. The population of Madagascar grew from c.2.5 million in 1900 to an estimated 16.4 million during the 20th century. The demands of this growing population for both subsistence and market crops have led to new areas being brought under cultivation and the intensification of existing areas of cultivation. The particular trajectories of change are further shaped by labour migrations, government interventions, and local environmental characteristics (LeBourdieu 1974, Raison 1984, Rakoto Ramiarantsoa 1995a, Kull 1998, Laney 2002, Carswell 2003, McConnell et al. 2004).

Another aspect of crop field change that is shown by some of the photo pairs is field splitting. Seven of the 42 photo pairs with crop fields show some field splitting, as indicated by new bunds separating rice paddy parcels, or by spatial gaps between dryland crops. Such splitting may either be due to multi-cropping decisions, investments in better water and soil management techniques, or subdivision of parcels between separate farmers (though the latter will not always be visible in photos). In the 1970s and 1980s, it was commonly proposed in the literature on other regions

(reviewed, for example, in Turner et al. 1993) that population growth where no additional land is available leads to excessive subdivision of crop parcels among inheriting children – leading in turn to agricultural non-viability. The relatively small amount of field splitting shown in the photo pairs, the continued availability of open lands, as well as critiques of the excessive subdivision idea (for example, Turner et al. 1993) lead to the tentative conclusion that this process is not occurring on any important scale in highland Madagascar.

Grasslands

The expansion of tree cover and crop fields occurs at the expense of grasslands. The ubiquitous grasslands of the Malagasy highlands – characterized in many places by just a few pan-tropical species such as *Aristida* spp., *Heteropogon contortus*, *Hyparrhenia rufa*, *Loudetia simplex*, and *Ctenium concinnum* – serve largely as extensive rangelands. While herd owners rely on them for seasonal pasture, they are viewed by many farmers and the state as reserved open land, available for cropping or ‘reforestation’. The photo pairs demonstrate exactly such trends, showing a distinct loss of grasslands. (As grassland extent is inversely correlated with woodlot and crop field extent, I did not tabulate this variable separately. In addition, since most photo pairs were landscape views, not close-ups, and not taken during similar seasonal and lighting conditions, it was impossible to compare range condition and species composition.)

Erosion

Repeat photo pairs highlight visible forms of soil erosion, such as gullies and denuded land adjacent to trails. Less can be said about sheet and rill erosion, especially if seasons and lighting are not comparable (Stocking 1996). In addition, soil fertility changes can only be judged through inference from persistence of cropping systems.

The vast majority of photo pairs (66%), showed no directly observable change in soil erosion, defined in this instance as gullies and denuded land. Of the rest of the photos pairs, 10 showed increased erosion activity, and 9 showed a decrease or stabilization (Fig. 8). Most dramatic, perhaps, are new or expanded erosion gullies in photo pairs west of Miarinarivo (Figs. 1 and 9) and near Ilaka, 25 km north of Ambositra. A surprising finding is the stabilization of a number of erosion gullies – fresh scars visible in several older photos are now filled in with vegetation, some deliberately planted (e.g. bananas) and others probably spontaneous.

Houses

The remaining landscape element easily visible in repeat photography is infrastructure, particularly buildings. The number of houses increased in nearly half of all photo pairs. The three cases of declining house numbers corresponded to two pre-colonial political centres (Manazary Rova on the south shore of Lake Itasy, and Ambohimanga Rova near Antananarivo) that lost their administrative and ritual centrality, as well as a case of abandoned colonial industrial infrastructure near Lake Itasy. In some photo pairs, there is considerable renewal of housing stock – houses present in older photos have disappeared but are more than compensated for by new constructions nearby. In other cases, old buildings have remained in place but have been supplemented by newer constructions. The driving force behind the increase in

house numbers is clearly the population trends described above; indeed, house numbers can in many cases serve as a close proxy for population.

DISCUSSION AND CONCLUSION

This study has posed both a question that is both empirical and a methodological. Regarding the empirical question, the analysis of repeat photos suggests a number of trajectories of environmental transformation in sections of highland Madagascar. A century ago, open grasslands dominated the highlands. Human settlement was less dense, with correspondingly fewer houses and crop fields, though a strong network of valley-bottom rice fields was already established near villages. Trees were largely absent outside villages, riparian zones, and certain wooded areas such as the *tapia* woodlands. Over the past 100 years, the open grasslands have given way to an increasing cover of rain-fed crop fields and exotic tree plantations. Both farmers and state agents have planted fruit trees, eucalypts, pines, and acacias across the highlands. A growing population is clearly reflected in more houses, more crop fields, and more investment in soil conservation, such as benching and terraces. Visible trends in erosion are ambiguous, with problem spots offset by others where erosion has stabilized.

Overall, the photo pairs show a dynamic landscape very much shaped by humans seeking to make their homes and secure their livelihoods. If land degradation is defined as a reduced capability to meet needs (Blaikie & Brookfield 1987), then evidence from the repeat photos cannot be said to show this, as the photos show a farming system that is persistent, expanding, and intensifying. This corresponds with the findings of other studies in the region, based on intensive field research as well as air photo analysis (Rakoto Ramiarantsoa 1995a, Kull 1998, Blanc-Pamard & Rakoto Ramiarantsoa 2000). In all of these studies, some farmers are shown to be expanding the agricultural frontier – transposing their farming system to upland areas, or to outlying regions – while others are innovating in already-settled zones in response to market signals, by planting oranges, winter wheat, eucalypts, carrots, pineapples, etc.

These kinds of changes correspond with what might be expected based on studies in other world regions. The growth in fruit trees and woodlot forestry trees is akin to the observations of Rudel et al. (2002) of an incipient ‘tropical forest transition’, where increasing populations and a modernizing economy lead to re-growth of forest in deforested areas (albeit a very different kind of forest). Increased investment in soil conservation in populated areas reflects institutional, economic, and demographic incentives to manage the land for maximum benefit (Tiffen et al. 1994). Key forces behind all kinds of environmental changes have, in particular, been markets and institutions (Lambin et al. 2001) – in the Malagasy case, the market is largely for regional food production, and the institutions shaping the changes include the colonial and post-colonial governments, rural communities, and market commodity chains.

These empirical results bring us part of the way to answering the study’s methodological question: can repeat photography be a useful, efficient and effective method to survey regional land use change? As demonstrated above, the method provides useful empirical results that, while not fully representative or conclusive, correspond with the conclusions of other research techniques. The method has some clear advantages over other techniques such as remote sensing and air photo analysis (Table 3). In particular, as a result of the oblique perspective and high resolution (at least of the foreground), repeat photography allows easy identification and monitoring

of landscape features not reliably detectable in air photography, and near impossible to identify in satellite-based approaches. These include fruit trees, individual plant species, house renovations, erosion gullies, and field benching and bunds. Each of these features is important in the activities of rural farmers; each is a key component of agricultural change.

A further advantage is the depth of historical reach. Ground-based photography was present a century before satellite images, and half a century before systematic aerial photography. As a result, repeat photo analyses of land use change in Madagascar can address the entire colonial and post-colonial period.

Repeat photography demands only a relatively modest investment of time and money, particularly if it can be done opportunistically alongside other field research tasks. Table 3 compares the method with three other approaches in terms of cost, time, advantages, and disadvantages. Cost and time estimates for repeat photography are based on the hypothetical case where a researcher makes a concerted effort to focus on finding repeat photographs in one trip. (In reality, I undertook this research while in Madagascar on other projects, slowly collecting historical photos, building my local knowledge of places, and opportunistically seeking to re-photograph photos when passing through. Finding and re-photographing photo sites without exact coordinates or significant local knowledge requires a significant amount of time. Sometimes, I spent an entire day with a rented four-wheel drive unsuccessfully chasing an enigmatic historical photo.)

Table 3 shows that – based on the methods described and assumptions listed – air photos analysis is by far the most expensive approach, while repeat photography is the least expensive approach. The cost of repeat photography would reduce further if opportunistically incorporated as part of other research trips. As far as time investment, remote sensing analysis is the quickest, even including a one-week trip to field check land cover types for improved classification, while air photo analysis is the slowest. Due to the time-consuming nature of finding historical camera stations, repeat photography, takes perhaps twice as long as remote sensing, but half the time of air photo analysis. A fourth method compared, village studies based on rapid re-surveys of five villages profiled in the 1960s, would require medium amounts of time and money.

In sum, the most competitive approaches in terms of time and money are remote sensing and repeat photography, and each has rather distinct advantages and disadvantages. Remote sensing covers the full region for uniform time periods, and even allows the analysis of intervening years (at further cost, though). This challenges the non-random spatial distribution of data and the non-uniformity in time period found in repeat photography. On the other hand, repeat photography has much deeper historical reach, and can clearly show changes to farm and field-scale objects (individual trees, species types, gullies, plot boundaries) that are crucial manifestations of farmer interactions with the landscape but invisible to most satellite analyses.

Repeat photography as applied in this study is a useful way to gain an insight into trends of regional land-use change. Most efficient when undertaken opportunistically in conjunction with other field-based research activities, the method allows researchers to identify key trends for further investigation, to corroborate results from other techniques, to seek data as far back as the late 1800s, and to illustrate changes in ways that are easily accessible to all audiences.

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FIGURES

Fig. 1. The central highlands of Madagascar showing the areas referred to in the study.

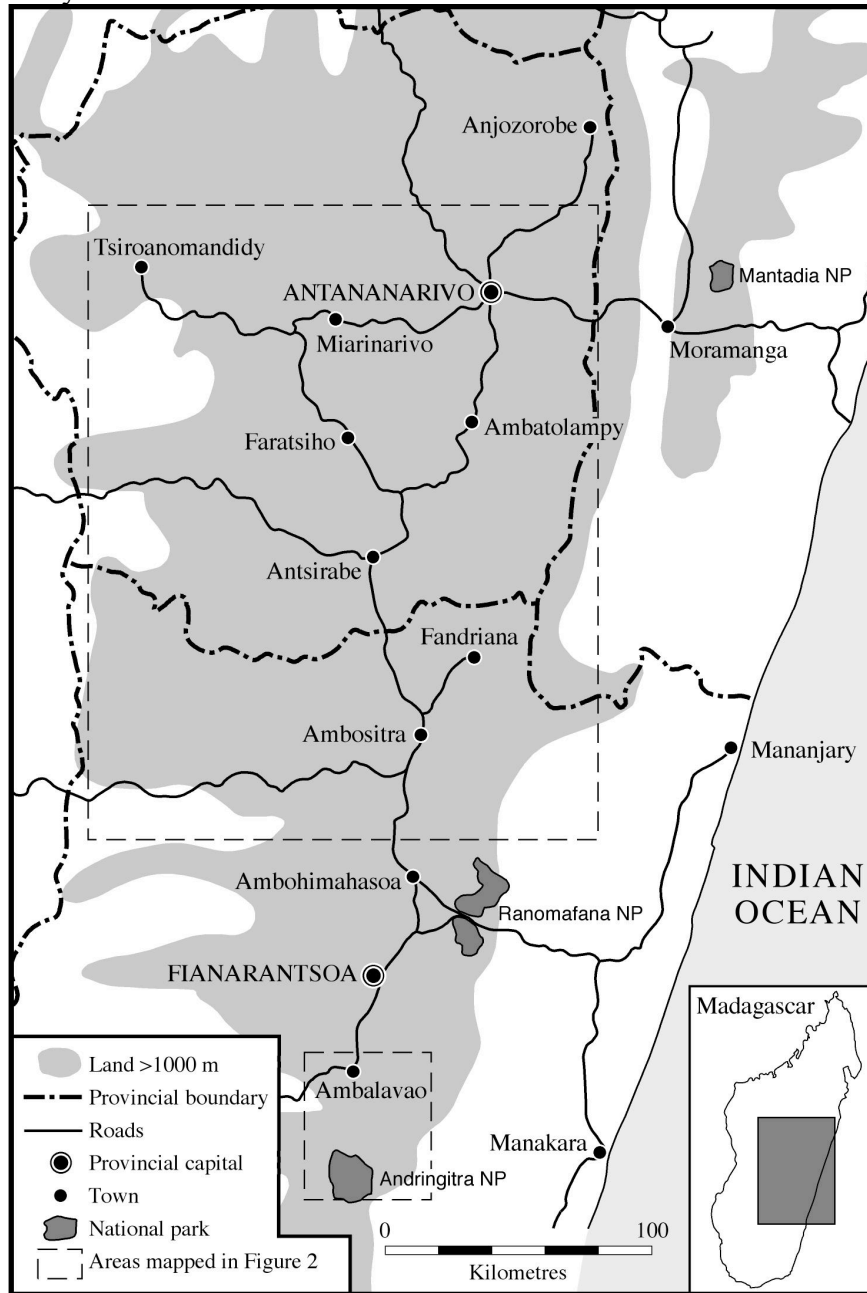
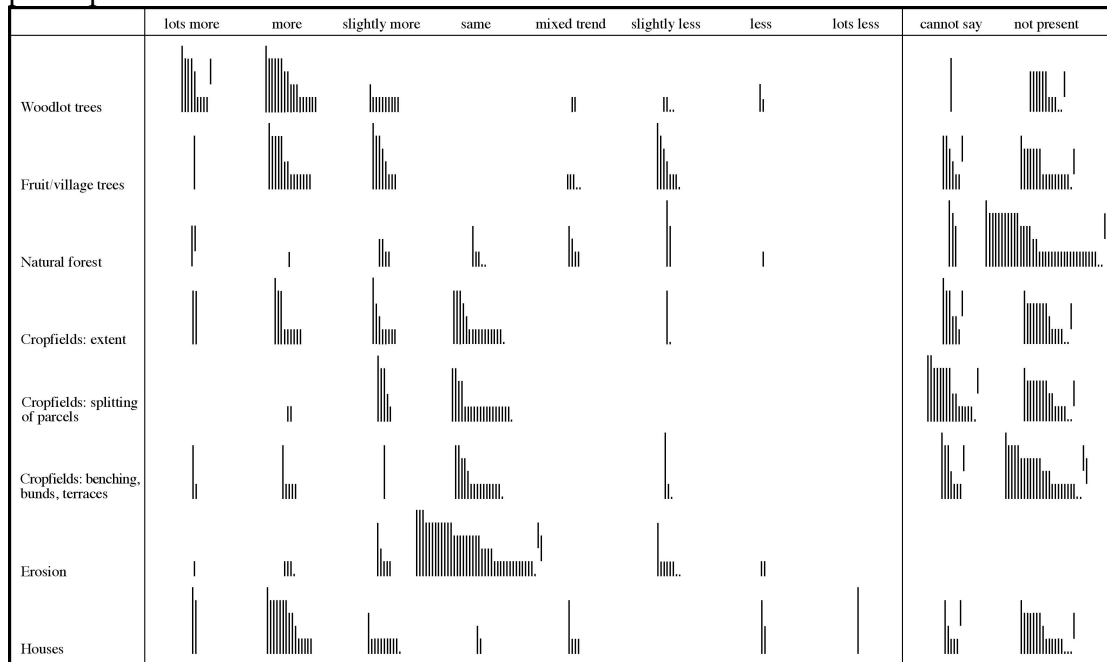


Fig. 2. Cumulative results of analysis of repeat photos showing the trends in land cover and the different time periods to which the trends apply. Each photo pair is represented by a vertical bar, the length of which represents the time period of that photo pair.



KEY

Vertical bar represents one photo site at one time period.
Length of bar represents time period.

From 1880 - 1899
1900 - 1919
1920 - 1939
1940 - 1959
1960 - 1979
To 1980 - 2003

Fig. 3. Pine afforestation and deforestation on Mt. Ivohitra, a volcanic cone on the eastern outskirts of the city of Antsirabe. All three images are details of larger photos taken from different camera stations with different foregrounds. 1900 photo taken from near former Ambohipiantrana leper colony (probably by J. Smith, NMS 000487-02124); c.1946 photo taken from Hôtel des Thermes balcony (photographer unknown, NMS 019701-02127); 1996 photo taken from residence in Norwegian school grounds (by author).

1900



1946



1996

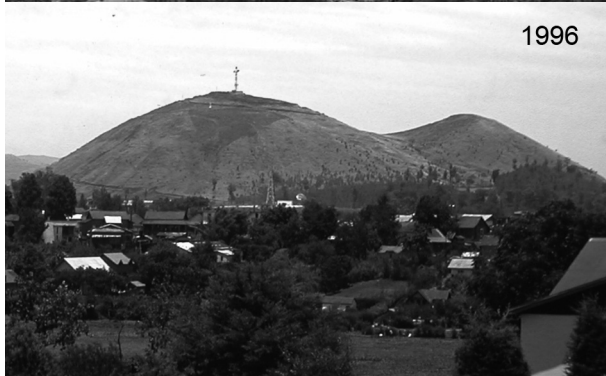


Fig. 4. Cartographic representation of repeat photo analysis results. Location of mapped area, including inset, indicated in Fig. 1.

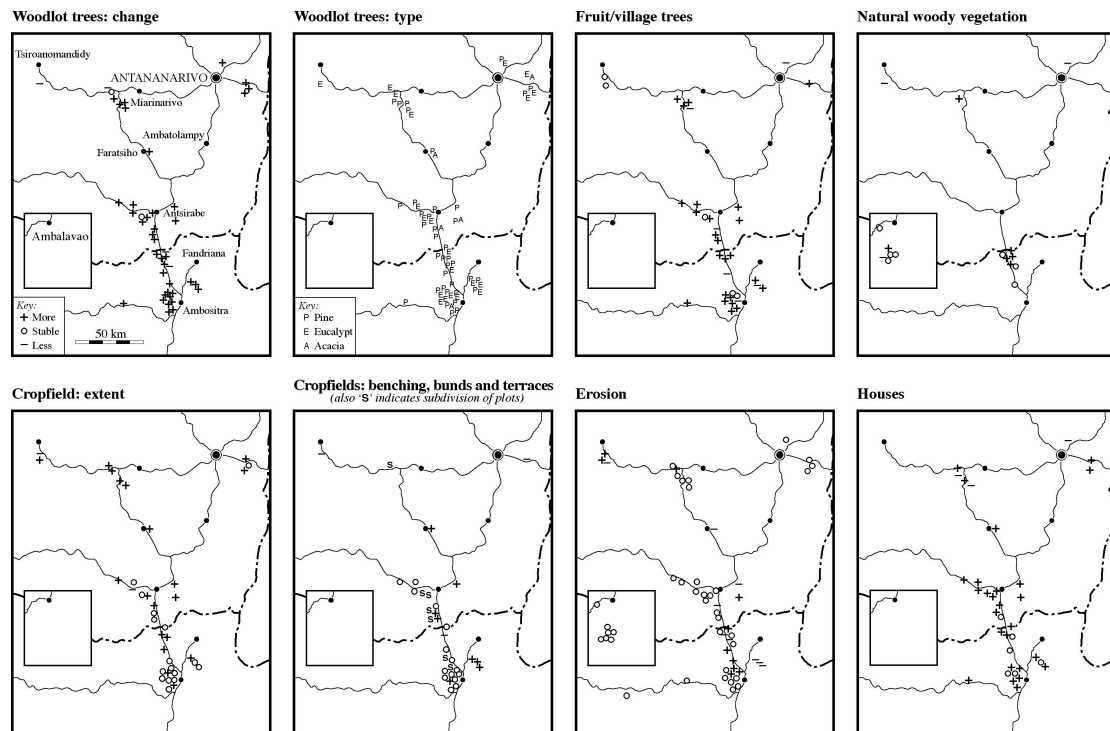


Fig. 5. Expanding pine forests at Loharano mission station. Near village of Ambohimiarivo, 13 km east of Antsirabe. The church was last used in 1958 and replaced by a new one in the village centre. The central building from 1900 is still standing (behind the tallest pines) and is in use as a Lutheran school for the blind. 1900 photo by T. Jørgensen (NMS A006Ma-00388); 1998 photo by author.



Fig. 6. The grave of missionary Peder A. Pedersen and intensifying land use in the background, Ambohiponana, Manandona, 20 km south of Antsirabe. Top pair of photos shows original photo and re-photography from same camera station. Due to the vegetation growth around the grave, it was necessary to seek an alternative camera station to re-photograph the background landscape (bottom pair). 1901 photo by J. Einrem (NMS AO13Ma-00550); 1998 photo by author.



Fig. 7. View northeast from Tritriva crater: the expansion of crop fields and woodlots. 15 km south-west of Antsirabe. The earlier photo is from slightly higher and more distant camera station, so foreground locations do not match up exactly – letters A, B, and C indicate points of actual alignment. The *c.*1893 photo by J. Smith (NMS A145Ma-02230); 1998 photo by author.

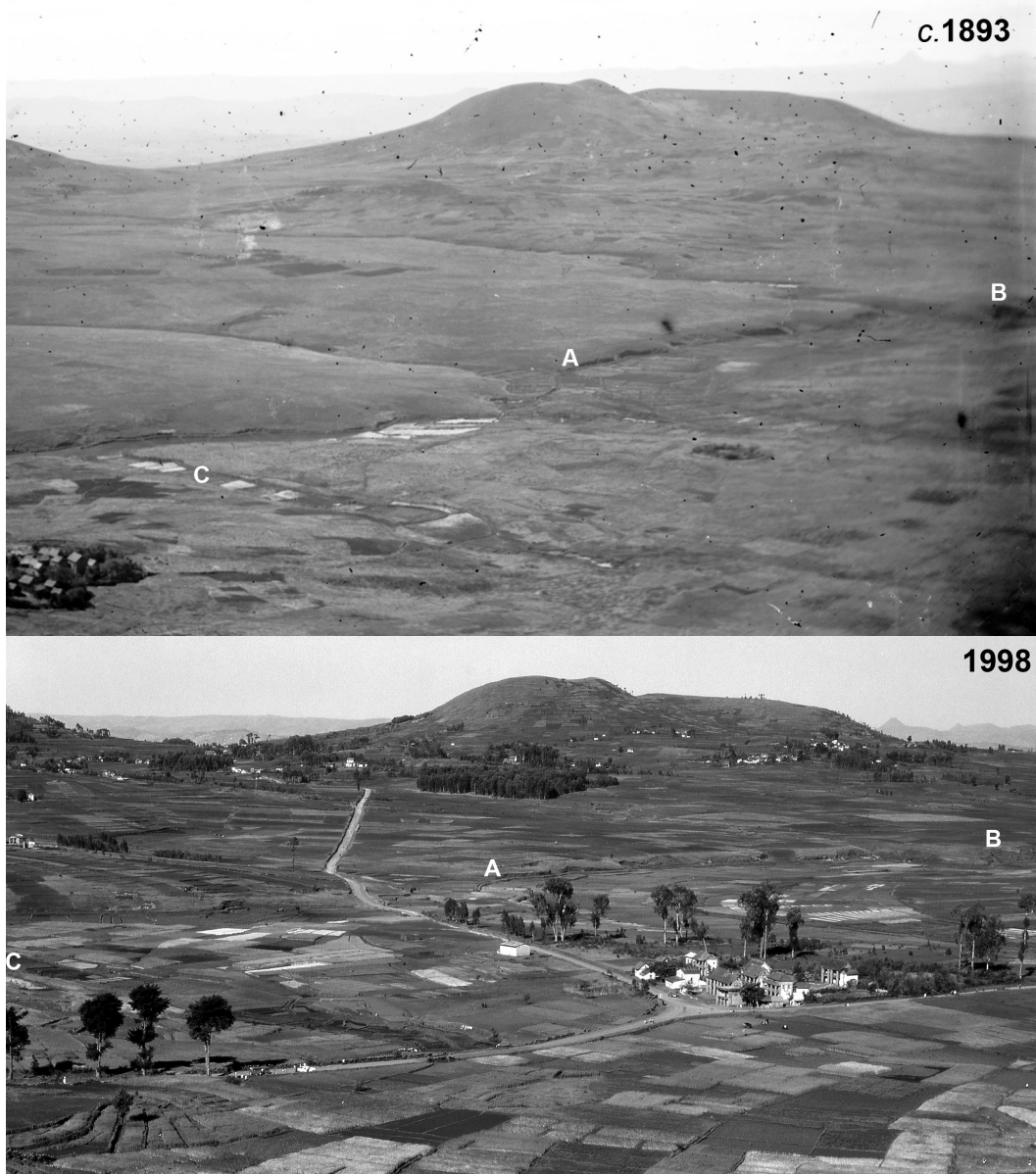


Fig. 8. Soavina village and mission station seen from the flank of Mioza mountain, 36 km west of Antsirabe. Changes in hillside moats and gullies necessitated a slightly different camera station, hence the inconsistency in the foreground. 1922 photo by T. M. Einrem (NMS AO12Ma-01749); 2003 photo by author.

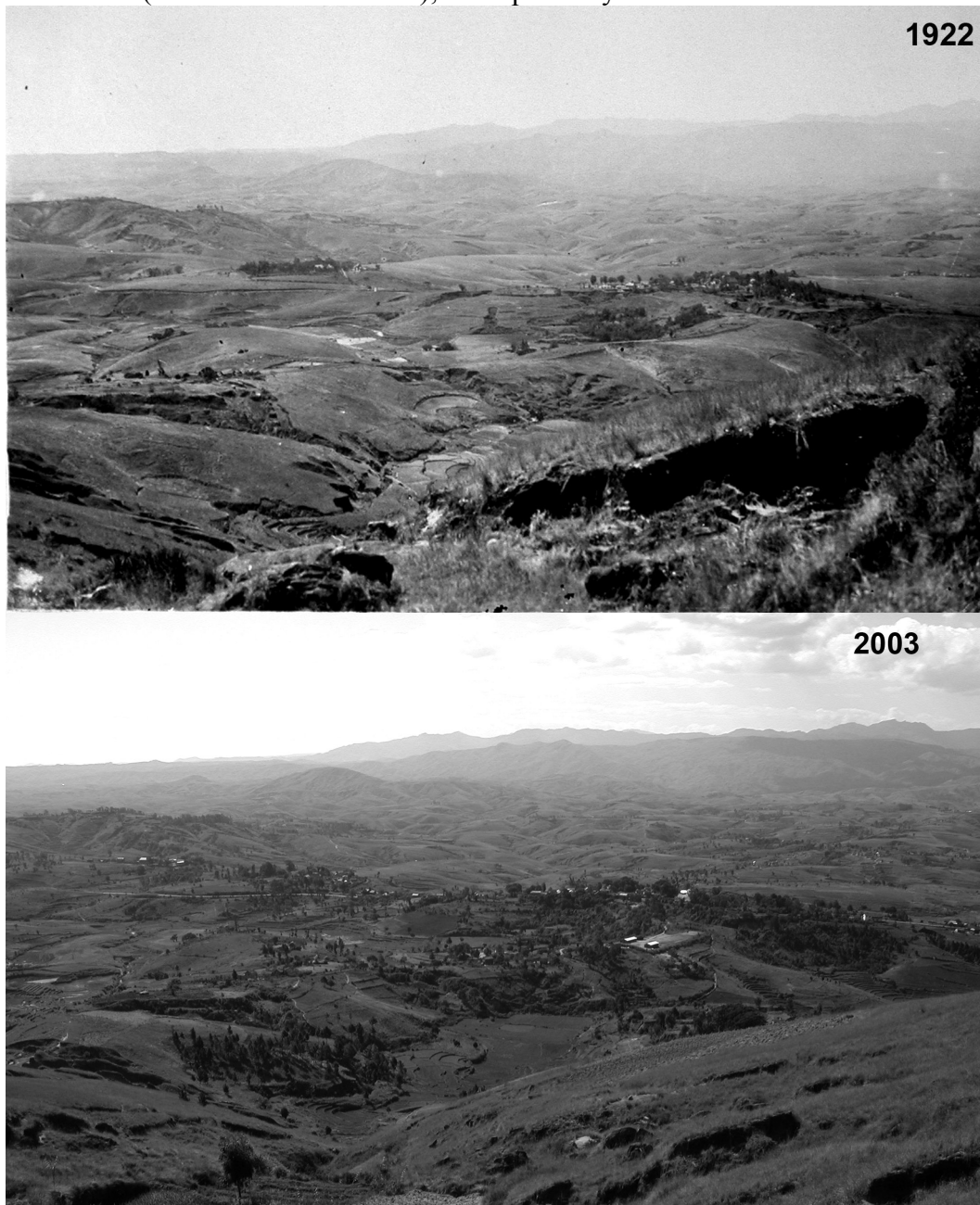
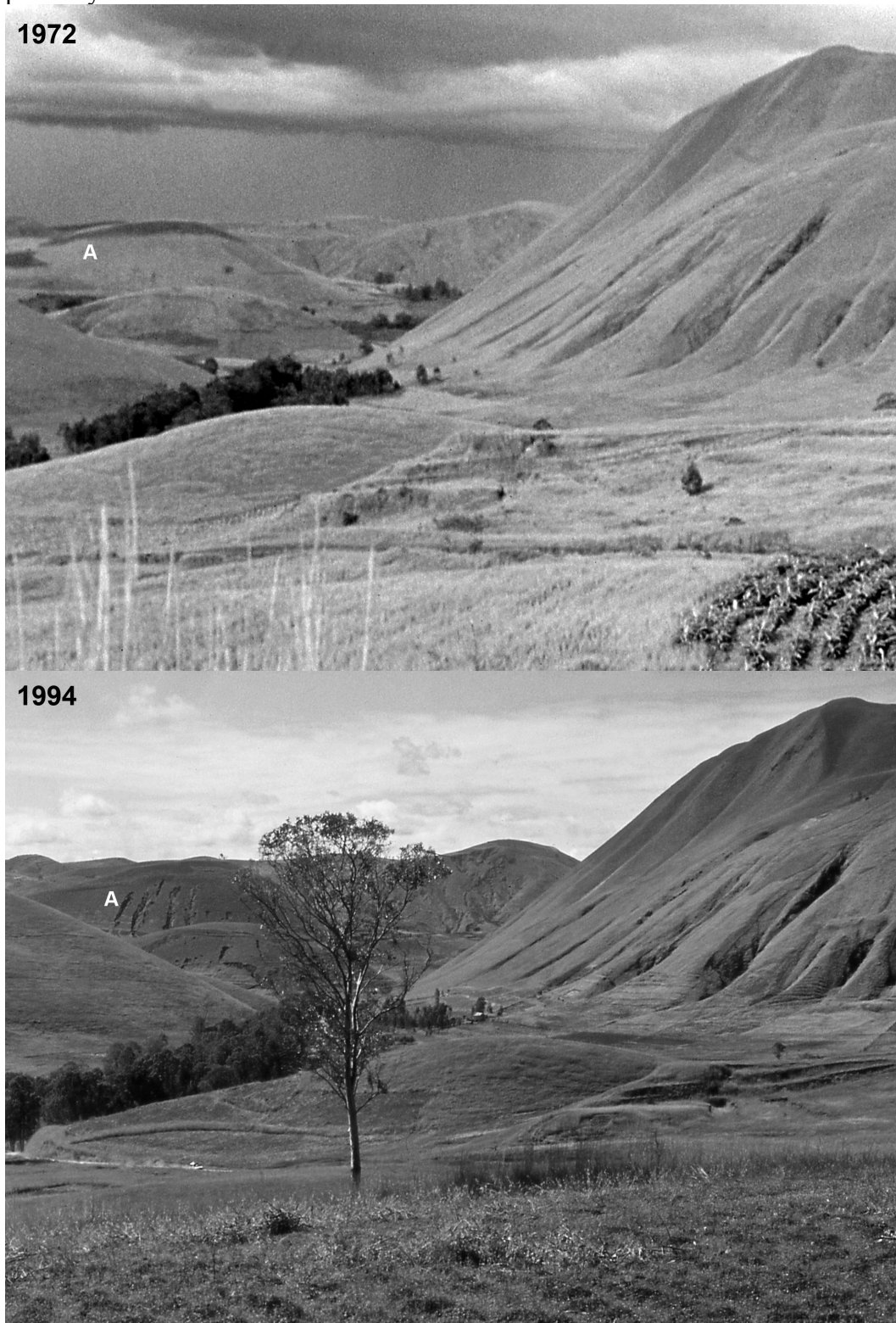


Fig. 9. Volcanic landscape along *Route Nationale Ibis*, c.26 km west of Miarinarivo. Note the new erosion gullies at 'A'. 1972 photo by P. Ottino (NMS uncoded); 1994 photo by author.



TABLES

Table 1. Qualitative analysis of photo pairs relating to Figs. 5–9, extracted from a database of 56 photo pairs.

	Forests	Village & fruit trees	Crop fields	Erosion	Houses, etc.
Fig. 5. Loharano mission (1900–1998)	major afforestation of hill in back (from 0 to 75% cover, in pine); maturation and increase of trees around mission	foreground open but 4 new peach/plum trees	pasture is now dryland crop fields (maize); crop field benching halfway up background slopes	gully in back now possibly stabilized (partly hidden)	Lutheran school for the blind still standing; old school replaced and more buildings
Fig. 6. Pedersen's gravesite (1901–1998)	back ridge change from open hill to landscape dotted with pine, brush	gravesite grown over with fruit/ornamental/weeds; village trees increased in background	additional benching (new intermediate benches)	no signs of erosion (cannot say)	grave surrounded by brick enclosure; one house gone, five new houses (near doubling)
Fig. 7. Tritriva view (c. 1893–1998)	dozen new eucalypt/pine trees in foreground; middle no trees; background change from no trees to 25% woodlots	new hamlets all have associated trees (ornamental/fruit?)	intensification of existing foreground crop fields (perhaps subdivided; new winter crops); middle & background only 20% crops before, now 80–100%	no signs of erosion (cannot say)	large increase in homes and new road; new houses in distance
Fig. 8. Soavina village (1922–2003)	in foreground left, 3 dozen new pines; new pines, etc. in village periphery, new woody vegetation in hollow mid-right; on ridge back left, woodlot growth from small to medium	village trees thicker	foreground rice fields stable, establishment of new hillside crop fields & benches mid-ground, otherwise hills unchanged	foreground gullies different angle but present in both; fosses/gullies mid-ground stable, frequently with bushes & trees inside	new school buildings and hamlet on mid-ridge in front of village; new houses (1) b/w two main village sites (2) to right along road (3) on ridge left of village to left
Fig. 9. Analavory volcanoes (1972–1994)	roadside/ripari an eucalypts are slightly thicker, but some distant small woodlots gone	none visible	foreground cultivation different but similarly widespread; crop fields expanding up base of volcano	no change on right; 9 new gullies in background	perhaps one new house

Table 2. Results summarized by *Fivondronana* (district). Results represent the median value of all photo pair results for each district, not including ‘cannot say’ and ‘not present’.

Province	District	No. of photo sites	Woodlot trees: change	Woodlot trees: main species	Fruit/village trees: change	Natural forest: change	Crop fields: extent	Crop fields: plot splitting	Crop fields: benching & bunds	Erosion	Houses
Fianarantsoa	<u>Ambalavao</u>	7				stable				stable	
	<u>Ambatofinandrahana</u>	2	lots more	pine						stable	more
	<u>Ambohitra</u>	17	slightly more	pine	slightly more	slightly more	stable	stable	stable	stable	slightly more
	<u>Fandriana</u>	3	lots more	mix	slightly more		stable	stable	more	less	slightly more
Antananarivo	<u>Antsirabe II</u>	6	more	pine	more		more	slightly more	more/slightly more	stable	more
	<u>Anstirabe I</u>	1	more	pine						stable	more
	<u>Betafo</u>	6	more	pine/mix	slightly more		stable	stable	stable	stable	more
	<u>Faratsiho</u>	1	more	pine			more	stable	more	slightly less	more
	<u>Soavinandriana</u>	3	more	pine	more	slightly more	lots more			stable	more/less
	<u>Miarinarivo</u>	3	stable	eucalyptus	slightly less		slightly more	slightly more		stable	slightly more/less
	<u>Tsiroanomandidy</u>	3	slightly less	eucalyptus	stable	less	more/less slightly		slightly less	more	
	<u>Antananarivo Avaradrano</u>	1	slightly more	mix	slightly less	slightly less				stable	lots less
	<u>Manjakandriana</u>	3	more	mix	slightly more		slightly more		slightly less	stable	more

Table 3. Comparison of repeat photography with other methods. The hypothetical purpose is to describe land use change in the highlands of Madagascar.

Method	Cost*	Time	Advantages	Disadvantages
<p>Repeat photography as described in this article (c.60 photo pairs)</p> <p><i>(assumes single trip of 4 weeks intensive effort; in reality, travel costs were subsumed into other research efforts)</i></p>	archive fees: \$ 250 films, etc.: \$ 250 travel: \$ 5500 total: \$ 6000	4 weeks travel plus 2 weeks analysis: 240 hours medium	<ul style="list-style-type: none"> historical depth of data (1890s on) fine detail of information 	<ul style="list-style-type: none"> spatially unrepresentative non-uniform time periods old photos sometimes poor quality
<p>Air photo survey based on random sample of 25 3 x 3 km² study sites using 1950 and 1991 photos (research currently underway by author)</p>	air photos: \$ 4000 GIS labour: \$ 7500 travel (to purchase air photos): \$ 3000 total: \$ 14,500	2 weeks travel to purchase plus 10 weeks analysis: 480 hours long	<ul style="list-style-type: none"> relative historical depth (1949 onwards) fairly detailed information mappable results 	<ul style="list-style-type: none"> old photos sometimes poor quality
<p>Satellite image remote sensing analysis comparing 1970s and 2000s images for entire region (along lines of McConnell 2002; McConnell et al. 2004)</p>	3 scenes 1970s: \$ 900 3 scenes 2000s: \$1800 analysis labour: \$ 1500 travel (to ground truth, 1 week): \$ 3250 total: \$ 7450	1 weeks travel for ground truth plus 2 week analysis: 120 hours quick	<ul style="list-style-type: none"> coverage of entire region mappable results 	<ul style="list-style-type: none"> no information prior to 1970s low pixel resolution misregistration and interpretation issues (McConnell 2002)
<p>Village re-studies of sample of 5 villages documented and mapped in the 1960s using field mapping and interviews (Kull 1998; Blanc-Pamard & Rakoto Ramiarantsoa 2000)</p>	maps & supplies: \$ 100 GIS labour to create maps: \$ 750 travel (6 weeks fieldwork): \$ 6500 total: \$ 7350	6 weeks fieldwork plus 2 weeks analysis: 320 hours medium-long	<ul style="list-style-type: none"> fine detail of information causal analysis included 	<ul style="list-style-type: none"> non-representative at regional level few baseline studies before 1960s

* Cost calculations assume cameras, GIS, and computing facilities are available. Values in USD. Trip costs calculated at \$ 2500 for international airfare, \$ 250 per week maintenance, and \$ 500 per week 4-wheel drive car hire (if necessary). Costs assume required technical assistance for GIS and remote sensing analysis of air photos and satellite images, hired at c.\$ 23 per hour.

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