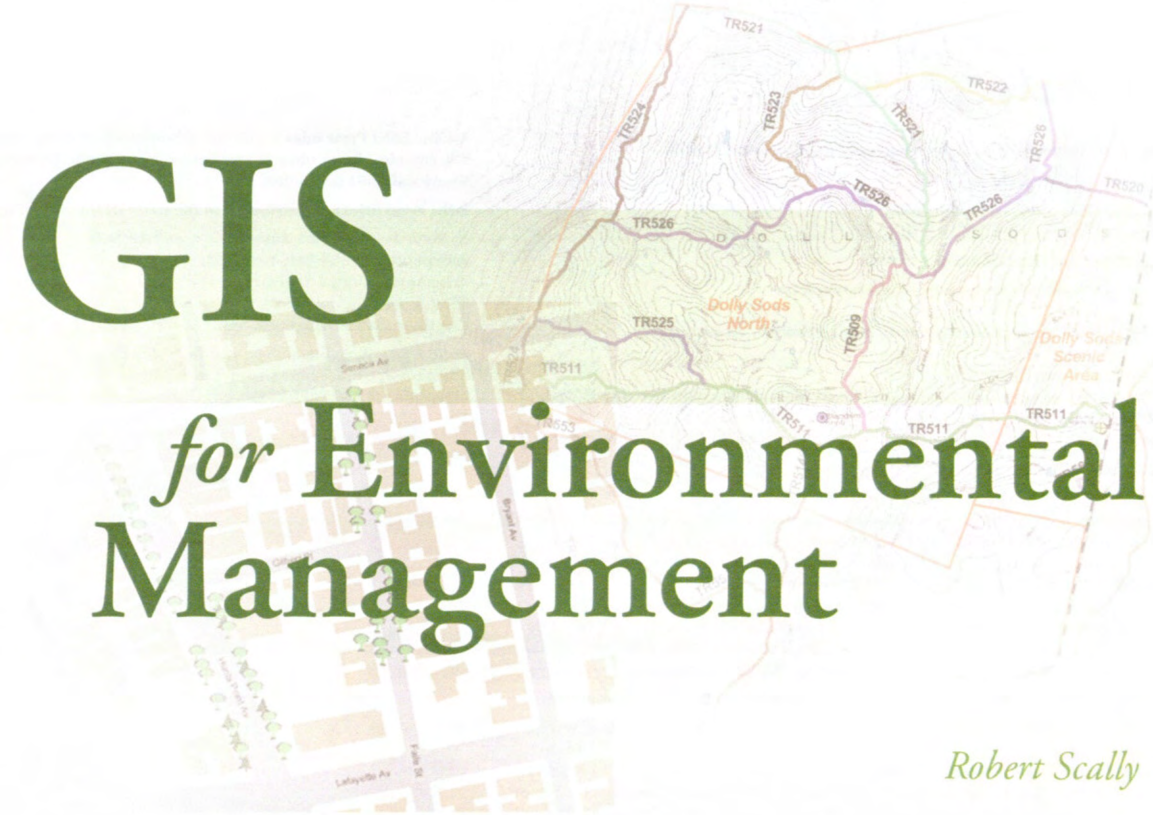

GIS *for* Environmental Management

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Foreword

Earth's environment is a single, vast interdependent system. We cannot make demands on the environment in one part of the world without creating consequences in another. Humanity's effect on these interdependent ecosystems presents difficult challenges for governments, scientists, businesses, and environmentalists in every discipline. Finite natural resources and an ever-increasing population mean responsible and successful environmental management worldwide is no longer a luxury, but rather a necessity.

Protecting and restoring the environment requires better ways of managing our world using informed, responsible, and successful techniques. GIS technology is playing an increasingly crucial role in the delivery of information to decision makers, environmental managers, and the public.

GIS for Environmental Management showcases some of the most innovative GIS projects created by governments, businesses, and individuals. Balancing technology with practical human applications, these case studies give voice to the people using GIS to better manage our environment.

Jack Dangermond
President, ESRI

Preface

Earth's increasingly complex environmental challenges demand increasingly sophisticated solutions. Geographic information systems (GIS) technology is one solution to humanity's need to better manage, protect, and preserve our environment.

Along the U.S.–Mexico border, choking dust threatened the health of residents in Douglas, Arizona, and nearby Agua Prieta, Mexico. GIS identified the sources of the dust and aided in the efforts to solve the problem.

The Missouri Botanical Garden used GIS-based data gathered during twenty-five years of research to help Madagascar expand its ecologically protected areas as part of a campaign to preserve the earth's biodiversity.

In Japan, a university professor created an Internet site that uses GIS to link scientists with others interested in preserving a historic wetland. Another professor in the United States relies on GIS to assess the health of wetlands along the shore of Lake Ontario in upstate New York.

These are but a few of the innovative projects presented in *GIS for Environmental Management.* The projects showcase solutions in various aspects of environmental management, ranging from biodiversity and pollution to more specific subjects such as coastal zone management and habitat change detection.

During the 2005 ESRI International User Conference keynote address, renowned zoologist and conservationist Dr. Jane Goodall said, "Anywhere I see a problem, I see groups of dedicated people trying to right those problems." The theme of the 2005 User Conference, "GIS—Helping Manage Our World," dovetails with this book's message. While the job of managing our environment grows more complex, GIS is helping make the task more manageable.

The case studies in this book are about more than just technology. They also discuss the people using GIS to preserve our environment for future generations. In each of these cases, GIS professionals and scientists devised projects and conducted analyses that would be impossible or impractical without computers and GIS. In several of these projects, solving the technological problems was the easy part. Getting disparate organizations and individuals to work together to create GIS-based solutions that met a shared need or solved a common problem were the projects' true accomplishments.

Acknowledgments

I want to thank Nick Thomas of ESRI's marketing department for conceiving the vision for this book, sorting through more than two hundred potential case studies, and being a great listener and a good friend. I would like to acknowledge two former ESRI Press staff members, R. W. Greene and Christian Harder, for providing support and guidance early in this project.

My editor at ESRI Press, Mike Kataoka, provided his considerable skills and patience in the editing of this book and helped guide it to completion. Thank you, Mike.

Thanks also go to Gary Geyer of Centerville, Indiana, who generously donated his time and finely honed knowledge of the English language. He read one of the final drafts of this book and made edits and suggestions. Gary, you are one of the nation's great teachers; your students are fortunate to have you.

Most importantly I want to thank my wife, Lisa, who is also a great writer and editor, for all of her help, support, and patience. I couldn't have done it without you. Last, but not least, I want to thank my children, Clark and Ava, for their love and support.

I commend all of the people involved in the case studies in this book for their professionalism, depth of knowledge, and cooperation in the making of *GIS for Environmental Management*. Thank you all.

Biodiversity 1

Expanding Madagascar's national parks and protected areas

Madagascar's remote location and unique climate have made it one of the earth's most biologically diverse places.

Data provided by 2004 ESRI Data & Maps

For botanists and biologists, Madagascar is a fabled lost world alive with numerous unique plants and animals. Eighty percent of the island's twelve thousand to fourteen thousand plant species are endemic, including 850 of 1,000 orchid species. Madagascar is one of the earth's most geographically remote and biologically diverse places and its fourth largest island. It sits in the Indian Ocean about 200 miles (300 kilometers) off the eastern coast of Africa and is about the size of France, its former colonial ruler. A combination of its size, remote location, and varied climate create unique biological environments.

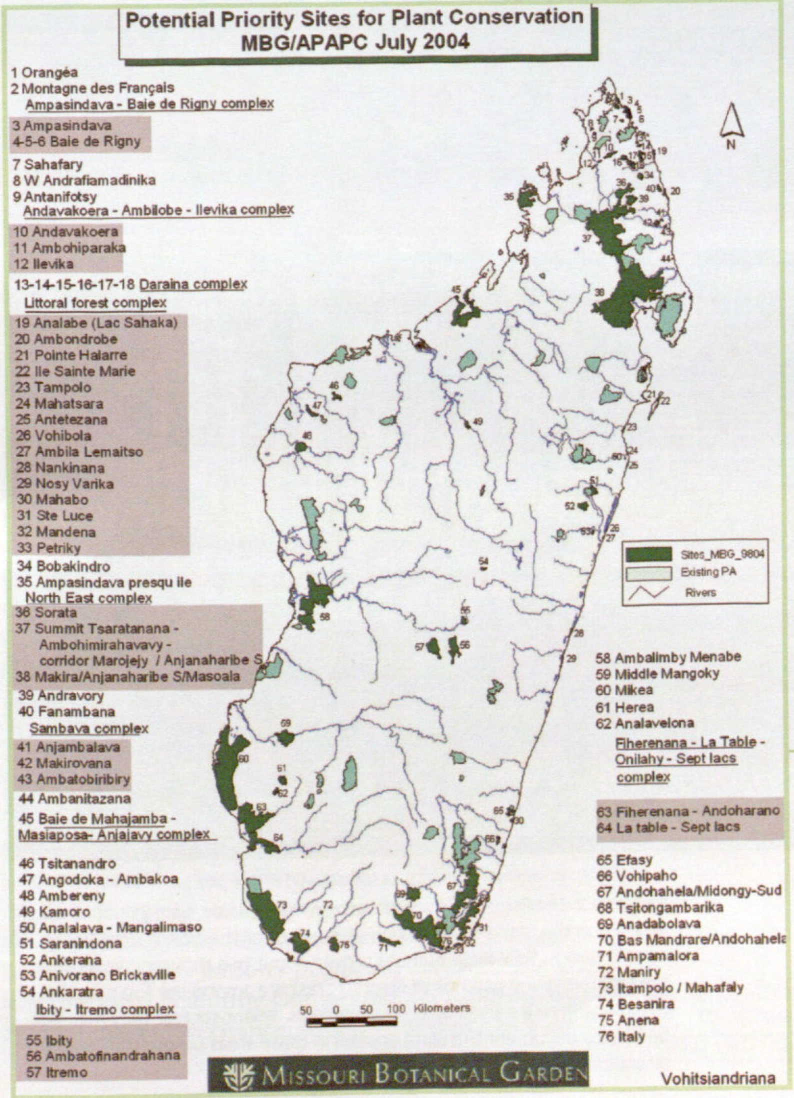
"Madagascar is a living laboratory of evolution," said Dr. George Schatz, biologist and curator at the Missouri Botanical Garden (MBG) in St. Louis, Missouri, and expert on the island's flora.

A new conservation vision

Due to its unparalleled biodiversity, Madagascar is one of the world's top conservation priorities. In 2003, Madagascar's president, Marc Ravalomanana, proposed a major expansion of the nation's national parks and environmentally protected areas. Ravalomanana's conservation plan, known as the Durban Vision, proved fortuitous for MBG researchers. The MBG is a leader in the study of Madagascar's flora and conducted continuous research and numerous conservation projects on the island for more than twenty-five years. Much of the MBG's data is managed within an ArcGIS system, which helped the scientific analysis and created informative maps.

The Malagasy government asked the MBG to recommend plant life to include in the country's expanded protected areas. The MBG used GIS to tap into its vast Malagasy botanical research database to rapidly assemble a comprehensive and authoritative report.

With a permanent research presence in Madagascar, MBG has helped train several Malagasy scientists and, more recently, GIS professionals. When President Ravalomanana conceived of the Durban Vision, MBG researchers happened to be assessing priority sites for plant conservation. That multiphase project, the Assessment of Priority Areas for Plant Conservation (APAPC), was underwritten by the Critical Ecosystem Partnership Fund and is ongoing. The APAPC project fits well with the objectives of the Durban Vision project.



Map by Tantely Raminosoa, Missouri Botanical Garden.

Figure 1.1 Seventy-six sites of plant conservation importance proposed in a two-day workshop at the Missouri Botanical Garden (MBG). Participants included MBG botantists who have worked in Madagascar for more than fifteen years, as well as several Malagasy biologists.

Photo by David Rabehevitra, Missouri Botanical Garden.

Figure 1.2 The littoral forests of eastern Madagascar, such as Nankinana, located on the island's east coast forest north of the city of Nosy Varika, have shrunk rapidly since humans arrived about two thousand years ago. The few remaining patches of littoral forest are among the top priorities to include in new parks and protected areas. Scientists fear they may not be able to document the plant species in these areas before the forests disappear.

Because the island supports a rapidly growing population, which numbered about 15 million people in 2005, there is great demand for development. Much of Madagascar's remaining rich natural environment was unprotected until recently. More than 80 percent of the island's original forest has been destroyed. In 2000, an estimated 34,000 square miles (8.8 million hectares) of Madagascar's forest remained, with about 4,479 square miles (1.16 million hectares) of the forest within the protected areas network managed by the Malagasy National Association for Protected Areas Management (known as ANGAP for *Association Nationale pour la Gestion des Aires Protégées*). The protected areas represented about 3 percent of the country's land and included eighteen national parks, five natural reserves, and twenty-three special reserves. The Malagasy Water and Forest Direction managed another 6,564 square miles (1.7 million hectares) of forest outside of the protected areas. The remaining Malagasy forest, about 23,166 square miles (6 million hectares), was unclassified by the government and considered *forêt domaniale*—national forest—vulnerable to anyone with a chainsaw or an ax.

That situation improved during the September 2003 World Parks Congress in Durban, South Africa, when President Ravalomanana proposed tripling the size of the island's protected areas. Up to 17,375 square miles (4.5 million hectares) of new protected areas, including wetland and marine environments, are included in the expansion, equal to about 10 percent of the nation's overall area. Ravalomanana reiterated his commitment to expanding his nation's protected areas during the International Scientific Conference on Biodiversity, Science, and Governance, which took place in Paris during January 2005. Making the connection between the need for sustainable development and conservation, Ravalomanana asserted that biodiversity protection is an important element in decreasing poverty and increasing opportunities for Madagascar's people. In December 2004, after extensive GIS analysis, the MBG delivered its recommendations for expanding Madagascar's environmental preserves to President Ravalomanana. It took just six months to produce the report for the Durban Vision initiative.

"This project came about because of our firm commitment and long history in Madagascar," said Trisha Consiglio, GIS analyst for the Missouri Botanical Garden. "The environmental community recognized that we were the foremost plant experts and had the best information about plant conservation."

Using decades of data

Working with the Malagasy government, the MBG used GIS to help propose new conservation areas. Base data layers for climate, topography, and geology already existed when the process began, so complex and comprehensive maps were built quickly. "We pulled in all of these years of collecting and the botanists' knowledge of the areas," Consiglio said.

Although the MBG had much of the data for the report either in-house or available from other institutions, producing scientifically sound recommendations in such a short time frame required careful and creative planning. Preparing the materials for the Durban Vision report brought together all aspects of the MBG's Madagascar research and used its connections to other international botanical institutions. Botanists, biologists, and GIS professionals in St. Louis, at England's Kew Gardens, the *Jardin des Plantes* in Paris, and in the MBG's Madagascar office, as well as research institutions in Belgium and Switzerland, all provided various pieces of background data used to create the MBG's Durban Vision report. "This project was neat because it was totally interdisciplinary," said Consiglio.

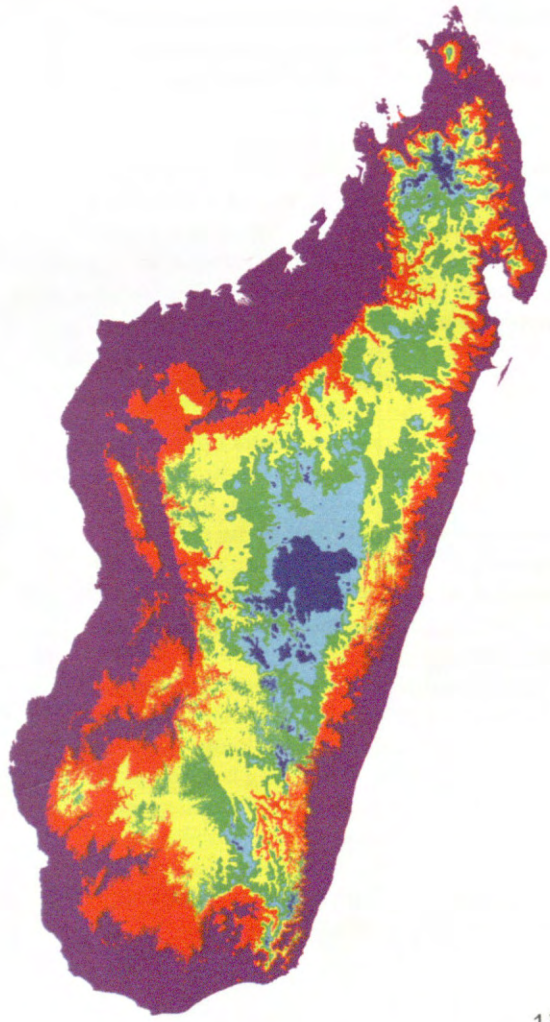
1.3a

Figures 1.3a, 1.3b, and 1.3c Data layers for climate (1.3a), geology (1.3b), and elevation (1.3c) used in the modeling for the Assessment of Priority Areas for Plant Conservation project. Figure 1.3a is a refined classification of the primary vegetation of Madagascar based on the underlying geology.

Source: Missouri Botanical Garden. Digitized by George Schatz based on Cornet, A. 1974. Essai de Cartographie bioclimatique a Madagascar. ORSTOM, Paris.

1.3b

Du Puy, D. J., and J. Moat. 1996. A refined classification of the primary vegetation of Madagascar based on the underlying geology: Using GIS to map its distribution and to assess its conservation status. In *Proceedings of the International Symposium on the Biogeography of Madagascar*, ed. W. R. Lourenço, 205–218, + 3 maps. Editions de l'ORSTOM, Paris.



1.3c

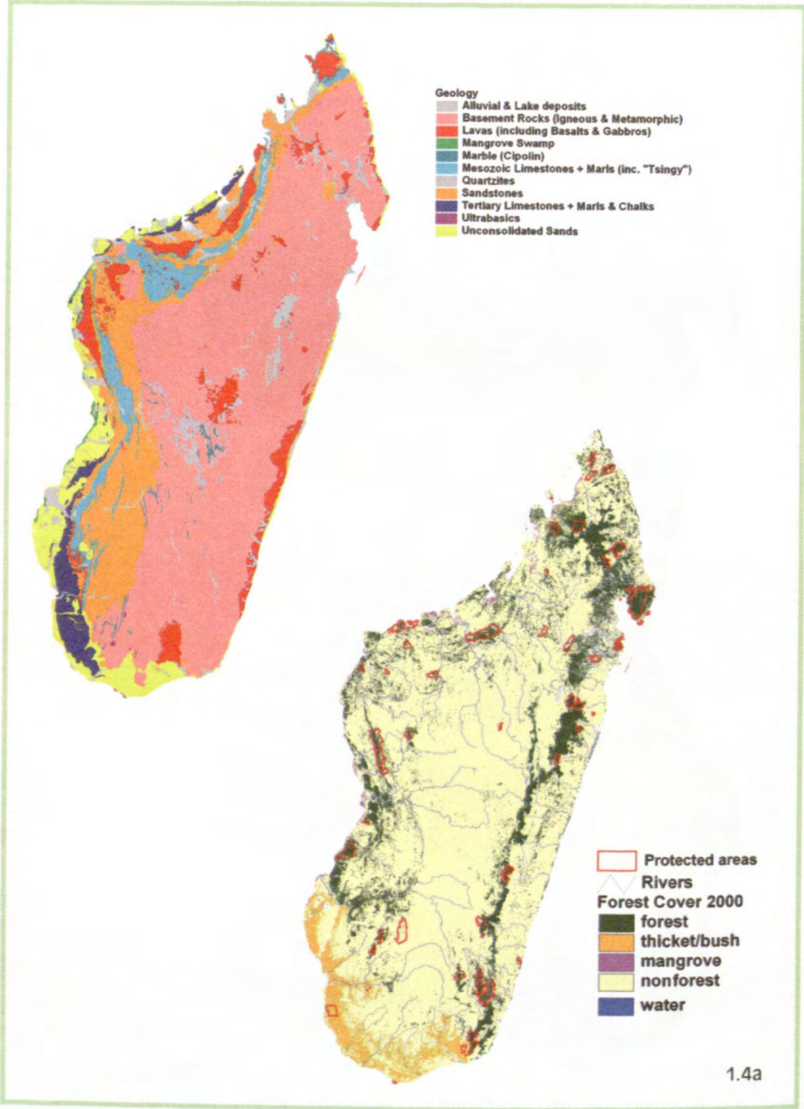
USGS Global 30-Arc-Second Elevation Data Set. (U.S. Geological Survey, Sioux Falls, South Dakota, 1996).

Botanical brainstorming

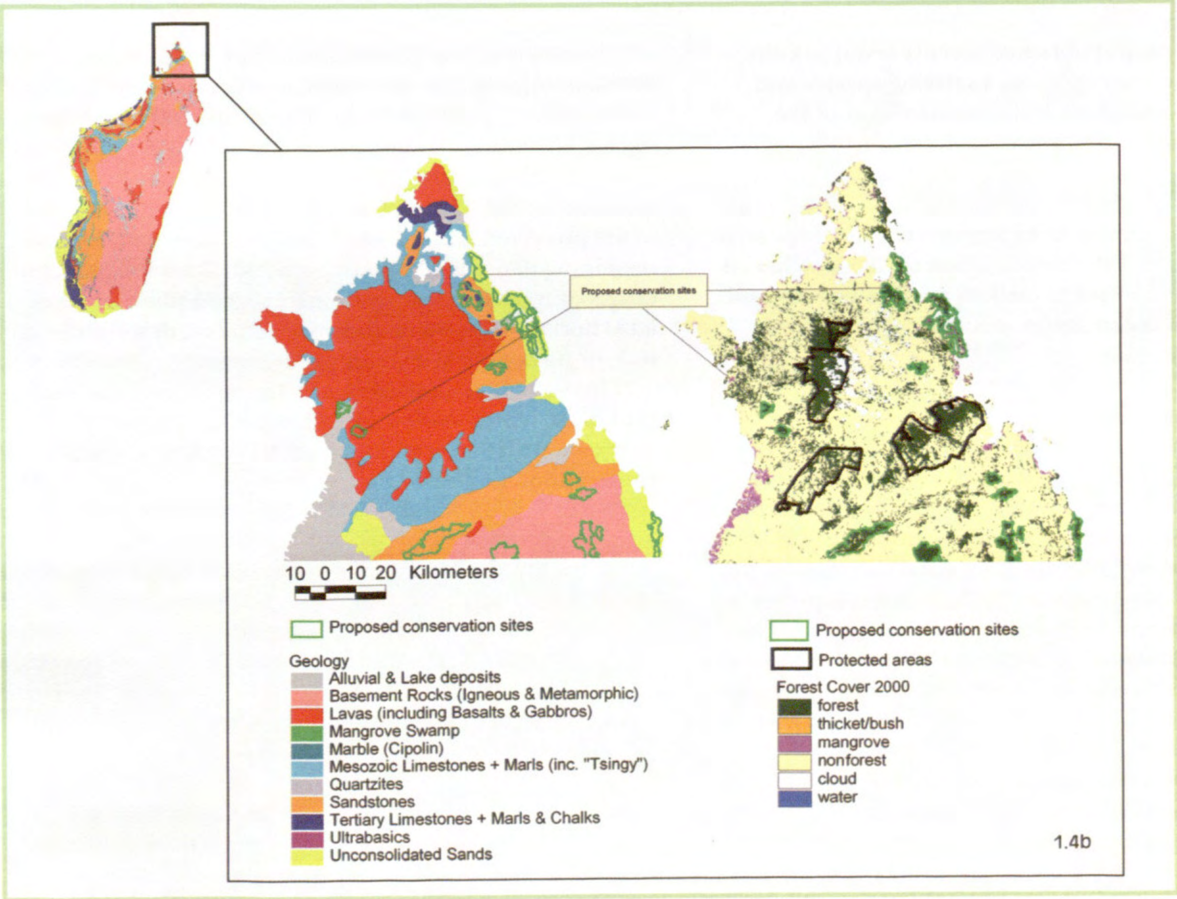
The Durban Vision report GIS was constructed during a collaborative meeting. "What do we know and what do we need to know?" were the primary questions on everyone's mind in July 2004 when the MBG's GIS and Madagascar experts gathered in St. Louis for a brainstorming session. During two long days, botanists and GIS technicians studied paper maps and digital data layers, making decisions about what to include in the GIS and digitizing maps of areas that would be examined more closely. Combining quantifiable GIS work with the knowledge of botanists on the MBG's Durban Vision project proved to be a powerful mix.

"We came up with seventy places right off the bat that [participants] thought might be interesting, just based on the knowledge they had from working in the field and doing research," Consiglio said. "A lot of people can use the data we have and do a lot of nice things with it, but to have that expert knowledge to drive it, that's what's really important."

After the brainstorming session, Tantely Raminosoa, GIS technician for the Missouri Botanical Garden, Madagascar Program, led the two-week process of creating base data layers with the help of Paris- and Madagascar-based botanists. Raminosoa had previously conducted the GIS analysis of the Malagasy Plant Conservation Database that identified priority areas of the APAPC project.



Maps by Trisha Consiglio, Missouri Botanical Garden.



Maps by Trisha Consiglio, Missouri Botanical Garden.

Figures 1.4a and 1.4b Geology, remaining forest cover, and protected areas were used to initially determine potential sites for plant conservation. Using a gap analysis approach, proposed conservation sites were identified as those unique in geology across different bioclimatic zones, occurring on forest patches not already currently protected.

The APAPC project obtained seventy-seven priority areas for plant conservation by analyzing species and habitat. "It was a product of the combination of the intense GIS analyses and the considerable expertise of botanists. Creating the map for the Durban Vision Group is one important component of the GIS activities that are held within the APAPC project. The characteristic of its approach is the combination of the presence of significant plant species in the GIS analysis process and the expertise of botanists [in identifying] the habitat gap," said Raminosoa.

Conducting the analysis

With the data layers in place, scientists could concentrate on analysis and generating maps. The scientists used a database of approximately 1,200 species consisting of more than 15,700 georeferenced records to perform the analysis. Criteria for selecting plant species for the GIS analysis was primarily based upon endemism, the relative "representativeness" and taxonomic framework of each species. The first step was to map the primary occurrence of each species using ArcView GIS software. Once the distribution of a species was determined, project botanists verified the accuracy of the location and presence of each species.

MBG botanists conducted a species distribution analysis using WORLDMAP software. Raminosoa produced maps showing richness and range size and rarity of each species. The botanists used a spatial and tabular gap analysis to determine which species were found within and outside the current ANGAP protected areas. (Gap analysis is the scientific method of identifying and classifying components of biological diversity and determining which components are already in protected areas and which components are absent from or underrepresented in protected areas.) MBG botanists also conducted a habitat gap analysis using environmental parameters, including environmental surrogacy, climate, substrates, elevations, and vegetation type. They selected remaining areas of extant primary habitat for analysis and defined important botanic areas not included in the protected areas. Researchers used co-occurrences of remaining native vegetation, combined with a unique set of ecogeographic features, to strongly suggest where areas of local floristic richness or endemism existed, despite having little or no botanical data for those areas.

"This work is composed mostly by spatial analysis, using grid data," Raminosoa said. "They will be part of the data compilation sheet that is a full description of each conservation site."

Species distribution modeling: Predicting where plants live

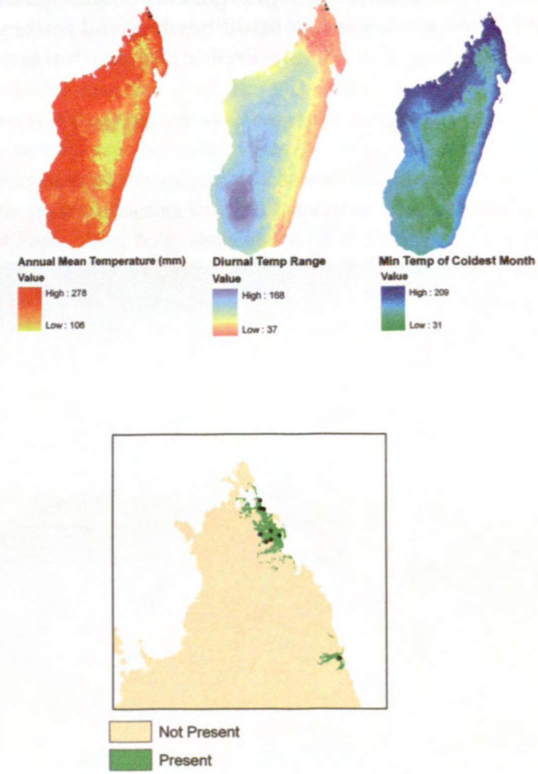
MBG botanists used species distribution modeling to analyze the potential distribution of important plant species that exist outside of the current protected area network. The MBG used a modeling technique that maps similarities between areas based on ten environmental layers:

- Bioclimate
- Length of dry season
- Simplified geology
- Elevation
- Annual mean temperature
- Mean diurnal temperature range
- Temperature seasonality
- Minimum temperature of the coldest month
- Annual precipitation
- Precipitation seasonality

To improve results, the MBG integrated other prediction algorithms such as Genetic Algorithm for Rule-set Production (GARP) into its analysis. GARP is a method that automates the use of environmental data collected through field surveys to produce distribution maps and models.

Once the priority areas were defined, GIS produced basic information composed of the following seven categories for each site:

- Site identifications
- Administrative information
- Geographical information
- Botanical information
- Substrate information
- Bioclimatic information
- Vegetation information

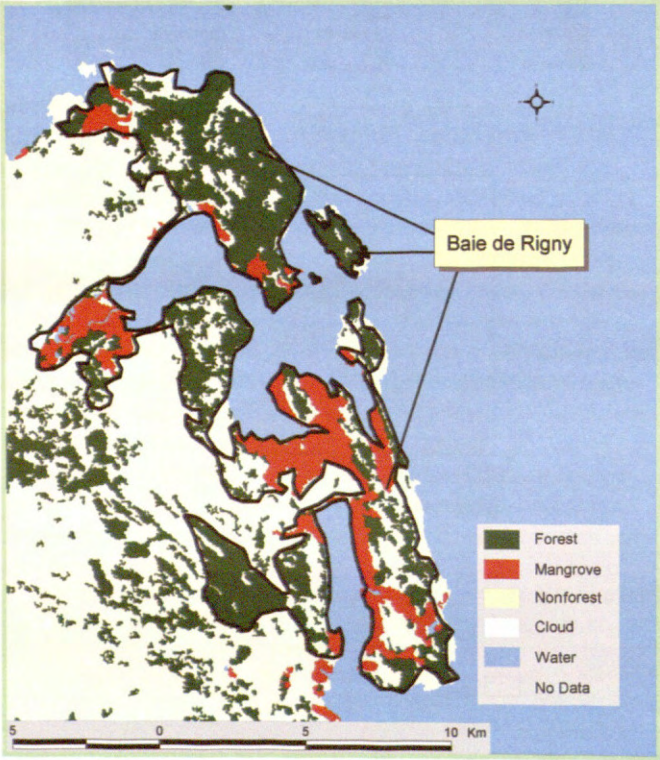


Map by Trisha Consiglio, Missouri Botanical Garden.

Figure 1.5 Climatic data layers were used to create potential distribution maps for species of conservation concern. The potential distribution of *Rhopalocarpus triplinervius* was determined by using the DOMAIN similarity algorithm applied to various climatic data layers and specimen collections of the species.

Minding the gaps

The MBG's GIS work, an integral part of its Madagascar research, extends beyond political borders and far beyond general mapping. The MBG is exploring ways that spatial modeling and remote sensing can help scientists discover where various unique plants are likely to grow. By combining GIS, prediction algorithms, and reserve selection criteria, the MBG helped devise recommendations to protect areas of high biodiversity and centers of endemism.



Map by Tantely Raminosoa, Missouri Botanical Garden, using data from Steininger, M. et al. 2000. *Forest Cover Fragmentation and Clearance in Madagascar.*

"We measure the distribution of plants against a number of environmental parameters such as underlying geology," Schatz said. The geological data layer exemplifies the international nature of the MBG's Madagascar GIS work. The base geology map used in the MBG analysis was produced by a team at Kew Gardens, which in turn based its work on a geology map of Madagascar produced by the French government in the 1960s. "That's been an extremely useful data layer for us to measure plant distributions against," Schatz said. Much of the work involved gap analysis of various plant species overlaid with the nation's current protected areas. Using GIS, some trends were immediately apparent.

Northern Madagascar has several large protected areas, but about forty to fifty plant species living in sandy soil and endemic to the region were not represented in the protected areas. "It was absolutely revealing to map these species against the geology and against the current protected area polygons and go 'Wow, look at that.' All of these species are occurring on sandstone, and there's no sandstone in the protected areas. It's a dramatic story that we can present to the Malagasy government and say there's this entire ecosystem that's lacking protection in the north," said Schatz.

Figure 1.6 Detail of a proposed protected area near the Baie de Rigny in northeastern Madagascar.

Malagasy researchers play key roles

The MBG's work in Madagascar has benefited the conservation of one of the world's most ecologically sensitive places. It has also created jobs and educational opportunities for Malagasy scientists and GIS professionals. Over the years, the MBG has employed Malagasy staffers to work on research and conservation efforts. Its Malagasy staff was essential in preparing the analysis and maps for the Durban Vision Group. Two Malagasy MBG Conservation and Research Program botanists, Sylvie Andriambololonera and Jeannie Raharimampionona, are coordinators of the APAPC project. Graduates of the University of Antananarivo's botany department, Andriambololonera and Raharimampionona have worked for the MBG Madagascar program since 1992. They also participated in weekly working sessions of the Durban Vision Group, focusing on the technical and scientific aspects of the process. The MBG was the primary botanical institution within the Durban Vision Group and led its flora subgroup.

"From the start of the process, MBG viewed the Durban Vision as a great opportunity to integrate the APAPC project's results in a conservation zone as a whole," Andriambololonera said. "Therefore, since the beginning, MBG has been fully involved in the implementation of the Durban Vision process." Raminosoa brought together the Durban Vision Group's GIS experts to produce and refine the preliminary maps of potential new protected areas. This work builds on the World Wildlife Fund's analysis of conservation priorities for Madagascar's ecoregions.

Photo by David Rabehevitra, Missouri Botanical Garden.

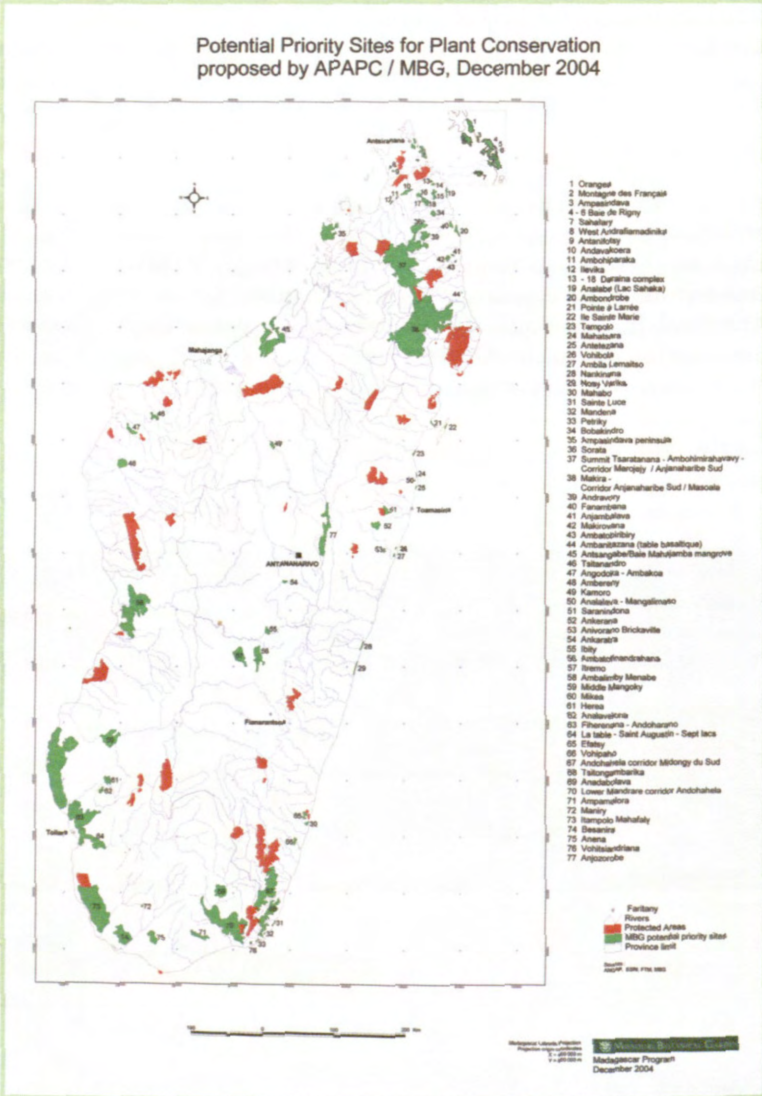
Figure 1.7 Preservation of unique forest habitats, such as this one in the Antaimby area of Madagascar, is one of the highest priorities for the Malagasy government and conservation organizations.

Future research and analysis

With the Durban Vision Group's mapping process in its final stages, work on the APAPC project continues. "We are now conducting the modeling of species distribution (those falling outside the current protected areas) using different algorithms," Raminosoa said.

Collaborating with different groups on the Durban Vision process created a demand for the MBG's GIS services. "As MBG is becoming more involved with consultations with other organizations, we are furnishing our services based on our competence, including GIS analyses activities of the botanical collections database," he said.

Raminosoa also leads the GIS activities of the MBG's consultancy with the Ambatovy Mining Project and works with researchers, specialists, and students on their GIS analysis projects. He continues to focus on the Priority Areas for Plant Conservation project as well as other GIS analyses related to different projects of the Missouri Botanical Garden, Madagascar Program. Thanks to GIS, the MBG was able to present a very real and compelling scientific report that will help realize the Durban Vision of expanding the nation's protected areas and preserving one of the world's most biologically diverse places.



Map by Tantely Raminosoa, Missouri Botanical Garden.

Figure 1.8 The final map of proposed new biologically protected areas in Madagascar, December 2004. It was developed by creatively using GIS and twenty-five years of the Missouri Botanical Garden's research on the island's flora.

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