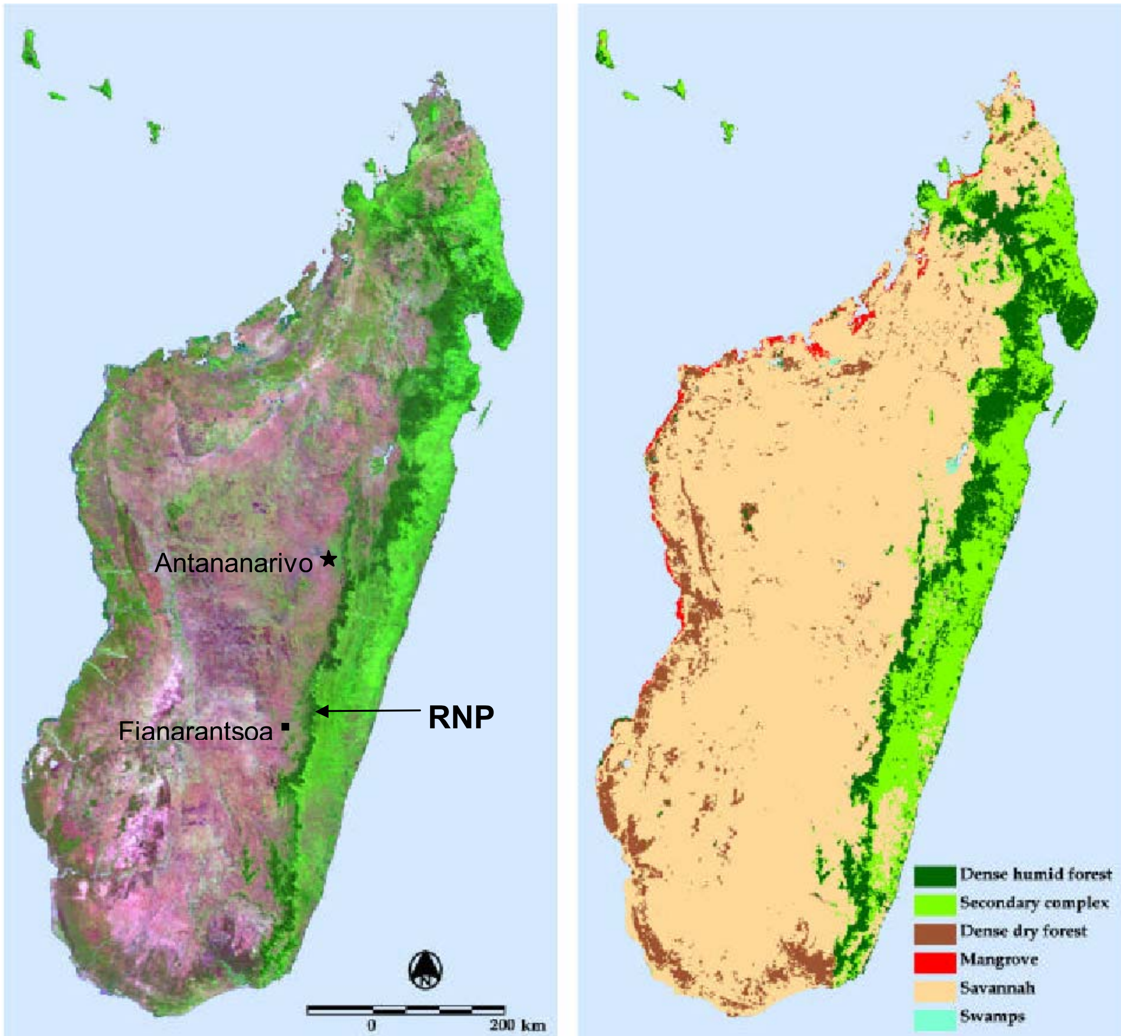
1. INTRODUCTION

Madagascar ranks at or near the top of the world's "biodiversity hotspots". This is a poignant designation, because the scientific ranking is based upon "areas featuring exceptional concentrations of endemic species *and* experiencing exceptional loss of habitat." (Myers et al., 2000; emphasis added) The poignancy takes on added meaning when we understand that the threat of numerous extinctions derives not from international logging companies or large-scale ranching, but largely from the efforts of resource-poor farmers to simply sustain their families.

By any measure, Madagascar's unique biological resources command attention. As stated by Russ Mittermeier (2000, p. xvii), "Madagascar's endemism is so striking that it has the highest ratio of endemic to non-endemic species, for both plants and vertebrates, of any of the [world's] twenty-five hotspots– ecoregions that were chosen in the first place in large part because of their high endemism." Most of Madagascar's numerous plant and animal species are simply found nowhere else on earth. The United States and Canada together possess over 30 times the land area of Madagascar and contain only two endemic plant families, yet Madagascar hosts 11 endemic families of plants (Myers et al., 2000). The island contains roughly one-quarter of all African plant species, and has more orchid species than the entire African continent, despite the fact that Africa is 50 times larger (Conservation International, 2001). With regard to primates, Madagascar occupies 0.4 percent of the earth's total land area, yet it holds 21 percent of all primate genera and 36 percent of all primate families (Mittermeier, 2000). The remarkable list goes on.

Much of this tremendous biodiversity resides in Madagascar's eastern rainforests. While scholars debate the total extent of the island's forest cover prior to human arrival, it appears highly probable that the eastern rainforest once extended eastward from the vicinity of Madagascar's "great escarpment" all the way to the east coast, and north-south for nearly the entire length of the island. Green and Sussman (1990) estimated that roughly half of the total rainforest loss in Madagascar occurred between 1950 and 1985, the implication being that the historic rates of deforestation accelerated dramatically within the last several decades. Today, most of the rainforest south of 18ºS latitude consists of thin remnants that are restricted to the steeper slopes of the eastern escarpment (Figure 1.1). These forest remnants already display a degree of fragmentation that jeopardizes many rare species, including lemurs. Because so many rainforest organisms are ecologically interdependent and rely upon continuous forest cover for long-term population viability, continued fragmentation will eventually render some species extinct. Madagascar's extraordinary endemism insures that many of those lost species would effectively be worldwide, not island-wide, extinctions.

While the biological resources of Madagascar exist in a precarious state, the same can be said for most of the country's human population. The United Nations ranked Madagascar 147th out of 179 countries in its "Human Development Index", based upon life expectancy, adult literacy, education level, and per capita gross domestic product (UNDP, 2002). The World Bank, based upon World Health Organization data, reports that 40 percent of Malagasy children under age five are malnourished, and that the mortality rate for children under age five is 150-160 children per 1,000 live births. This child mortality rate, equivalent to other sub-Saharan countries, is roughly double the world average and 20 times the child mortality rate in the United States. The estimated population density (26 people km^{-2}) and high



(a) (b)

Figure 1.1. SPOT composite imagery and interpretive map, illustrating the remaining extent of primary rainforest in eastern Madagascar: (a) SPOT-4 color composite of June 1999 vegetation, (b) forest cover map derived from SPOT data. The rainforest south of Antananarivo exists as a narrow remnant (dark tone) along Madagascar's eastern escarpment. The arrow indicates the approximate location of the Ranomafana National Park, or RNP (figure from Mayaux et al., 2001; RNP and city locations added).

population growth rate (3.1 annual percent) are also comparable to sub-Saharan Africa (World Bank, 2000). Approximately 70 percent of Madagascar's residents live in rural areas, and 1993 census data indicate that population densities in districts within the eastern rainforest region approximate the national average (UNDP, 1998). In short, the rainforest that houses some of the world's greatest biodiversity occurs within the same landscape as an impoverished, rapidly growing human population.

The major proximate cause of deforestation in eastern Madagascar is straightforward: slash-and-burn agriculture, or *tavy* in the Malagasy language. Kull (2000) correctly points out that French colonial plantations and selective logging historically accounted for some deforestation or forest alteration, yet *tavy* is well documented as the predominant cause (Olson, 1984; Sussman et al., 1994). Subsistence farmers rely upon this centuries-old practice as a means to clear land and temporarily improve soil fertility for growing food crops. Upon slashing and burning, the rainforest biomass rapidly releases nutrients that accumulated over decades or centuries, making the nutrients readily available to planted annual crops. Crop yields inevitably decline within a few years without further inputs, due to decreases in available nutrients, increased weed infestations, etc. (Sanchez, 1976). At some point, the farmer moves to a new area of forest and repeats the process.

This practice is ecologically sustainable where population densities and/or soil fertility allow long enough periods for sufficient forest regeneration prior to another cropping cycle at the same site (National Research Council, 1993; Brady, 1996). However, in regions where a combination of high population density and low inherent soil fertility do not allow sufficient time for complete forest regeneration prior to another slash-and-burn cycle, the forest ecosystem is disrupted to the point where it is ecologically degraded or ceases to regenerate at all. The latter scenario unfortunately appears to be the current case in much of eastern Madagascar.

The tragic irony of Madagascar's rainforest destruction is that the agents of deforestation, the Malagasy forest farmers, view the rainforest as *tanindrazana* or "land of the ancestors" (Peters, 1996). For these farmers, the forest is at once a source of livelihood, a way of life, a central element of their landscape, and (where burial grounds are located) a sacred cultural resource. The practice of *tavy* represents a continuation of *fombandrazana*, or "the way of the ancestors," a powerful tradition in a society that weaves ancestor worship into the fabric of daily living. On a more pragmatic level, forest farmers believe that clearing the forest for agriculture and utilizing other forest products is simply less labor and input intensive, more flexible, and ultimately more reliable for providing basic needs than farming rice paddies or permanent plots (Peters, 1996). Although most of the forest farmers operate in poverty at the subsistence level, Kull (2000) aptly states that, "Poverty does not drive the system, farmer rationality does." This latter point is critically important for any agricultural development scheme that would seek to arrest and/or reverse deforestation in eastern Madagascar.

An obvious dichotomy exists in the collective characterization of Malagasy forest farmers as both indigenous people who revere the forest, and their role as agents of widespread forest destruction. Yet both characterizations are true. Farmers may well perceive *tavy* as inherently sustainable, based upon centuries of tradition, the local scales of their observations, and perceptions of regional forest extent. From this perspective, there is little incentive to change, and good reason to perpetuate a proven system.

Decades of scientific research indicate that slash-and-burn agriculture is not *inherently* sustainable or unsustainable, but depends significantly upon demographic conditions and agroecological factors. Published estimates of deforestation rates in eastern Madagascar, ranging from 1000-3000 $km^2 year^{-1}$ (Richard and O'Connor, 1997), confirm that *tavy* in eastern Madagascar is ecologically unsustainable and incompatible with forest preservation under current and projected demographic conditions. The interconnected solutions to deforestation, biodiversity loss, and human development in Madagascar are ultimately dependent upon the perceptions and behaviors of forest farmers. Kottak and Costa (1993) argue that people will not alter deeply ingrained practices to preserve the environment if they do not perceive the threat to it, understand its implications, have satisfactory incentives and alternatives available, and have the desire, means and power to implement change.

The Ranomafana National Park (RNP) and its associated projects provide a case study of the complexities regarding rainforest conservation and sustainable development in eastern Madagascar. The RNP contains many of the species typically found in the eastern rainforest, a global resource worth protecting in its own right. But it was the near-simultaneous discovery of a previously unknown lemur species (*Hapalemur aureus*) and a presumably extinct lemur (*Hapalemur simus*) that catalyzed efforts to establish the area as a national park (Wright, 1992). With the encouragement of the Malagasy government, Dr. Patricia Wright guided the complex process of designing and funding a viable national park project. The project organization ultimately involved several Malagasy government ministries, the United States Agency for International Development (USAID), the World Bank, conservation organizations, universities, non-governmental organizations (NGOs), and private foundations (Wright, 1992).

The Ranomafana National Park Project (RNPP) approach was fashioned upon an “integrated conservation and development project” (ICDP) model. The ICDP philosophy essentially states that long-term conservation cannot succeed without improving the living standards of people living around the protected area, especially because many traditional forest resource uses (*e.g., tavy*) are incompatible with the conservation action. Four basic elements of the ICDP approach include: 1) managing protected areas for biodiversity, 2) establishing and maintaining buffer zones around the protected areas, 3) compensating or providing alternatives to local residents, and 4) promoting local social and economic development (Wells and Brandon, 1992; Peters, 1998).

The RNPP coordinated research efforts that were designed to address the various ICDP elements. Initial surveys of villages surrounding the RNP indicated that villagers were most concerned with “the closure of park lands to agriculture, forestry, and an immediate need for improved health services.” (Duke University and North Carolina State University, 1989) A 1989 grant proposal to USAID, seeking funding for applied research in these subjects, explicitly acknowledged the connection between participatory development and ultimate conservation success:

> Creation of Ranomafana National Park by government decree will not necessarily ensure its protection. Continuing slash and burn agriculture and unmanaged forestry activities pose the greatest threats to the national park…From the outset of the park project it was recognized that long-term conservation of the park would only be possible with the willing cooperation of the local population. (Duke University and North Carolina State University, 1989:1-2)

Research directed toward meeting the RNPP goals eventually included fields such as protected area management and tourism, biodiversity, forestry, agriculture, health, and socioeconomic research.

The long-term viability of the RNP protected area largely depends upon the successful identification and implementation of suitable alternatives to *tavy* that increase, diversify, and stabilize agricultural production within the RNP vicinity. On the technical side, one fundamental step in this process is the systematic characterization of soil properties and a survey of soil distribution across the landscape. This information is essential for identifying the constraints to, and potential for, agricultural production under varying levels of inputs and management. Soil characterization/survey data are also basic tools for forestry and agroforestry planning.

The eminent soil scientist Dr. Guy Smith, paraphrasing Milton Whitney, repeatedly and eloquently stated the rationale for soil survey as it applies to agrotechnology transfer: the purpose of soil surveys is to be able to transfer soils data, research, and experience reliably from one part of the world to another (Smith, 1984). Within the last few decades, an extensive body of scientific knowledge has been compiled for soils of the humid tropics (e.g., Sanchez, 1976; Sanchez and Hailu, 1996; Beinroth et al., 1996), regarding soil properties, management strategies, and sustainable agriculture. Soil characterization and survey data allow this accumulated knowledge to be systematically transferred to areas where little or no agricultural experiment data exist, as is the case in eastern Madagascar.

Selective application of this soils-based knowledge allows developing countries to forego much basic soils research that has been repeatedly verified around the world, saving countries considerable time and money in addressing their pressing needs (Buol and Denton, 1984; Eswaran et al., 1992). Nations can then target their limited resources to investigate agricultural and forestry issues that are unique to their setting, adapting technologies that are most suited to the special circumstances facing their farmers. The successful transfer of locally appropriate agricultural technologies depends upon many factors other than soil properties, including climate, topography, weed ecology, pests and diseases, social, economic, and cultural factors (National Research Council, 1993). However, agrotechnology transfer cannot be systematically and reliably accomplished without consideration of soil characteristics (Buol and Denton, 1984).

Modern detailed studies of Madagascar's rainforest soils are scarce (see Chapter 2), although maps and/or reports exist that describe the general properties and distribution of soils in eastern Madagascar (FAO, 1977; Segalen, 1995; WSR-USDA-NRCS, 1996). Systematically testing and implementing long-term sustainable alternatives to *tavy* in the RNP region requires detailed soil characterization data and soil survey information, which helps to define the range of soil properties and their occurrence within the area.

This dissertation research represents one component of the RNPP, namely a soil characterization and reconnaissance soil survey to support the agricultural and forestry development efforts of the RNPP. The specific objectives of this study were as follows:

- To systematically investigate the range of soil properties within the RNP region, based upon variations in soil genetic factors such as geology, topography, climate, etc.
- To provide pedon descriptions and characterization data for representative soils within the region, as well as for any unusual soil types.
- To provide a basis for future soil mapping through documenting changes in soil properties across the landscape.
- To provide soil interpretations for potential land uses, utilizing a natural classification system (Soil Taxonomy) and a technical classification system (Fertility Capability Classification, or FCC).