4 Deforestation in Madagascar

Debates over the island's forest cover and challenges of measuring forest change

William J. McConnell and Christian A. Kull

Introduction

Forests – and their absence – are linchpins between Madagascar's biotic richness, its degradation by humans, and conservation action. Much of the justification for conservation action depends on descriptions of previously extensive forests being cut and burned, on documentation of the threats to the patches that remain, and on success in slowing or stopping deforestation. Forest cover change is a highly iconic outcome of the different kinds of human interactions with the environment since the island was settled (Figures 4.1 and 4.2; see also Chapter 3 by Dewar and Chapter 5 by Scales). This chapter investigates measurements of forest cover and its change on the island, and focuses attention on the technical challenges and social context of that scientific effort.

The evidence for the deforestation of indigenous woody vegetation in certain places and times is strong: early settlers' fires reduced the woody cover of the island's interior over a millennium ago (Burney et al., 2004), a deforestation frontier has progressively moved inland from the east coast over recent centuries (Brand, 1998), and dramatic clearance for maize cultivation has affected the southwest in recent decades (Harper et al., 2007). Yet the science of measuring forest area in different time periods, and of assessing change to that forest cover, using historical data, air photos, and satellite images is surprisingly messy and difficult. There are difficulties with categories, with scale, and with other aspects of change assessment. Furthermore, the science of measuring and quantifying deforestation takes place in a social context, one where certain discourses and metaphors condition the kinds of questions that are asked and the kinds of results that are highlighted (Larson, 2011). In the case of Madagascar, there is a dominant normative understanding of environmental change in which an idyllic and nature-rich island is rapidly despoiled by a burgeoning human population, trapped in a spiral of poverty and degradation (Kull, 2000). This has encouraged, we argue, the curious persistence in the literature of certain dubiously sourced and now outdated statistics claiming with relative certainty that 80 or 90 percent of the island's original forest is gone. The

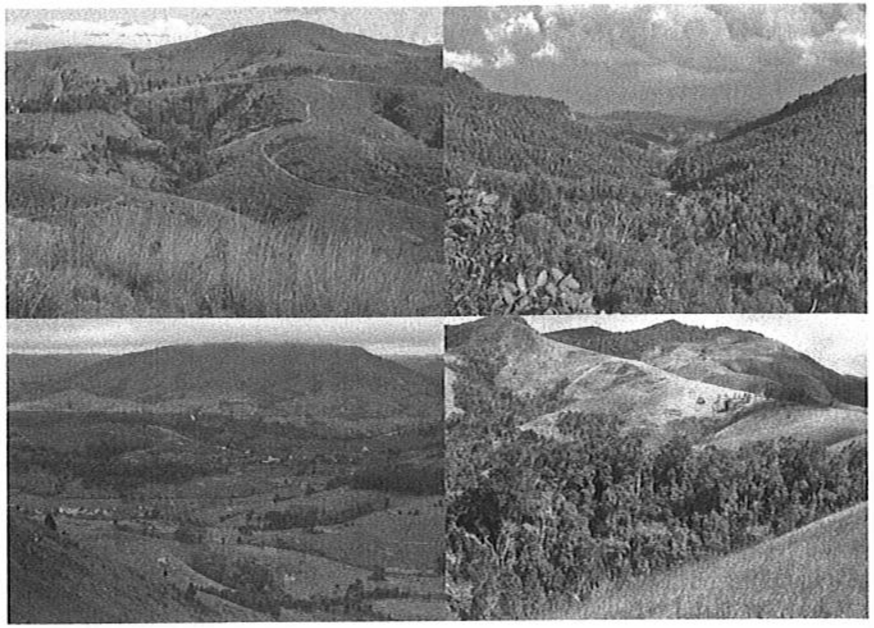

Figure 4.1 Forest patches in the highlands landscape. Are these images of deforestation or reforestation? Top left: NE of Antananarivo, trees on the ridge are clearly eucalypts and other species planted in grassland by people. Yet in the hillside hollow, which is also cultivated, are these remnant 'native' trees or planted fruit trees or both? Top right: eastwards view in Ialatsara forest station (southern highlands): large area of native forest (cut by rice fields) with large pine plantations in the distance. Bottom left: north of Anjozorobe, this is a landscape in process of colonization and afforestation (mostly with eucalypts). Bottom right: ecotone of native grassland and forest at the eastern end of Alaotra basin.

Source: C Kull (1996–2010).

loss of forest in some portions of the island is, as we have reviewed earlier, dramatic enough that such exaggerations are unnecessary. These exaggerations are even potentially harmful in that they can undermine scientific authority, put blinders on the types of questions that are asked, and push to the sidelines important debates about the impacts of strong conservation policies on rural people.

An assessment of deforestation in Madagascar requires an analysis of forest cover at different time points. We review the data and debates over historical and contemporary forest cover. This involves reviewing the theories and evidence for pre-settlement forest cover, and the published estimates of more recent conditions, beginning with the work of colonial botanists.

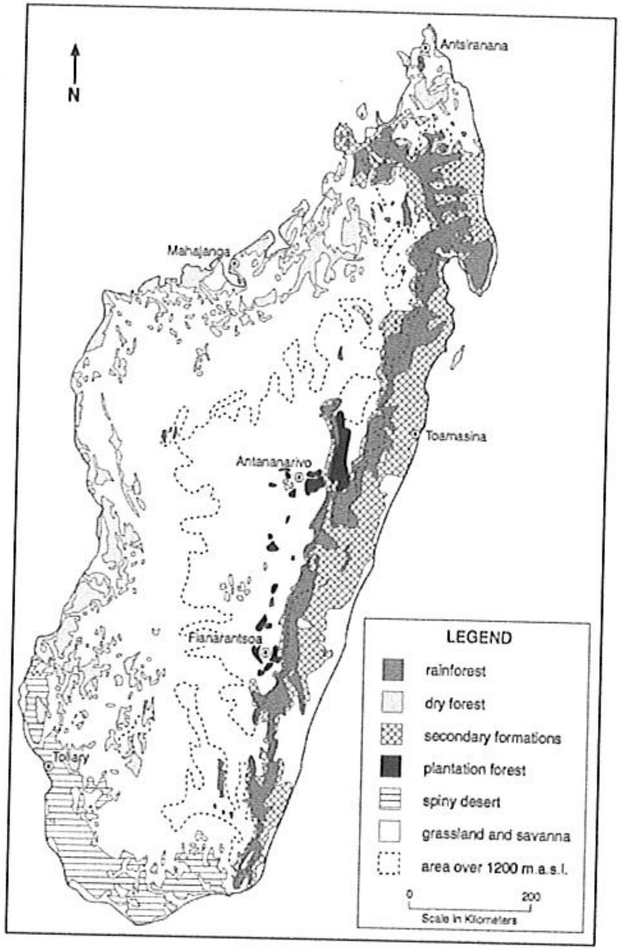

Figure 4.2 Current vegetation zones of Madagascar

Source: Kull (2000). Map is generalized from AGM (1969), Green and Sussman (1990), CI et al. (1995), and, in the case of the plantation forests, personal observations (meant to be representative, not necessarily precise).

Then we turn to subsequent analyses employing increasingly sophisticated technology for observing the land surface, first from the air and later from space. We explore the degree of divergence between the resulting estimates and then focus in on the challenge of estimating change. All along the way, our story becomes intertwined – of necessity – with a history and sociology of science, as the ideas that various authors argued for or against, and the approaches taken, reflect the worldviews and political contexts in which those authors were operating. This leads us to investigate, in the penultimate section, the social context in which a particular idea (the 80 or 90 percent deforestation hypothesis) has persisted. We conclude by presenting a number of recommendations for improved understanding in the spirit of evidence-based policy making.

How much forest was there 'originally'?

The question of what the landscapes of Madagascar looked like 'originally' is far from settled (see Chapter 3 by Dewar). The answer is likely to be quite different depending on the specific region concerned, and whether 'originally' is taken to mean before colonial records, before widespread evidence for settlement, before first human visits, at the end of the last ice age, or at some other point in time. Over the past 150 years, published claims about the island's 'original' vegetation have varied greatly, with some commentators presuming the existence of a dense, island-wide forest, and others defending the pre-human presence of grassy biomes, particularly in the highlands. The former claims were often rooted in ideological perspectives ranging from climax-based ecological theory, to temperate–climate conceptions of 'fire as disturbance', or colonial attitudes towards indigenous people's resource management. Evidence for these differing claims ranged from casual empirical observations of forest islands in grassland zones, to place names referring to no-longer extant forests, to oral histories of a 'great fire', or to rigorous analyses of biogeographical distributions, floral functional types, pedology, fossil beds, lake or marsh sediment pollens and charcoal.[1]

Particularly relevant to this chapter are the stances of colonial naturalists Perrier de la Bâthie (1921, 1936) and Humbert (1927, 1949, 1955), who argued that forest vegetation covered nearly all of Madagascar before human settlement.[2] Their conclusion has largely been taken at face value and repeated in numerous publications and reports, shaping, as we show later, the reporting of forest change statistics. Meanwhile, scientific debate about pre-human vegetation continues, with new forms of evidence emerging (Burney et al., 2003, 2004; Wilmé et al., 2006; Bond et al., 2008; Virah-Sawmy, 2009; Quéméré et al., 2012). Extrapolating from such research, it appears possible to make several conclusions. First, the strong version of the Perrier–Humbert island-wide forest hypothesis has been falsified, in that heathlands, grasslands, and a variety of non-forest vegetation covers predate humans on the island, maintained by lightning, moments of drier climate, and now-extinct mega-herbivores. Second, humans have certainly altered the vegetation cover of the island since their arrival, likely increasing grassland cover at the expense of woody vegetation. Third, the vegetation cover was quite dynamic before human arrival in response to climate shifts, with forest types expanding and contracting. Fourth, the story is quite different in different geographic regions. Finally, any estimate of [illegible] forest cover must be treated more as conjecture than as fact.

How much forest was there historically?

While it is not surprising that the extent and nature of the 'original' forest cover before written records remains contested, it is also the case that forest cover during the late pre-colonial and colonial periods (late 1800s–1960) is still not fully settled. The estimates of missionaries, colonial scientists, and foresters – based at first on field assessments and, after 1949, on measurements from air photos – resulted at times in wildly different numbers, reflecting differences in approach and materials, and these estimates have often been reproduced uncritically in more recent assessments.

Early mapping efforts can be attributed to missionary scientists such as James Sibree, whose 1879 map shows the distribution of dense forests (Figure 4.3). Like such maps, the quality of the first published *quantitative* estimates of Madagascar's vegetative mantle was limited by the size of the island and the inaccessibility of many areas. Estimates varied widely and exhibited no clear trend (Table 4.1).

Guichon (1960) made the first attempt to use remote sensing data to comprehensively estimate the island's forest cover. Advances in aerial photography during World War II had enabled the French to acquire imagery between 1949 and 1957 that served as the basis for the country's 1:100,000 topographic map series and a more systematic quantification of Madagascar's land cover. The cartography was not yet complete when Guichon's paper was published, but he drew reassurance that his 'first approximation' of 12,472,923 ha of lightly and non-degraded forest corresponded with the estimate of Girod-Genet and the later estimate of Lavauden, and that his estimate of 16,731,722 ha of total forest (including degraded stands) closely matched the more recent estimate of Perrier de la Bathie (1936). When including *savane arborée*, or wooded savanna, Guichon's estimate rose to 19,380,722 ha.[3]

The same air photos were later used by H. Humbert and colleagues to create a landmark map of vegetation zones. In the report accompanying the map, they estimate 19,819,000 ha of 'forest formations' (Humbert and Cours Darne, 1965, after p82), but do not specify what vegetation categories are included or excluded. Subsequent work based on the same aerial photography data led to somewhat different totals, illustrating the confusion that is quite common surrounding the use and re-use of land cover data by different researchers. This can be illustrated by the authoritative 1996 report on the national forest inventory (*Inventaire Ecologique Forestier National*, or IEFN). In its 'Table 5.02', the IEFN report provided four different forest cover estimates for 1949–1957, presumably all based on the same aerial photographs (DEF et al., 1996). What is striking is the inconsistency with which these estimates were handled. As Table 4.2 shows, different categories of forest are included (or not) in the 'total forest cover' figures, inconsistent figures (due to methodological differences or rounding, we presume) are not explained, and the source references are confused.

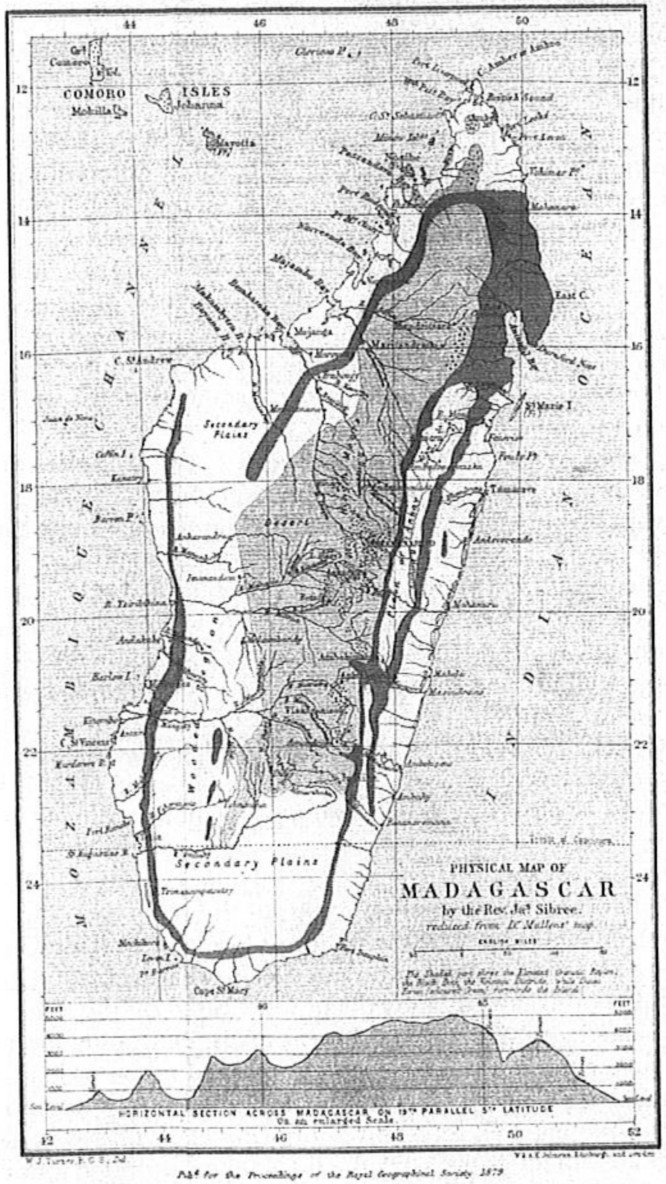

Figure 4.3 James Sibree's (1879) Physical Map of Madagascar emphasizes the extent of barren hills encountered by early visitors ('desert' and 'high moors') and gives a potentially reasonable, albeit rough, representation of the distribution of 'dense forests' at the time in dark shading. Light shading denotes the 'elevated granitic regions'.

Table 4.1 Colonial period estimates of Madagascar's forest cover

Auteurs	Date	Superficie en millions d'hectares	
—	—	—	
LAVAUDEN	1895	20	(1)
GIROD-GENET	1899	12	
P. DE LA BATHIE	1921	7	
Prof. HUMBERT	1927	2 ou 3	(3)
LAVAUDEN	1931	10	
P. DE LA BATHIE	1936	17	
M. R. HEIM	1955	1,5	

Notes: reproduced with permission from Guichon (1960, p409). Estimates vary widely, and show no clear trend, particularly considering Guichon's notes in which he suggests that (1) Lavauden's 1895 estimate was probably exaggerated and (2) that Humbert's 1927 estimate excluded several important types of forest cover.

A second example of how old data are used and misused comes from Harper et al. (2007), which contains the most recent published estimate we are aware of based on the same air photographs. They digitized the Humbert and Cours Darne (1965) map and present an estimate of 1949–1957 forest cover different again from all previous interpretations. Echoing the inconsistencies in the IEFN report, Harper et al. leave a confused reference trail and fully explain neither their choice of forest types included in the figure nor how their numbers were derived (Table 4.2).

The examples above show how maddeningly frustrating efforts to quantify forest cover have been. Not only have scientists struggled with the difficult and vast terrain and the enormity of the task of nation-wide air photo analysis, but their tendency to discriminate, lump together, and emphasize different categories of forest cover have led to much confusion, which, it appears, is exacerbated by later inattention in re-using older work.

So, how much forest was there historically? Clearly, the eyeball estimates from the late 1800s onwards are quite divergent and not usable without diligent triangulation with other region- and date-specific sources. As far as the air photos acquired between 1949 and 1957, one may possibly conclude that the areal extent of the main 'forest' categories (excluding savannas) was on the order of 16 million hectares. The highly variable forest cover figures circulating in the literature result from differing definitions of forest, with changes in cartographic technology also contributing. These issues are developed more fully below, following a review of the work estimating forest cover from space.

How much forest was there recently?

A new round of nation-wide estimates of forest cover emerged in the 1980s, benefitting from the new, space age technologies of satellite-based remote sensing. As far as we can ascertain the first published map of Madagascar's

Table 4.2 Inconsistent re-interpretations of total forest cover according to the 1949–1957 air photos (and the topographic maps derived from them)

Forest cover 1949–1957	*Source*	*Types of forest included*	*Other comments*
As presented by IEFN (DEF et al., 1996) in 'Table 5.02' as total of evergreen and other forest formations			
16,695,000 ha	Guichon, 1960	No explanation provided in IEFN; our assessment is that the figure presented is for all forest *except* raphia and savanna.	Slight divergence from Guichon's own figure likely due to rounding.
19,148,000 ha	Humbert and Cours-Darne, 1965	No explanation provided in IEFN; based on Dufils (2003), we take this figure to include degraded and/or secondary forests, as well as mangrove, gallery, and plantation forests.	Divergence from Humbert and Cours-Darne's own (1965) estimate (19,819,000 ha) probably due to different methods (they likely used a manual planimeter, while the IEFN likely calculated from digitized versions of the maps).
12,378,000 ha	Eaux et Forêts, 1953–1974	No explanation provided in IEFN.	Confusion over what the actual source was: the IEFN bibliography only refers to 'Direction des Eaux et Forêts et de la Conservation des Sols (1971) Inventaire forestier à Madagascar, 70 pages'.
10,300,000 ha	Lanley [sic], 1986 [sic]	According to the IEFN, only closed-canopy broadleaf formations, and based on incomplete 1:100,000 map series, perhaps excluding southern forest and bush/scrub.	Considerable confusion over source and interpretation of data: the IEFN cites Nelson and Horning (1993), who in turn report having obtained the Lanley [sic] (1981) estimate from Grainger (1984). The actual source appears to be Lanly (1981) which indicates that this forest cover figure is meant to be an estimate based on the 1949–1957 air photos and *extrapolated to 1980* based on deforestation trends.
As presented by Harper et al. (2007) in 'Table 2' as 'total forest area'			
15,995,900 ha (159,959 km^2)	Blasco 1965; Humbert and Cours-Darne, 1965	According to Harper et al., this figure applies to 'forest and mangrove suffering little or no degradation'. Strangely, the terms 'little or no degradation' are not found in the Humbert and Cours Darne (1965) map, though they are reminiscent of Guichon's (1960) table. Harper et al. explicitly state that their study considers forest cover to consist of 'primary vegetation dominated by tree cover at least seven meters in height'.	Harper et al.'s bibliographic references are problematic. Blasco (1965) is actually a chapter in the Humbert and Cours-Darne (1965) volume bearing the title they provide (Blasco is also the first of four cartographers named on the Humbert and Cours-Darne (1965) maps, and perhaps this is the reason he is cited). The figure 15,995,900 ha does not appear anywhere in the document and must derive from Harper et al.'s digitization of the maps (and the difference with other figures above is due to not including savanna and to methodological divergences between digital areal calculations versus measurements made with a manual planimeter).

forest cover from satellite imagery employed visual interpretation of printed images from the Landsat Multispectral Scanner (MSS) sensor acquired in the 1970s (Faramalala, 1988a). It did not include a numeric estimate of forest cover, explaining that cloud cover made this impossible (Faramalala, 1988a, p147). However, the map was later digitized (Faramalala, 1995) and used by Du Puy and Moat (1999), who report that it revealed 10,784,000 ha of 'primary vegetation' including evergreen and deciduous forest, as well as mangrove and marshland. The IEFN report (DEF et al., 1996, p75) cites 'statistics published by Faramalala (1995)' as the source for an estimate of 15,812,000 ha of forest.[4] This includes 10,676,000 ha of evergreen forest, likely differing from the Du Puy and Moat (1999) estimate in the exclusion of mangrove and/or marshland. Later, Mayaux et al. (2000) reported that data from Faramala (1981)[sic][5] reveal 10,603,200 ha of dense humid and dense dry forest, as well as mangrove. When they add 'secondary complex' they find a total of 15,484,400 ha. It is difficult to understand the reasons for the discrepancies (albeit minor) between these figures and those reported by DEF et al. (1996), as they are presumably based on the same digital polygons.

More recently, Harper et al. (2007) exploited MSS data from the same period as Faramalala, reporting a total of 14,731,000 ha of humid, dry, and spiny forest (mangrove is listed as 'not available'). Their study's 'Table 3' contains an arithmetic error and the total of the three listed categories is actually 13,933,500 ha. The total forest estimate differs by as much as 12 percent from those reported by the IEFN (DEF et al., 1996) and Mayaux et al. (2000). It is likely that much of the difference is attributable to different methodologies: while Faramalala used visual interpretation of printed satellite images, Harper et al. re-classified images from the same time period digitally using a supervised classification technique (see Box 4.1).[6]

Subsequent island-wide studies have employed a variety of satellite sources, taking advantage of not only Landsat but also other platforms. For example, Nelson and Horning (1993) used three Local Area Coverage (LAC) scenes acquired in 1990 and 1991 by the Advanced Very High Resolution Radiometer (AVHRR) sensor to derive an estimate of 6,091,800 ha of forest in four bioclimatic vegetation zones (rainforest, hardwood, grass, and spiny). The study employed an automated classification procedure with Landsat MSS photoproducts serving to 'train' the classifier, and the Faramalala (1981[sic]) data as a reference map to evaluate the quality of the product.[7]

The IEFN report (DEF et al., 1996) contributed a new mapping of forest cover based on visual interpretation of Landsat TM (Thematic Mapper) data from 1990–1994. Importantly, this mapping was accompanied by extensive, detailed fieldwork in different vegetation types. This analysis resulted in an estimate of 13,260,000 ha of forest, including 6,062,000 ha of evergreen forest.

The next island-wide assessment (Mayaux et al., 2000) used data from the SPOT-4 VEGETATION instrument, which collects data at roughly the same spatial resolution as AVHRR-LAC. The study used 36 ten-day image

composites from 1998 and 1999 (the ten-day composites minimize cloud contamination, while the time series takes advantage of vegetation phenology). As in the Nelson and Horning (1993) study, semi-automated classification was performed using Faramalala (1981[sic]) and other reference data. Mayaux et al. (2000) reported a total of 17,303,200 ha of forest, including 10,104,100 ha of 'dense humid', 'dense dry', and 'mangrove' along with 7,199,100 ha of 'secondary' forest.

The most recent assessment of Madagascar's land cover published in the peer-reviewed literature is presented in Harper et al. (2007). Forest cover in the 1990s was analyzed using Landsat TM data yielding a figure of 10,605,700 ha (combining four categories of 'primary' humid, dry, spiny, and mangrove forest); the situation around the year 2000, using Landsat ETM+ (Enhanced Thematic Mapper) yielded an estimate of just 8,982,100 ha. This is considerably less than the most comparable estimate (Mayaux et al., 2000).

A subsequent map published by a consortium of United States Agency for International Development (USAID) partners (CI et al., 2007) extends Harper et al.'s analysis to 2005 using much of the same data and techniques. Curiously, while the map's tabular estimate for c.1990 is quite similar to the figure published in Harper et al. (2007), the map's estimate for c.2000 (9,677,701 ha) is considerably higher than the earlier figure (8,982,100 ha) and closer to the Mayaux et al. (2000) estimate. They estimate forest cover c.2005 at 9,216,617 ha. No explanation is provided on the map of the reason for the revision. From these estimates, one may surmise that something like ten million hectares of 'primary' forest existed around the end of the twentieth century.

The divergent results of the above studies emphasize the ways in which different techniques – based on different definitions, assumptions, satellite data sources, and classification methodologies – influence measurements of current forest cover. In the next section, we see the implications of these issues for measuring forest cover change. First, however, we should mention that in addition to the national-scale remotely sensed analysis of forest cover reviewed above, numerous studies have undertaken original analyses of remote sensing data for sub-national land cover analysis in Madagascar. They are too numerous to review here (some important examples include Green and Sussman 1990, which we discuss below, as well as Laney, 2002; McConnell et al., 2004; Agarwal et al., 2005; Irwin et al., 2005; Vågen, 2006; Elmqvist et al., 2007; Scales, 2011; Quéméré et al., 2012). With respect to these regional studies, what should always be kept in mind (particularly when dealing with *trends* in forest cover, the topic of the next section) is that choices over scale and boundaries can have a major impact on study findings; inclusion of large non-forest areas will lower forest cover rates substantially, as can coarsening the scale of analysis, by excluding small patches.

What are the *trends* in forest cover? The challenges of quantitative change assessment

The simplest way to represent change in forest cover is to compile estimates for particular time points and present them in tabular or graphic form. This is the approach employed by Guichon (1960) (Table 4.1) and subsequent authors, including Nelson and Horning (1993), the IEFN (DEF et al., 1996), McConnell (2002), and Dufils (2003). As explained above using the case of Guichon (1960), rather than contributing to an understanding of the evolution of forest cover on the island, this approach has instead served to illustrate the incommensurate nature of the individual estimates and to caution us against simple comparison. Guichon (1960, p408) suggested three key reasons for the significant disparity in the estimates: '(1) the definitions of different types of forest formations vary among the authors; (2) cartographic documentation was absent, insufficient or imprecise; and (3) sometimes, the figures were deformed, consciously or not, in order to prove a thesis or to justify a position' (authors' translation).

Below, we examine quantitative, remote-sensing-based estimates of forest cover change in Madagascar in light of Guichon's first two, rather technical, constraints. The following section then addresses the third, perhaps more contentious, issue. It is not just in Madagascar that widely varying definitions of forest have confounded those hoping to understand deforestation. Indeed, the FAO (the UN's Food and Agricultural Organization, the foremost authority on global forest cover) amended its canopy closure threshold in between two of its decadal global Forest Resource Assessments in order to be able to account for important changes in woody cover in semi-arid parts of Africa, much of which would have been missed under the prior definition. The effort required to revise prior estimates to match the new definition was substantial, and the procedure undermines confidence in the comparability of the data across assessments (Rudel et al., 2005).

This issue is accentuated in Madagascar by the wide range of environmental conditions in which trees grow on the island. While relatively undisturbed forest on the eastern escarpment would meet just about anyone's definition of forest, smaller patches in this landscape, as well as gallery forests and sparser woodlands of the highlands and west coast may not, particularly in analyses relying on satellite sensors that form images of the earth's surface in 30 m, 80 m, or even 1 km pixels. The issue is even more pronounced in the 'spiny forest' of the arid south, while mangrove formations present their own unique set of challenges, due to the high degree of moisture below the canopy, complicating the spectral signature registered by the satellite. The problem of inconsistent characterization of Madagascar's land cover was perhaps most usefully addressed by Lowry et al. (1997), who review the history of vegetation classification in Madagascar and argue for an 'objective approach to chorological analysis and physiognomic classification in Madagascar' (p110). As described in the preceding section, mapping

efforts in Madagascar have typically defined forest according to the capabilities of the sensors they employ and the analysts' particular goals. This has been a major constraint on efforts to precisely estimate change in the island's forest cover.

Perhaps the most widely cited study of deforestation in Madagascar using remotely sensed data was conducted by Green and Sussman (1990). The study compared 'original' forests (no source cited) and the Humbert and Cours Darne maps of forest cover (based on 1949–1957 aerial photography) with the authors' own interpretation of Landsat MSS imagery from 1985, concluding that the island's eastern rainforests diminished at a rate of 1.5 percent per year from the 1950s to the 1980s. We cannot know to what degree the forest cover types analyzed across periods differed, because of the second problem identified by Guichon: insufficiency of cartographic documentation. Unfortunately, in the Green and Sussman (1990) article the methods were described quite briefly, with no discussion of the comparability of the techniques employed to analyze the two very different data sources.

A subsequent, island-wide comparative study by Dufils (2003) also used data from the Humbert and Cours Darne (1965) maps, as well as those from the IEFN (DEF et al., 1996) and Mayaux et al. (2000).[8] Where Dufils differed from Green and Sussman (1990) was in taking into account the issue of forest cover types. Specifically, he attempted to isolate a comparable 'evergreen' class from the vegetation cover classes presented in these three sources, even as he acknowledged the difference in classification schemes across these studies. Unsurprisingly his harmonization of categories was imperfect and casts doubt on the trends reported.[9] A consequence is that, for example, the mismatch of forest types between the two source datasets would likely have led to the inflation of the deforestation rate of 1.6 percent per year which Dufils reports for the 1990s (as forest present in the later period was excluded). Unfortunately, the study is also afflicted with typographic errors,[10] and problematic assumptions about time points.[11] To the author's credit, the text acknowledges some of the key challenges in estimating rates of change, particularly the different estimates likely to come from different remote sensing systems. However, given the issues described here, the published conclusions must be used with caution.

In order to increase the comparability of single date estimates used in calculating change, a later study (Harper et al., 2007) undertook fresh interpretations of satellite imagery from the 1970s (MSS), c.1990 (TM) and c.2000 (ETM), in conjunction with the Humbert and Cours Darne (1965) maps. Laudably, the study set out to create comparable maps by applying a common set of criteria for defining forest (see Box 4.1).

Using this approach, they calculate annual deforestation rates in four geographic zones, over three periods. Results range from modestly negative (i.e. increase in forest cover) to strongly positive rates of nearly two percent per year in certain parts of the island. At the level of the entire country, their analysis suggests that deforestation was more rapid during the 1970s

Box 4.1 Using satellite imagery to classify land cover

Satellite images are made up of layers of data collected in different parts of the electromagnetic spectrum. These are referred to as spectral bands. Different surfaces absorb, radiate, and reflect electromagnetic radiation in different ways, yielding distinct 'spectral signatures'. Using these properties, each pixel in a satellite image can be classified into a land cover category (e.g. forest, grassland) based on the spectral signature of the ground cover (e.g. trees, grass, bare earth).

The science of deriving land cover maps from remotely sensed imagery (whether from an orbital or airborne platform) entails a number of key decisions that have major impacts on the outcome (Figure 4.4).

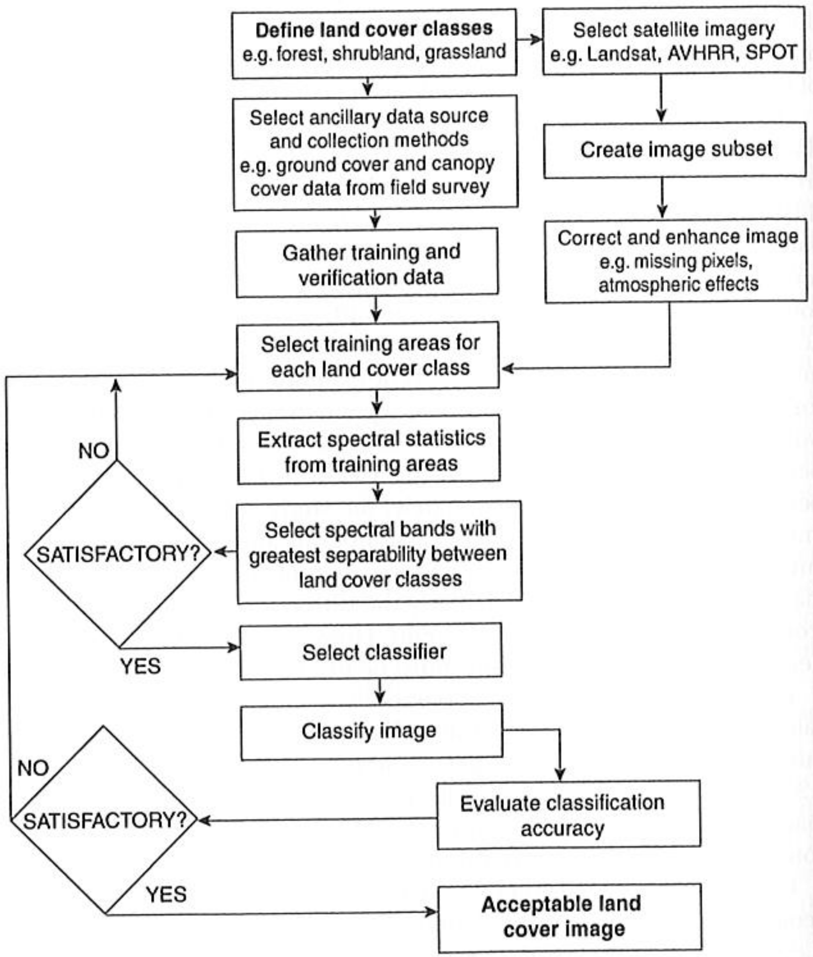

Figure 4.4 Key steps in the classification of satellite imagery

Source: adapted from Wilkie and Finn (1996).

1 Define land cover classes. While the appropriate set of land cover types for a given region may seem self-evident, they are anything but. Instead, the selection of categories is often a mix of the goals of the study and what is distinguishable in the imagery being used. Choices about which categories to analyze have profound, though often unrecognized, implications for policy (Kull, 2012). Globally, classification schemes vary enormously depending on bioclimatic zone. There exists no universal nomenclature and unambiguous definitions of a given land cover are rare. A laudable exception to this was a recent study whose authors specified that 'we defined "forest" as areas of primary vegetation dominated by tree cover at least seven meters in height, with neighbouring trees crowns touching or overlapping when in full leaf. In practice, this means that the canopy is at least 80% closed' (Harper et al., 2007, p2).[12]

2 Select imagery. Ideally this choice follows from the analytical needs, in an objective consideration of the spatial, spectral, and temporal characteristics of different sensors with respect to the particular study area and research questions. However, in practice other considerations often come into play, such as the analyst's familiarity with a particular sensor. On the other hand, sometimes it is the novelty of the sensor that motivates the land cover change study itself. This dynamic was in evidence in the testing of the new SPOT-4 VEGETATION instrument, with the results explicitly compared to previous exercises with the similar AVHRR instrument (Mayaux et al., 2000).

3 Create image subset. This chapter is limited to only island-wide studies, largely because the comparability of sub-national studies is hampered by incommensurate spatial bounds. When the spatial extent of a study is arbitrarily defined by the extent of map sheets, aerial photographs, or satellite images, this can have a major effect on the rate of change, since a relatively small change in study area extent – to include or exclude areas that are not representative of the overall change – can drastically alter the overall rate of change. There is no obvious solution to this, and all change rates calculated on such arbitrarily defined study areas must be treated with caution. It may be more appropriate in these cases to limit the reporting to the areal change in different periods (e.g. Vågen, 2006) or to graphical representation of change between time periods (e.g. Elmqvist et al., 2007).

4 Evaluate classification accuracy. In practice, the thresholds separating land cover categories (e.g. closed forest and open woodland) can be quite difficult to apply consistently and reliably without a

great deal of very expensive field work. In addition, the arbitrary sampling of the landscape often results in pixels representing mixtures of land covers (especially when the heterogeneity of the landscape occurs at a finer scale than the sample rate (pixel size) of the sensor). As a result in remote sensing studies, 85 percent accuracy is considered pretty good, yet it is common to see studies that set out to explain single digit percentage changes in land cover from images classified with double digit errors; moreover the change is concentrated all along the edges of land cover patches where the bulk of the classification error occurs.

and 1980s – around 1.7 percent per year – than in the preceding and subsequent periods (0.3 percent in the 1950s and 1960s, and 0.9 percent per year in the 1990s). A map subsequently published using many of these same data and techniques (CI et al., 2007) tabulates an overall deforestation rate of 0.83 percent per year during the 1990s (why the rate for the 1990s differed between the two studies is unclear). It also presents new data indicating that this rate slowed to 0.53 percent per year during the period 2000–2005.[13]

This brief review suggests that our knowledge of forest cover at particular points in time is subject to high degrees of uncertainty, and that the hazards are compounded in the estimation of forest cover change. The studies reviewed above estimated rates of change ranging from less than half a percent per year to almost two percent per year. Unfortunately, no two studies cover the same forest types, in the same area, during the same period, and therefore none can serve to verify another. The studies also do not, typically, engage at all with confounding evidence of forest recovery or forest planting. We suspect that the unstated reason for this is that neither secondary forests nor plantations tend to be valued as highly for conservation purposes. In contrast, the IEFN (DEF et al., 1996) mapped a considerable extent of plantation forest from very similar data. Harper et al. (1997, p3) follow Green and Sussman (1990, p213) who admitted to being unable to distinguish large tracts of secondary forest and plantations from primary forest. Meanwhile, other studies (e.g. Rakoto Ramiarantsoa, 1995; Kull, 1998; McConnell and Sweeney, 2005; Elmqvist et al., 2007) acknowledge the local importance of reforestation and afforestation and set out to quantify and explain these phenomena.

In some cases, the individual studies provide information that can be used to judge the reliability of their estimates of forest cover at a given point in time, or of their estimates of change. We examine that briefly in the next section, before turning to Guichon's concern about the motivations of different analysts.

Methodological issues and accuracy assessments

Several issues repeatedly arise in the previous sections that complicate the measurement of forest area and changes in forest area. These range from data inconsistencies, to methodological assumptions, to definitional disagreements. Below we expand on one particular aspect: the importance of assessing the accuracy of the different forest mapping products. All empirical measurement approaches entail uncertainty, arising from error during the collection and analysis of data, and in the reporting of results. In this section, we briefly comment on some problematic cases concerning island-wide analyses of Madagascar's forest cover.

The analysis of the aerial photographic record, as embodied in the topographic map series and the Humbert and Cours Darne (1965) maps, generally relies on the analyst's expert opinion, often informed by direct, in situ, observations, as well as by knowledge of the ways in which different land covers reflect sunlight back to the camera, and experience with the typical appearance of certain features (Kull, 2012; Box 4.1). Given the time lapse since these analyses were conducted, it is virtually impossible to judge the accuracy of the product, since the landscape is bound to have changed and few reliable references (such as terrestrial photographs) exist.

In satellite-based remote sensing, one way to judge the quality of results is to compare classification results with reference data (e.g. maps or imagery from other sensors) used to 'train' the manual interpretation or automated classification algorithm. For example, Nelson and Horning (1993) used the Faramalala (1981[sic]) data as 'ground reference' to report 81 percent agreement between that reference and their AVHRR-based forest cover estimate. They go on to specify that while they achieve 94 percent correspondence between the non-forest pixels in the two datasets, the value for forest was just 62 percent, and describe the agreement in their hardwood stratum as 'abominable' (p1472). They ascribe much of the disagreement to differences in the ways in which the MSS and AVHRR sensors image the landscape, declining to speculate on what proportion of the difference might be attributable to actual change in the landscape between the 1970s and 1990/1991.

Mayaux et al. (2000) used the same MSS-based dataset to train their SPOT-4 based classification, but based their accuracy assessment on maps derived from contemporaneous TM data interpreted by local experts, as contained in a report commissioned by the authors' organization. This validation yielded a 'user's accuracy' (the probability that a pixel's land cover label in the map corresponds with the reference data) of 87.8 percent, and a 'producer's accuracy' (the probability that the land cover category of a certain location in the reference data was labeled as such in the map) of 85.6 percent. In other words, discrepancies exist between the map product and the reference data in approximately 12–15 percent of the cases. The authors note that part of the error is attributable to imperfect co-registration between their 1 km resolution SPOT-4 VEGETATION data and the 30 m reference data.

Similar procedures may be employed to assess accuracy in studies aiming to detect change in the landscape. For example, Harper et al. (2007, p329) used contemporary ground reference data to calibrate and to validate land cover maps derived from TM imagery, estimating '89.5% accuracy in identification of forest and non-forest'. If their c.1990 and c.2000 maps each contain errors of approximately 10 percent, this raises questions about their finding of 15 percent of forest loss between these two maps. While it is likely that many of the errors cancelled each other out (in the sense of the net change in forest cover), it must be admitted that the bulk of such classification errors occur at the forest edge, where so-called 'mixed' pixels (depicting a mixture of forest and non-forest cover) predominate, but also where most of change has occurred. It is important to keep these issues in mind when interpreting the results of forest cover change analyses; when our measurement error approaches or exceeds the observed dynamics, we should temper our confidence in the claims about the change said to have occurred.

The record of sub-national studies with respect to accuracy assessment is mixed, with some authors (e.g. Vågen, 2006; Scales, 2011) providing detailed information, while others (e.g. Green and Sussman, 1990; McConnell et al., 2004) provide less rigorous estimates or general caveats.

The curious persistence of the 90 percent claim

We have shown in the above sections that estimates of forest cover before the remote sensing record provide dubious benchmarks and, more than anything else, demonstrate fundamental problems that continued through much of the subsequent work. We have joined others (e.g. Nelson and Horning, 1993; Ingram and Dawson, 2005) in showing that technical challenges and inconsistent definitions, compounded by sometimes insufficient documentation of methods, leave considerable uncertainties around certain aspects of air photo and satellite-based analyses. Clearly, without denying that native forests – in general – are shrinking, more caution about estimates of forest area and loss is warranted than is generally accorded.

Here we turn to the question of how views of forest cover change have been shaped by the received wisdom of the 'island-wide forest'. We focus in particular on the persistent reproduction of the notion that 90 percent of the island's forests have been lost, and ask to what degree its persistence may be attributable to its usefulness in emphasizing dramatic deforestation. The 90 percent claim arises directly out of the island-wide forest hypothesis developed by Perrier de la Bâthie and Humbert (Burney, 1987; Kull, 2000). Specifically, Perrier de la Bâthie (1921) stated that the island was once completely covered by an 'arborescent' vegetation, and that nearly *nine-tenths* of this original vegetation had since been destroyed by shifting cultivation,

grassland fires, and logging. This claim has been abundantly repeated and reworked. The statistic appears further confirmed by today's assessments that the island is about 10 percent forested, but only if one fallaciously assumes the rest was previously fully forested.

These ideas, used to contextualize the introduction of scientific articles (e.g. Hannah et al., 2008), to sell conservation activities in the promotional material of environmental agencies and simply to describe the island in media and tourism writing (e.g. Bradt et al., 1996; Wikipedia 'Madagascar' page, accessed 21 May 2012), is at best a problematic assertion. At times it is tempered or modified, with '90 percent' replaced by '80 percent', or 'forests' replaced by 'natural vegetation'. Indeed, words like 'virgin', 'primary', 'secondary', and 'natural' are frequently used without careful definition, tending to reaffirm the discourse initiated by Perrier de la Bâthie and Humbert.

Why this penchant to uncritically repeat a figure based on vague and contested ideas of the original vegetation? Why not use more recent figures? We showed above that the more reliable aerial photo analyses document that between 16 and 20 million hectares of the island were forested in the middle of the twentieth century, depending on which categories of woody vegetation cover are included. Island-wide studies using satellite images show that by the end of the century, somewhere between nine million and 17 million hectares of forest remained, again depending on the methods used and the categories included. From this, one might conclude that at most more than half of the forest cover may have been converted to other uses in the past 50 years, perhaps much less (cf. Table 4.3). The loss of even one-tenth of the island's forest in a lifetime is certainly alarming and arguably sufficient cause for action. Why, then, is the 90 percent figure repeated? Is a bigger number more attractive, does it better reinforce the claim that Madagascar deserves special 'hotspot' status by 'virtue' of having lost 90 percent or more of its natural vegetation? Below, we seek to answer these questions. First, we investigate the 'genealogy' of the 90 percent claim, picking apart its origins and its reproduction. Then, we comment on the discursive and political environment that facilitated this process.

Deconstructing the claim's origins and reproduction in the scientific literature

We focus our analysis on articles in scholarly publications that make a claim about 80 or 90 percent loss of forest or of natural vegetation more broadly. This claim is remarkably persistent in the conservation biology literature: we identified some 27 articles making such claims (Tables 4.3 and 4.4).

Four of the articles cite no source for the claim (Table 4.4). In some cases the claim is implicit, combining recent estimates of contemporary forest cover with conjecture about the conditions when humans first arrived, leaving the reader to surmise the gravity of the loss. For example, Durbin

Table 4.3 Analysis of articles in scholarly publications making the 90 percent claim

Article/journal	*Claim*	*Their source or citation*
Myers, 1988	'Nationwide, only 5 percent of the original vegetation remains' (p192).	Leroy, 1978; Guillaumet, 1984; Jolly et al., 1984; Lowry, 1986; Mittermeier, 1986; Jenkins, 1987.
Durbin and Ratrimoarisaona, 1996	'Most of [Madagascar's] biological diversity is concentrated in forests, which are believed to have covered around 90% of the island around 2000 years ago but ... less than 11% of the island is now covered with forest' (p346).	Nelson and Horning, 1993.
Lowry et al., 1997	'Perhaps 10% or so of Madagascar might still be covered with native vegetation' (p117).	None.
DuPuy and Moat, 1998	'Over 80% of the island has already been stripped of its native vegetation cover ... the majority of which is now very species-poor secondary grassland which is burnt annually and is subject to intense erosion' (p1).	Analysis of Faramalala (1988a, 1995) data.
Hannah et al., 1998	'Estimates of forest destruction indicate that 50–80% of Madagascar's original forest cover has disappeared in the 1500–2000 years since the arrival of humans' (p31).	Green and Sussman, 1990; Nelson and Horning, 1993; Faramalala, 1995.
Article/journal	*Claim*	*Their source or citation*
Myers et al., 2000	'Madagascar's remaining primary vegetation (% of original extent)'; shown as 9.9% in Table 1 (p854).	Calculated on the basis of 'Original extent of primary vegetation' of 594,150 km² (the entire island) and 'Remaining primary vegetation' of 59,038 km². While the sources of information on endemism are included in the Supplementary Materials (both experts and publications), no sources are cited for the estimates of 'original' or 'remaining' primary vegetation. The text stipulates that 'Additional details are available in ref. 16' which is Mittermeier et al. (1999), which contains no citation for its statement that 'Estimates vary, but it is thought that at least 85% and probably 90% or more of Madagascar's natural forest cover has already been lost ...' (p198).
Ganzhorn et al., 2001	'Habitat loss [in Madagascar is] estimated at >90%' (p346).	Lowry et al., 1997.
Lehtinen et al., 2003	'At least 90% of the original forests have been lost' (p357).	Green and Sussman, 1990.
Goodman and Benstead, 2005	'This island nation ... retains only an estimated 10% of the natural habitats that existed before human colonization' (p73).	None.
Lehman et al., 2005	'The loss of 80–90% of forest habitats in Madagascar' (p232).	Du Puy and Moat, 1998.
Bakoariniaina et al., 2006	'Over 90% of the Malagasy original forest is now gone' (p241).	None.

Continued

Table 4.3 Analysis of articles in scholarly publications making the 90 percent claim, *continued*

Article/journal	*Claim*	*Their source or citation*
Bollen and Donati, 2006	'Over 80% of the island has already been stripped of its native vegetation cover' (p57).	Du Puy and Moat, 1998.
Hume, 2006	'Less than 10 percent of primary growth vegetation remains in Madagascar' (p288).	Nelson and Horning, 1993; Du Puy and Moat, 1996; Myers et al., 2000.
Ingram and Dawson, 2006	'It has been estimated that the country retains only 9.9% of its primary vegetation' (p195).	Myers et al., 2000.
Lehman et al., 2006	'The loss of 80–90% of forest habitats in Madagascar' (p294).	Green and Sussman, 1990; Du Puy and Moat, 1998.
Norris, 2006	'Today Madagascar … has lost over 90 percent of its original forest cover' (p960).	None.
Sandy, 2006	'Only about 11 percent of the "original" forests remain' (p305).	WWF's *Living Planet Report* (Loh et al., 1999).
Hanski et al., 2007	'Currently, roughly 10% of the original forest cover remains' (p344).	10% claim not referenced (it is in abstract), elsewhere they cite Dufils, 2003.
Allnutt et al., 2008	'Recent analyses using remote sensing reveal that only 10–15% of original forest remains' (p174).	Harper et al., 2007.

Article/journal	*Claim*	*Their source or citation*
Andreone et al., 2008	'Ongoing habitat destruction has already led to destruction of 90% of the original vegetation' (p944).	Myers et al., 2000; Harper et al., 2007.
Hannah et al., 2008	'Deforestation has claimed approximately 90% of the island's natural forest' (p590).	Ingram and Dawson, 2005; Harper et al., 2007.
Craul et al., 2009	'Madagascar has already lost 90% of primary vegetation' (p2863).	None.
Whitehurst et al., 2009	'Madagascar's primary vegetation has decreased to 9.9% of its original extent' (p275).	Myers et al., 2000.
Barrett et al., 2010	'As much as 90% of the country's primary forest already lost' (p1109).	Myers (2000); Yoder and Nowak (2006); Harper et al. (2007).
Volampeno et al., 2010	'The loss of 80–90% of forest habitats on the island' (p306).	Du Puy and Moat, 1998; Mittermeier et al., 2010.
Durkin et al., 2011	'It has been estimated that continued habitat destruction has led to the disappearance of 90% of the original vegetation cover' (p114).	Harper et al., 2007.
Johnson et al., 2011	'Since the arrival of humans *ca* 2000 yr ago, Madagascar has lost 80–90 percent of its natural forest cover' (p371).	Harper et al., 2007.

Table 4.4 Description of the sources cited by articles in Table 4.3 to justify their 90 percent claims

Cited source	*Relevance to 90 percent claim*
Category 1: Primary sources of data (all discussed at length in chapter text)	
Humbert (1955); Humbert and Cours Darne (1965)	Vegetation cover analysis based on c.1950 air photos. No change analysis.
Faramalala (1981[sic], 1988a, 1995)	Visual interpretation of 1970's satellite images. Change analysis is implied in the mapping of secondary vegetation types, based on untested assumptions about the genesis of a broad range of vegetation types thought to be degraded.
Green and Sussman (1990)	Despite study's restricted focus on the humid forests of the east, it has often been cited in claims about overall deforestation. They calculate that 3.8 million hectares of eastern rainforest found in the 1980s represents 50 percent of that mapped in the 1950s, and 34 percent of the 'original' forests. No 90 percent claim is made.
Nelson and Horning (1993)	As a single date analysis, this may be cited to support '10% island-wide forest cover around 1990', but it does not imply or show the other 90 percent is former forest.
Harper et al. (2007)	State that 'forest covered 90% or more of the island' but go on to say that 'others argue that it was less'. In their discussion: 'By the 1950s, only 27% of Madagascar was forested and even a conservative estimate of pre-human forest cover suggests it had already lost more than half of its forest cover; the loss may have been as much as two-thirds, or more. Forest cover further declined to approximately 16% in c.2000, a loss of 40% in 50 years.'
Category 2: Secondary sources not already listed	
Leroy (1978)	A botanical review article.
Jolly et al. (1984); Guillaumet (1984)	General natural history reference book and chapter within it reviewing vegetation types.
Lowry (1986)	No relevance: dissertation on New Caledonia.
Mittermeier (1986)	A WWF action plan.
Jenkins (1987)	A natural history overview of Madagascar from IUCN, UNEP, and WWF.
Du Puy and Moat (1998)	Uses land cover data from Faramalala (1988a, 1995).
Loh et al. (1999)	WWF's *Living Planet Report.*
Ingram and Dawson (2005)	State that 'Considerable discrepancies exist between the estimated amounts and distribution of forest cover and loss in Madagascar' (p1449) and present results from analysis of 14 years of change using NOAA AVHRR.
Yoder and Nowak (2006)	A study on the evolution of Madagascar's fauna.
Mittermeier et al. (2010)	A 676pp lemur field guide.

and Ratrimoarisaona (1996) state that forests 'are believed to have covered around 90% of the island around 2000 years ago' (p346) without citing any source. They then cite Nelson and Horning's (1993) figure of 11 percent contemporary forest cover, leaving the reader to infer that around 88 percent of the island's forest disappeared 'since the arrival of man'.

In other cases, the claim is made explicitly, but without a source being cited. This is particularly problematic when such claims are subsequently used as sources for others. For example, Lowry et al. (1997) state that 'perhaps 10% or so of Madagascar might still be covered with native vegetation' (p117), but neither provide a source for the claim nor proffer any analysis to substantiate it. Later, Ganzhorn et al. (2001) cite the Lowry et al. (1997) chapter as the source of their statement that habitat loss is estimated to exceed 90 percent.

In still other cases, the claim is made explicitly with reference to a source that provides only partial substantiation. For example, Lehman et al. (2005) make an assertion about 'the loss of 80–90% of forest habitats in Madagascar', citing Du Puy and Moat (1998) and Green and Sussman (1990) (in a companion article by the same authors the following year (Lehman et al., 2006), the same assertion appears verbatim, though without the second reference). As it happens, Du Puy and Moat (1998, p1) used Faramalala's (1988a, 1995) land cover maps to conclude that 'over 80% of the island has already been stripped of its native vegetation cover … the majority of which is now very species-poor secondary grassland which is burnt annually and is subject to intense erosion'. Crucially, it must be noted that Faramalala (1988a) mapped secondary formations on the basis of untested assumptions about the genesis of a broad range of vegetation types thought to be degraded.

More recently, the Harper et al. (2007) study is being cited by many authors (e.g. Alnutt et al., 2008; Andreone et al., 2008; Barrett et al., 2010;

Durkin et al., 2011; Hannah et al., 2008; Johnson et al., 2011) as the source for their claims about the loss of 80–90 percent of the island's original (primary) forest (vegetation). This is particularly striking given that Harper et al. (2007) openly acknowledge controversy over the state of the island's vegetative mantle prior to the arrival of humans, and limit their conclusions to the five decades covered by the remote sensing data they analyzed.

The circulation of a claim about 90 percent forest loss is a striking example of the power of a received wisdom and of the fallibility of peer-reviewed science. One explanation is that authors simply repeat the 90 percent figure as a 'known fact', with a reference to a high-profile and much-cited article thrown in to support it, without actually checking to confirm whether this fact was indeed supported by data.

Yet, what our survey of the literature suggests is that there is a strong epistemic community of conservation scientists for whom this 'fact' forms part of motivating *raison d'être*, and as such becomes an unquestioned paradigm pervading the discourse. The most recent, and perhaps most authoritative, island-wide remote sensing-based study, Harper et al. (2007), acknowledges differing views on the question of forest loss statistics, yet persists in putting the 90 percent claim up front, and in pointing out the upper (but not the lower) bounds of forest loss statistics (see quote in Table 4.4). If they were not influenced by the dominant discourse, would they have phrased the discussion the same way? Their reinforcement of the conservationist dogma begs important questions of perspective and motivation. The authors are affiliated with the large conservation organization Conservation International. It is not insignificant that their analysis shows deforestation highest during the two decades of isolationist, socialist rule, with rates tapering off after 1990, when interventions by organizations such as their own boomed (see Chapter 7 by Kull). The article's conclusion may well be valid, but they bear verification to allay any potential concerns over the degree of objectivity of the analysis.

Amelot et al. (2012) point out two other instances in Harper et al. (2007) where oft-repeated ideas and theories from a conservation perspective probably unintentionally affect the statements and conclusions that are drawn. First, Amelot et al. investigate an inset map in Harper et al.'s Figure 1, which shows Madagascar as being covered by three forest zones: humid, dry, and spiny. Amelot and colleagues vividly illustrate the derivation of this simplified and misleading assessment. They trace this three-way forest classification back through its sources – through World Wide Fund for Nature (WWF) reports and botanic book chapters – to its origins in a complex map of climatic zonations they attribute to Cornet (1974). That pure climatic zonations became forest types through successive cartographic iterations reflects the discursive bias towards an 'original' (and potential) island-wide forest.

Second, Amelot et al. (2012) point out that the Harper study is used to justify claims about environmental change that it actually does not show.

The Harper study is cited in articles and policy documents that focus on slowing slash-and-burn cultivation in the eastern rainforest, yet the study itself clearly shows deforestation over the past two decades principally touched not the rainforest of the east, but the dry forest of the southwest (cleared for commercial corn production) and areas affected by urban demand for wood energy.

The interlinked influence of conservation interests and the dominant discourse

The persistence of the 90 percent claim can be traced to the paradigmatic dominance of certain ideas circulating in the administrative, policy, and scientific world about Madagascar's environment, and their correspondence with strong, foreign-funded conservation interests. The examples we show above are a manifestation of a broader phenomenon in Madagascar where what has been called a 'dominant discourse' influences the questions that are asked, the evidence that is seen, the stories that are told, and the actions that are taken. Dominant discourses are ways of understanding the world – shaped by the stories, metaphors, and language that we use – that gain their power from the influence of actors that initially promote them and that exercise power by shaping the realm of the possible (Fairhead and Leach 1998; Larson, 2011).

In Madagascar, it has long been clear that a certain discourse, a certain set of environmental narratives, dominates understandings of environmental change and the role of Malagasy farmers in that change (Jarosz, 1996; Kull, 2000; McConnell, 2002; Pollini, 2010; Amelot et al., 2012; Scales, 2011; Rakoto Ramiarantsoa et al., 2012). This discourse is rooted in a potent mix of fact with conjecture, spiced with the interests of its promoters – originally, colonial foresters and botanists, now conservationists – and made durable by their powerful position in the then colonial, now dirt-poor country with practically no tradition of rural social movements (whose voices might contest certain aspects).

The discourse paints Madagascar first and foremost as a hot spot of biological diversity, environmental degradation, and conservation action. It often relies on a narrative whose roots go directly back to the work of Perrier de la Bâthie and Humbert in the 1920s and 1930s. The story, as they framed it, begins with the original island-wide forest, and then blames the agricultural practices of Malagasy farmers as the primary cause of deforestation, together with colonial logging (see Chapter 5 by Scales). Perrier de la Bâthie and Humbert's stories had a great influence on contemporary writing; Madagascar became considered a type locality for the destruction of indigenous flora by fire and shifting agriculture. The narrative was reproduced nearly word-for-word by some scientists, in popular publications, and by development and environmental organizations throughout the environmental boom years of the 1980s and 1990s (Kull, 2000).

Scientific understanding of environmental change in Madagascar has continued to evolve. Yet for many scientists, as we show above, and in conservation and environmental organization documents, the Perrier-Humbert story remains the dominant narrative. This version of the story reaches the public through the media, the internet, travel guides, television documentaries, song lyrics (Emoff, 2004), environmentalists' writings, and agency documents, which use artistic license to further dramatize Madagascar's environmental degradation. They not only repeat the assertion of 90 percent forest loss due to slash-and-burn agriculture (for example on Wikipedia[14] and in *National Geographic News*[15]), but also build on tropes such as the blood-red, iron oxide-laden rivers that 'bleed' into the ocean, and the 'gangrenous wounds' of the island's *lavaka* erosion gullies (see examples reviewed in Kull, 2000, or Raharimahefa and Kusky, 2010 as a recent scientific example).

The persistence of the dominant narrative might not strike some people as unusual or problematic. After all, Madagascar *does* harbor a flora and fauna not shared with other places, native forest cover *has* declined in the past century in numerous regional contexts, and slash-and-burn agriculture certainly *is* one proximate cause of forest conversion. The discourse of exotic nature and environmental destruction, then, can be seen as necessary to justify conservation fundraising, policies, and actions, so it is unsurprising that it persists due to its compelling story line and its usefulness in gaining public and government support.

Yet, as Peet et al. (2011, p37) state, 'arguments over the apparently "given" facts and categories of ecology are always also arguments over social and political control of nature'. The dominant narrative and its exaggeration of forest loss contribute to strong conservation policies and actions that marginalize rural people, restrict their access to resources, and silence their viewpoints (see Chapter 14 by Kaufmann; Rakoto Ramiarantsoa et al., 2012). In addition, exaggerations, problematic assumptions and the use of outdated facts do a disservice to the credibility of science. They can undermine, and even contribute to the misuse of, scientific authority, serving to occlude other interpretations, forestall other topics of enquiry, and push to the sidelines important social debates about values and ethics (cf. Larson, 2011). It is important, then, that deforestation analyses return to careful, evidence-based approaches, in order to contribute to constructive debate about policy.

Lessons learned and the way forward

Our review of efforts to measure Madagascar's shrinking native forests results in four 'take home messages'. First, the science is complex and messy. Efforts to measure forest area, to determine historical and pre-historical forest area, and to assess changes over time are technically challenging and require more careful attention to detail than has heretofore been accorded.

Work has too often been motivated more by the assessment of new satellite sensors than by the careful repetition needed to build reliable knowledge.

Second, the dominant conservationist discourse influences interpretations of this complex and messy science. Power-laden ideas, such as that of the pre-human, island-wide forest, persist due to their correspondence with conservationist worldviews. They shape the questions that are asked, the interpretation of data, and the choice of statistics that are highlighted and repeated.

Third, the existing evidence documents a general trend of forest loss, though *not* of 90 percent as commonly cited. Increasingly rigorous comparisons of data derived from historical aerial photography and recent satellite imagery appear to be converging on an estimate that as much as half – but perhaps much less – of the most easily identified 'primary' forest types changed to other land covers during the latter half of the twentieth century. Changes in other forest types are quite varied, with some gaining and others losing. The available evidence does not support quantitative estimates at any time prior to the photographic record, and prudence demands that we avoid conjecture about forest cover dynamics during that time.

Fourth, there are specific ways in which forest cover analyses could be improved in order to support more evidence-based policy deliberations. Even if we succeed in defining forest for current purposes, we cannot change the definitions used in the past without redoing the prior analyses, and even if we were to repeat the prior analyses, the data we might use are different, leading to incompatible results. Perhaps the most certain way to judge land cover change would be to repeat the air photography conducted around 1950 and apply the same analytic methods (e.g. Kull, 2012). We must temper the habit of simply availing ourselves of the latest remote sensing technology in the belief that its superior qualities will lead to more reliable results and that it will become the standard to which future analyses will be compared. A number of concrete steps could be taken.

1. A systematic and fully documented reconciliation of the various remote sensing datasets should be undertaken. This would involve re-interpretation of at least some of the mid-century aerial photos, as well as of satellite imagery used in later studies. As part of this exercise, the topographic map series (at least the land cover information) could be digitized, with complete metadata, especially the dates of the photographs from which each sheet was derived. The exercise would require sharing access to all the imagery collected by different scientists. While this would require a significant investment of labor, the capacity exists in-country.
2. Rigorous validation should be conducted by an impartial third party.
3. The digital data and metadata from the exercise should be made freely available and further validation encouraged.
4. Careful classification of vegetation, allowing comparison with classification schemes used in prior studies, is absolutely crucial

Madagascar has long been counted among the world's conservation hotspots due to its highly endemic and unusual wildlife and plants, and a perception that this natural heritage was under grave and imminent danger of disappearing in the face of a growing human onslaught. The Earth's biological riches developed over hundreds of millions of years, and avoiding further erosion of biodiversity by human activity is certainly among the most important challenges facing society today. In this struggle, it is entirely appropriate to focus attention on those areas of particular richness and where the threat of human impact is the greatest. At the same time, however, curbing human activity is never a simple undertaking, especially when those activities are directly linked to basic human needs, as they are in a place such as Madagascar. In this context, policy success depends on confronting the values and interests of different actors, and such confrontations depend, in part, on quality information. Scientists and practitioners alike must seek to build knowledge around the best evidence, avoiding conjecture and hyperbole. Journals should enforce such restraint, and should require that authors make data available on an ongoing basis so that the chaotic state of our knowledge about what has occurred can be redressed. The gold standard of knowledge building is replication, and the existing studies should be repeated to verify their results. Policy decisions are, in the end, about values, interests, and power, but good data speaks volumes.

Acknowledgements

Thanks to Ivan Scales for unearthing additional 90 percent references!

Notes

1 Details in Kull (2000, 2004). See also Koechlin et al. (1974), Burney (1997), and Dewar (1984)

2 Perrier de la Bâthie (1921, pp260–261) made sure to note that he meant not a pure dense forest across the island, but an island-wide 'forest flora' including tall shrublands and xerophyllous plants.

3 It should be noted that Guichon's main table contains several arithmetic errors, and that the totals should probably be 16,791,672 ha and 19,440,672 ha, not including and including savanna, respectively.

4 Oddly, the IEFN report's bibliography does not include Faramalala (1995). It does, however, include Faramalala (1988b); unfortunately we have not yet succeeded in obtaining a copy of the 1995 work, which may contain numeric estimates.

5 The date should be 1988. Mayaux et al. (2000) also incorrectly lists Faramalala's data source as Landsat Thematic Mapper (TM). Green and Sussman (1990) and Nelson and Horning (1993) also apparently incorrectly cite this thesis as dated 1981.

6 It is also possible that the study used a slightly different set of images, however the link provided in the article to the Supplementary information (p5) is faulty, making it impossible to verify.

7 The IEFN report (DEF et al., 1996) cites Nelson and Horning (1993) as having detected 5,809,000 ha. The difference with Nelson and Horning's own figure may have resulted from a misinterpretation of their 'Table 3'. The IEFN report apparently rounded the original estimate of 'rainforest' (34,167 km^2) to 3,417,000 ha of 'evergreen forest', then combined the original estimates of hardwood forest (6,697 km^2) and spiny forest (17,224 km^2) and rounded the resulting 23,921 km^2 to get 2,392,000 ha, and proceeded to ignore the 6,697 km^2 of grassland forest, perhaps misunderstanding this item in the table as simply grassland.

8 Dufils cites not Mayaux et al. (2000), but JRC (1999), yet this reference does not appear in the chapter bibliography. JRC is the home institution of Mayaux et al. – Dufils may have been working from a draft report.

9 The Humbert and Cours Darne (1965) maps depict 34 land cover classes, arranged in an array of floristic *séries* and elevational stages within three broad types (*humide, sec, littoral*). It is not possible to know which of these classes were combined to constitute the 'evergreen' estimate; while Dufils presented the same total for this category as appeared in the IEFN (DEF et al., 1996), that report provides no information on the aggregation methods. Meanwhile, the IEFN employed four phytogeographic zones (*Est et Sambirano, Centre, Ouest*, and *Sud*) within which they floristically differentiated a dozen major classes of forest. From these, Dufils appears to have selected a) *Forêts denses humides sempirvirentes de l'Est, du Sambirano et du Centre*, b) *Forêts sclérophylles des pentes occidentales et du Centre*, and c) *Forêts et fourrés sclérophylles de montagne et du Centre*. Finally, Mayaux et al. (2000) mapped dense humid and dense dry forests, along with mangroves and secondary forest complexes, from which Dufils selected the 'dense humid forest' class. The comparison across Dufils' harmonized 'evergreen' category from these three studies was imperfect. One example is the inclusion of highland forests (Forêts denses humides sempirvirentes du Centre) from the IEFN study, and the exclusion of the dense dry forests of Mayaux et al. (2000), some of which lie in the IEFN's 'centre' zone.

10 Dufils' (2003) 'Table 4.5' includes an apparently misplaced decimal indicating an implausible deforestation rate of 9.5 percent per year between the 1950s and the 1990s; this was probably intended to read 0.95 percent per year (which, it should be noted, is markedly lower than Green and Sussman's (1990) estimate of 1.5 percent per year for a subset of the area over the same period).

11 Dufils' (2003) estimate of the rate of deforestation is inflated somewhat by his choice of 1953 as the date represented in the Humbert and Cours Darne (1965) maps. While this represents the median of the period during which the aerial photos were acquired (1949–1957), our experience suggests that the bulk of the flights actually took place at the beginning of the period, as reflected in Green and Sussman's (1990) choice of the year 1950 in their calculations. The addition of three years to the calculation of a deforestation rate would slightly lower the resulting number.

12 Harper et al. (2007, pp2–3). They continue:

> In practice, this means that the canopy is at least 80% closed. 'Spiny forest and woodland' is primary vegetation dominated by closed-canopy trees or shrubs in the arid southern and south-western regions of Madagascar, sometimes as low as two meters in height in the extreme south. We did not include open-canopy areas, secondary formations or plantations in our estimates of forest and woodland areas. Lightly degraded primary forest and mature secondary forest may be indistinguishable from primary forest in Landsat imagery.

13 Unfortunately our ability to judge the quality of the results is hampered by the lack of cartographic documentation. Harper et al. (2007) probably employed many of the same scenes used by Faramalala (1988a) but it is difficult to know since their metadata are inaccessible.

14 http://en.wikipedia.org/wiki/Madagascar, accessed 21 May 2012. This oft-read site states 'Since the arrival of humans ... Madagascar has lost more than 90% of its original forest' (citing a WWF/National Geographic website as its source) and continues 'key contributors to the loss of forest cover include the use of coffee as a cash crop, illegal logging, and slash-and-burn activities'. The reference to coffee cultivation as a major cause of deforestation is not representative of the broader discourse (this reference is linked to a music scholar article, Emoff (2004), who in turn cites – indirectly – research published in Jarosz (1996)).

15 Stefan Lovgren, 'Madagascar creates millions of acres of new protected areas', *National Geographic News*, May 4, 2007, available at http://news.nationalgeographic.com/news/2007/05/070504-madagascar-parks.html (accessed 15 May 2012). Many other examples are easily accessible via internet searches of terms like '90 percent Madagascar forest'.

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5 The drivers of deforestation and the complexity of land use in Madagascar

Ivan R. Scales

Introduction

Deforestation plays a central role in Madagascar's environmental discourse. The 1984 national strategy for conservation and sustainable development, for example, warned that forest clearance would lead to 'brutal and apparently irreversible savannisation' (MEEF, 1984, p15), while a World Bank report (1996, p10) stated that:

> Madagascar has already lost 80 percent of its original forest cover, and the rest is under severe pressure for reasons that relate principally to poverty ... Traditional forms of itinerant agriculture, which are relied on by the poor because they have no incentives to intensify production, result in the burning of savanna and forests.

Forest clearance is thus painted as a one-way process of degradation, driven by poverty and population growth and inevitably leading to the permanent loss of forest (Scales, 2011).

Madagascar's deforestation narrative is simple and appealing. It presents a clear problem and an obvious solution – by reducing poverty and persuading Malagasy farmers to adopt different livelihoods, forest loss could be avoided and Madagascar's biodiversity protected. However, I argue in this chapter that policy has tended to assume the importance of population growth and poverty as drivers of forest clearance, without exploring the role of other factors shaping land use. It has also tended to ignore the role of other land uses, especially large-scale commercial agriculture.

In the first section of this chapter I take an historical approach to forest loss, looking at the land uses that have led to deforestation during the twentieth century. I show that a range of land uses, and not simply forest clearance agriculture by rural households, have led to changes in forest cover. In the second section I focus on the land use practices of rural households. While the received wisdom and conservation policy have tended to focus on the role of poverty as a driver of deforestation, I show that rural households make land-use decisions based on a complex range of factors.