A Model for a Global Inventory of Ants: A Case Study in Madagascar

Brian L. Fisher

Reprinted from the
Proceedings of the California Academy of Sciences, ser. 4, 56(Suppl. I)
3 June 2005

Reprinted from the *Proceedings of the California Academy of Sciences*, ser. 4, 56(Suppl. I)

PROCEEDINGS OF THE CALIFORNIA ACADEMY OF SCIENCES

Volume 56, Supplement I, No. 8, pp. 86–97, 3 figs., 1 table. June 3, 2005

A Model for a Global Inventory of Ants: A Case Study in Madagascar

Brian L. Fisher

Department of Entomology, California Academy of Sciences, 875 Howard Street, San Francisco, California 94103, Email: bfisher@calacademy.org

For systematics to receive wide support across the biological and environmental sciences and attract public interest, taxonomic endeavors must be accelerated, products made more widely accessible across a broader community, and effort focused on global revisions of select taxa. Without this change in scope, systematics will never be in a position to respond to the needs of conservation or provide convincing examples of the role of taxonomy in society. Without this change, there will be little hope in attracting the broad and deep support needed to discover the vast amount of as-yet-undocumented diversity before it disappears.

Among the arthropods, ants (Hymenoptera: Formicidae) are an especially diverse and ecologically important group whose social behavior and ecological dominance have been the subject of intense biological study. These characteristics strengthen the selection of ants as a model taxon for global inventory. The model I describe is based on protocols tested in Madagascar to collect, inventory, process, prepare, and identify enormous numbers of ant specimens across diverse large-scale landscapes. In addition, the concurrent development of tools to accelerate species identification, description, and dissemination demonstrates the feasibility, challenges, and impacts of a global inventory of ants.

Systematists are charged with the intellectual enterprise of documenting and describing the history of life on Earth. They search for answers to the fundamental biological questions: What kinds of living things exist? Where do they live? How are they related? This is tedious and difficult work that requires enormous patience, experience and knowledge. Systematics has experienced a devastating erosion of its human capacity leading others to claim it is virtually dead (Godfray 2002; House of Lords 2002). The surge in funding and public awareness for conservation issues has almost completely overlooked taxonomy. Public and other funding bodies view systematics as unimportant and of little relation to the magnitude and urgency of the conservation crisis. They fail to appreciate the value of taxonomy.

But shouldn't society be clamoring for an increase in taxonomic information? Why are so few convinced that our goal should be to accelerate the collection and analysis of biodiversity information globally in response to the disappearance of natural habitats? Is it true that we don't need to know very much about what is living in a habitat to preserve it?

Biologists have argued that systematics provides an essential foundation for understanding, conserving, and using biodiversity (Blackmore 1996; Margules and Pressey 2000; Wilson 2000, 2003; Georgina et al. 2003). Yet systematists have been unable to convincingly demonstrate the vital role they could play in conservation. They have not demonstrated where taxonomy (or the lack of it) has had a profound impact on society. There are few examples that clearly illustrate the practical applications of knowledge on species distributions to the saving of more species and to the improvement of human society (for examples, see Balmford 2003; <*http://www.bionet-intl.org/*>). Without clear examples, the public and the scientific community will not understand how knowing about more species will greatly help us preserve and conserve a greater number of them.

Systematists have few examples. This is in part, because they know so little about life on this planet — only a small fraction of life on Earth has been scientifically described and this fraction is distributed across many taxa (Blackmore 1996). Thus, systematists lack sufficient baseline global data on specific taxa that are accurate, comparable across sites, and fine-scaled to effectively demonstrate its role in conservation. They even lack a model of how to acquire these data in a time frame that is relevant to conservation. The existing near-catastrophic species extinction rate is often voiced as a call for action, a call to create a grass roots movement to establish the deep changes needed to tackle the vast diversity yet to be described. However, if nothing is done to change the glacial pace of current efforts and practice, it will take centuries to complete even a preliminary "Encyclopedia of life" on Earth (Wilson 2003). It is clear that if systematics is going to play a practical role concerning the preservation and development of natural systems, changes need to occur throughout the entire systematic process, from collecting to description, from publication to dissemination, and from public outreach to advocacy.

In this paper, I show how taxonomic data can be gathered, analyzed, and synthesized into useful products in a timeframe that meets the challenge presented by the rate of biodiversity loss. I test a model for accelerating the taxonomic process with the aims of providing the necessary data for effective taxonomy, and — most importantly — the tools for making data accessible and applicable to the conservation agenda. The model is tested on a key taxonomic group, ants, and in an especially threatened area, Madagascar. I describe the inventory procedure, processing facilities, data management, and identification tools developed and tested in Madagascar as part of the Madagascar Ant Diversity Initiative project (MANDI).

Case Study: Madagascar

Urgency

Madagascar has been identified as one of the world's outstanding biological hotspots, harboring a unique and threatened biota, whose composition and origins are linked to the breakup of Gondwana (Battistini and Richard-Vindard 1972; Jolly et al. 1984; Storey et al. 1995; Lourenço 1996; Goodman and Patterson 1997; Goodman and Benstead 2003). As in many island environments (Gillespie and Roderick 2002), Madagascar's indigenous terrestrial arthropods are in severe danger of extinction due to habitat deterioration and invasion of exotic species. Since humans colonized Madagascar circa 1500–2000 years ago (Burney 1987), it is estimated that as much as 80% of Madagascar's original habitat has been destroyed (Sussman et al. 1996). Much of the island is now very species-poor secondary grassland, which is annually burnt and highly eroded.

Never has there been a more supportive political environment in which to address these threats in Madagascar. Over the next ten years, the Malagasy government plans to more than triple the number of protected areas and is committed to sustainable conservation planning. To accomplish these goals, areas of conservation importance must be determined. One major obstacle to the identification of areas for protection in Madagascar is incomplete knowledge of the island's patterns of species richness, turnover, and endemism (Schatz 2002). It is unclear which of the remaining patches of natural vegetation should be of highest priority for conservation. What data exist are often at inappropriate spatial scales required for conservation implementation, not standardized across sites, and focused on vertebrates, which represent only a small proportion of the biota.

Spatial Scale

Recent case studies confirm that shifting from broad-to-fine scale planning maximizes biodiversity conservation and that fine-scale data are usually required for implementation at local levels (Balmford 2003; Rouget 2003). In a case study focusing in on the Agulhas Plain within the Cape Floristic Region, fine-scale assessment was most important for heterogeneous and fragmented areas (Rouget 2003). Conservation assessment in the highly fragmented habitats of Madagascar will require fine-scale data to be gathered. For example, in eastern Madagascar, birds may be the least appropriate group to choose for fine-scale assessment whereas other taxa such as ants are far more sensitive instruments.

In a comparison of birds and ants at four reserves in eastern Madagascar (Parc National (PN) d'Andohahela, PN d'Andringitra, PN de Masoala, Réserve Spéciale (RS) d'Anjanaharibe-Sud), birds showed very low levels of complementarity (distinctness) and turnover between elevations within localities and between all four localities (Fisher 1997). Consequently, prioritization of protected areas based on preserving representative species of bird may not equally protect taxa with higher levels of turnover, such as ants, amphibians, reptiles, or insectivores. For example, based on the four localities, the RS d'Anjanaharibe-Sud had the highest species richness of birds and therefore could be chosen to receive the highest priority for protection. The RS d'Anjanaharibe-Sud also had the highest species richness for ants. Although 96% of the tropical forest dwelling bird species from the four localities would be preserved in the RS d'Anjanaharibe-Sud, only 47% of the ant species from all four localities would be protected. If high levels of turnover drive conservation evaluation, then data on ants and possibly other invertebrates (Olson 1994) are critical. MANDI is a model solution for this need and can provide vital fine-scale data for conservation planning and monitoring efforts.

Ants

Ants are of signal ecological importance. Our understanding of their taxonomy, diversity patterns, evolution and ecology, however, is limited and does not reflect either their crucial role in global ecosystems or their potential importance in land management and conservation (Agosti, et al. 2000). It is estimated that only half of the world's ant species — currently numbering about 11,000 — have been described. A more complete inventory of the world's ant fauna is essential to advance understanding of ant ecology, evolution and behavior, and to take full advantage of their demonstrated value in conservation priority setting, biomonitoring, and biological control. To inventory, describe, and classify all ant species are goals that should be embraced by the entire systematic and conservation community.

Until recently, the ant fauna of Madagascar was poorly known. It, thus, provides an ideal testing ground for developing a global ant inventory procedure (Fisher 2003). The objectives in Madagascar were to complete an overview of the ant fauna for taxonomic and evolutionary studies, and to create a map of diversity patterns for use in land management and conservation priority setting. Thus, the inventory goals were not to simply create a list of species for each locality, but to produce the necessary specimens for detailed systematic analysis plus the biodiversity data for the many users across the conservation community.

INVENTORY MODEL OVERVIEW, METHODS, TOOLS, AND IMPACTS

Inventory

Solutions to collecting and processing specimens were addressed by developing efficient, scaleable workflows, termed the "industrial strength" approach by E.O Wilson. The success required new specimen capture methods, fine-scale specimen processing techniques, establishment of industrial-sized processing centers, integrated data management, and intensive taxonomic training.

The overall collecting and inventory design is based on the hierarchical labor cost of taxonomy (Table 1). The least expensive aspect of systematics is the collecting. The next stage, data and specimen processing, ranks second, whereas taxonomic identification and description is the most expensive part of the process. Collecting and processing schemes, therefore, must maximize taxonomic product and reduce its costs. For processing, this translates to providing taxonomists the minimum number of correctly prepared and databased specimens of the greatest number of species. For collecting, this means choosing field sites that maximize new species capture and choosing methods that maximize species collection per endeavor.

TABLE 1. Relative skill level, time, and costs of personnel involved in collecting, processing, and identifying ant specimens in Madagascar.

Skill and Pay Level	*Activity Description*	*No.*
Field Team: 6 months/year		
Assistant level I	local field assistance	3
Assistant level II	field collection	4
Field leader, level IV	permits, field preparations	1
Processing Lab: all year		
Assistant level I	sort all specimens to order; label	3
Assistant level II	sort ants to genera	2
Assistant level III	mount representative ant species	4
Lab Manager, level IV	train and manage	1
Identification: all year		
Assistant level II	specimen data entry	1
Assistant level IV	sort to species	2

Site selection methods. The strategy was to maximize collection efficiency and species-coverage by sampling the full range of habitats found in Madagascar, based on vegetation, climate, elevation, and geological substrate. Previous fieldwork on the island has shown that these four factors strongly influence the species composition of ants on the island (Fisher 1996, 1998, 1999b). Based on the principle of sampling representative habitats and regions, 100 localities were identified for field collecting (Fig. 1). Due to the complex topography and high rainfall, the expeditions were some of the most complex and logistically challenging that have ever been conducted in Madagascar. Results from MANDI demonstrate that site selection based on unique combinations of bioclimate and substrate is an efficient method to capture representative ant species from regions where there are limited pre-existing collections (unpublished data).

Collecting methods. Ant researchers have been leaders in the development of efficient collecting and processing techniques (Fisher 1999a, 2002; Agosti et al. 2000; Fisher and Robertson 2002; Longino et al. 2002). These studies have evaluated: (1) efficiencies of different methods to capture ant assemblages; (2) effect of habitat on method efficiencies; (3) effects of (sub)sample size and spacing on completeness and ranking of species richness; (4) completeness of beta-diversity and complementarity values; and (5) use of surrogate or indicator taxa for estimating total ant richness.

MANDI employs a complement of inventory techniques that have been proven to maximize capture-rate of species per effort. These comprise the following principal quantitative methods: litter sifting, beating low vegetation, and pitfall traps. These techniques involve taking 25 (beating) or 50 (pitfall, leaf litter) subsample collections along a 250m transect for each method. The use of quantitative methods provides, in addition to a species list for each site, information for measuring completeness of the inventory as well as turnover or complementarity of species assemblages between sites (Fisher 1999a). In addition to the quantitative transects, light traps, Malaise, and manual hand collecting are employed. During a three year period, 2000–2003, 54 sites were inventoried across Madagascar using 3280 leaf litter samples, 1350 beating samples, 2700 pitfall trap samples, 216 nights of light trapping, 1350 days of Malaise trapping, and 5900 hand collections. Surveys confirm that the most efficient combination of collecting methods for ants in forest, spiny thicket, and grasslands is leaf-litter sifting plus hand collecting (Longino and Colwell 1997; Fisher 1999a; Fisher and Robertson 2002; Longino et al. 2002).

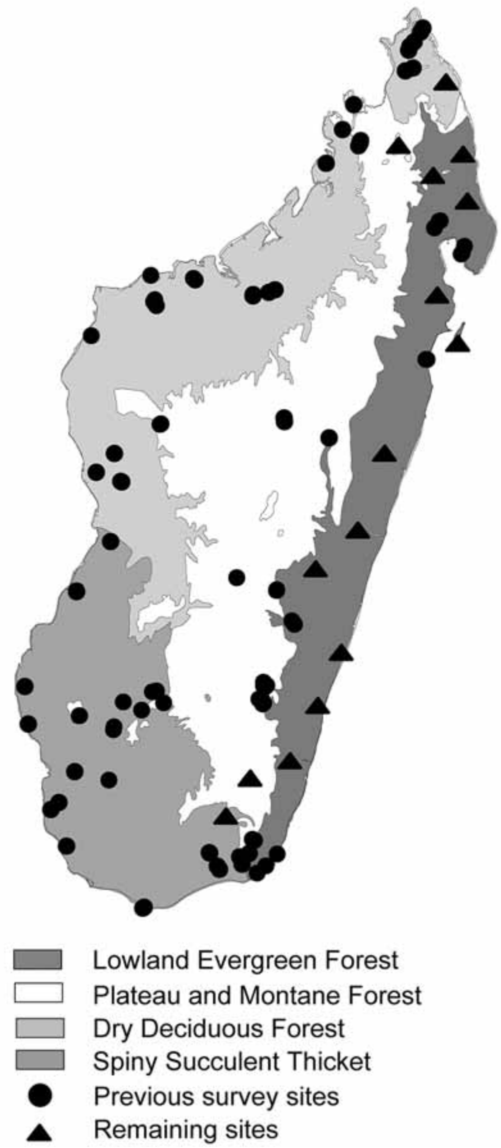

FIGURE 1. Madagascar: location of the 100 localities that were identified for field collecting

Processing

The challenge of processing specimens is its sheer magnitude. With little effort, one can collect millions of arthropod specimens. How do you extract relevant specimens for taxon-specific goals but at the same time make accessible the balance of the remaining millions of specimens for the global taxonomic community? To accomplish this, we developed a specimen-processing protocol that relies on extensive training of personnel, highly partitioned division of labor, and a built-in checking system to insure accurate data capture (Table 1). Specimen processing is more costly than collecting because it requires more people and an enormous investment in taxonomic training (Table 1). The cost in training greatly increases as taxonomic rank decreases. It should be noted, however, that the cost to train technicians to sort insects to order is very low and should be encouraged in all arthropod inventories. Sorting to order greatly increases the accessibility of specimens to taxonomists.

From 2000–2003, we estimate that more than 2 million arthropod specimens were processed and sorted to taxonomically accessible groups, and over 300,000 ants were pinned and labeled. Specimens were sorted at the processing facility in Madagascar and then sent to the California

Academy of Sciences for distribution to over 75 collaborating taxonomists. This approach emphasizes speedy shipping of specimens to active taxonomists.

Ant specimens are removed from each collection sample and sorted to genus. To save preparation costs and reduce taxonomists' specimen-handling time, only a subset of material is prepared. For ants, this translates to mounting one representative of each morphospecies from each mass sample or subsample (pitfall, Malaise, litter, beating, light) and nine representatives from each manual hand collection. Because trained preparators make the decisions about what representative specimens to mount (as opposed to the thousands that might stay in the vial), only a subset is prepared. This saves money in preparation and taxonomists' time in identification. It also reduces the costs of storing and managing prepared specimens of common species that would have been mounted by a mass preparation facility.

Even though this approach results in preparation of a small proportion of all collected specimens, it still represents an excessive number of common species, and at times too few rare species. For example, if a species is found in 1000 samples, this common species will be mounted at least 1000 times. Species found only in a few collections, however, may not be always sufficiently prepared and additional specimens may need to be retrieved from the alcohol samples during taxonomic revision. This is a simple problem, which is easily and cheaply resolved. The problem of mounting of too many common species, however, is costly to correct. Correction would require the preparators to have sufficient taxonomic knowledge to identify the common species that should not be mounted. This could be done if the collections are from a localized region, such as one national park, where the set of common species is constant. It is much more difficult to achieve if the samples are from a wide geographic region. The cost of training preparators may outweigh the savings in managing the excessive common specimens. I know of no simple solution to this problem of occasionally burdening the taxonomist with the handling of large numbers of the most common species.

Data management is an important aspect of the processing facility. Data acquisition is integrated with the demands of specimen processing, fundamental to label production and specimen management. We use the program Biota (Colwell 1996) for specimen data management. We have a centralized control of locality and collection data entry and regional input of specimen level data. Each pin and vial is labeled with a unique object code. Though all vials and pinned material carry unique codes, we currently database only specimens from unique collection records for each species. These are the minimum data necessary to fulfill the needs of taxonomists and to map biodiversity. More in-depth studies that compare rates of species accumulation will require additional data entry (every specimen) and will require an order of magnitude more effort in data entry.

Tools for Accelerating Taxonomy

MANDI has successfully demonstrated the feasibility of collecting and processing specimens at a global scale. New methods were invented and tested for collecting ants and industrial-sized processing centers were established. The enormous amount of material collected and processed, however, presents daunting new challenges: (1) how best to accelerate the analysis and synthesis of biodiversity data, and (2) how can the project achieve its goals to revise all ant species in Madagascar, including the description of 800 new species, and then disseminate this information in a time frame that contributes to conservation decisions?

Nothing can replace the countless hours of careful observation necessary to understand variation and to delimit species boundaries. New technologies, however, are being developed to overcome the most significant bottlenecks in the process of describing and identifying specimens. The necessary steps are: (1) enable more people to participate collectively in the taxonomic process; (2) drastically reduce the number of steps in the documentation, collation, publication, and dissemination of the products; and (3) permit a broader audience to experience and use taxonomic products, thus increasing the value of systematic research.

As part of MANDI, the tools being developed include: (1) access to integrated backbone taxonomic information; (2) digital imaging technology for identification and description; and (3) online infrastructure for digital collation and publication of taxonomic products (species descriptions, maps, etc.). These tools simultaneously address two of the most important issues facing the practice of taxonomy: a need to reduce the number of steps required to identify and describe taxa in order to save time, and an equal need to improve access to and visibility of taxonomic products.

Building the integrated foundation: the three pillars. Unlike other disciplines where publications are rarely accessed after five years, taxonomists need continued access to the entire 250 years of historical literature stored in specialists' museums and libraries. Every step forward, every new piece of data, must be first filtered through this mass of historical information. This enormous burden could be immediately mitigated through online integration of the three pillars of taxonomic knowledge: (1) catalog information; (2) primary taxonomic literature; and (3) images of primary types.

The portal AntWeb <*http://www.antweb.org*> was created to provide access to images of all primary type material in Madagascar, with links to existing catalog information (e.g., <antbase.org>) and digital versions of the original and subsequent relevant redescriptions (William L. Brown, Jr. Memorial Digital Library) (Agosti and Johnson 2002; Dalton 2003). For example, AntWeb includes images of all primary types of the 71 endemic *Strumigenys* in Madagascar, including links to catalog information and original descriptions from Fisher (2000). With little additional effort and cost, the entire taxonomic backbone of the 418 named ant taxa in Madagascar can be made available to everyone through AntWeb.

An image is worth 1000 words. Because the state of ant taxonomy leaves most regions of the world without accurate identification keys to species, the process of identifying specimens is a huge task, costing much more than the collecting and processing of specimens. One of the most significant bottlenecks in the process of identifying specimens is the necessity to examine relevant type material, a procedure both time consuming and costly — but absolutely essential where faunas are incompletely documented and without identification keys. MANDI has collected an estimated 1000 species of ants in Madagascar, representing 300,000 pinned specimens, all of which require identification. Unfortunately, the literature cannot be relied upon for identification because species descriptions in general do not always have accurately detailed descriptions of species limits, much less illustrations. The current procedure for identification relies on visiting type collections or borrowing type specimens, both of which include the difficult step of identifying the location of types. This problem, as illustrated with the ants from Madagascar, is shared by all poorly known taxa and is thus a problem for all inventories and identification efforts (Stevenson et al. 2003).

Because many of the historical ant species descriptions are less than 100 words, an image will go a long way in conveying information on the specimen in question. Digital imaging technology is being used in MANDI to overcome the bottleneck of specimen identification by providing images of named taxa (types) and unnamed (new species). These high resolution images are an in-focus composite of ten to forty images created using the Syncroscopy Automontage software (Fig. 2). A standard suite of images is taken of each specimen: head in full-face view, profile, dorsal and an image of the label.

In Madagascar, where we are documenting a fauna from scratch, images are used to record species as they are discovered and defined, providing placeholders for information and a quick reference for identification. The images represent named and unnamed species and grow as fast as species are discovered. The images are not a key, but with the AntWeb comparison tools, they facilitate comparisons of characters and species. Without AntWeb, comparisons would require access to collections of all possible species, a time consuming process that also presents risks to the specimens.

FIGURE 2. Image created using Syncroscopy Automontage software.

With AntWeb, a researcher will begin by reviewing all species of the genus on AntWeb, comparing images of similar taxa. If a working key has been already established, this key is used in conjunction with AntWeb to confirm identification and present users a reference to characters mentioned in the key. This tool is powerful because it includes all known named and unnamed taxa and includes geographic and colony variation. Images and AntWeb do not replace the enormous time needed to study and define species limits; they are tools to facilitate documentation and identification of specimens.

Digital imaging technology, combined with the ease and speed of distributing data through the Internet and other media, promise immense change to this whole identification and documentation process. Type specimens and entire regional faunas can now be imaged in great detail and made instantly available to the scientific community worldwide. Entire collections of types can be published digitally within weeks for a fraction of the cost of publishing typical printed catalogs. Such an effort has resulted in a large positive change in the rate at which we can document the ant fauna of Madagascar.

Publication. Technology is used to both acquire data and then manage and assemble data elements for publication and revision. The aim is to use the information gathered during the inventory (collection and locality data) and identification process (images, notes on diagnosis) as integral pieces of any published revision. The revision becomes the collation of data acquired during the collecting, processing, and identification steps. Specimen databases are used to create distribution maps and the image library developed to identify specimens provides the necessary illustrations for species descriptions. The challenge is to develop a protocol for online publishing of revisions with the least number of steps that satisfies the requirement of the zoological code and facilitates the integration of results into existing online taxonomic databases (type, descriptions, and catalog).

Public access. Historically, systematists have concentrated on naming and describing species, with little attention given to the final product and how those outside taxonomy could use it. Most biodiversity information languishes in inaccessible journal articles, books and museum collections. As much as ninety percent of all described species have never been incorporated into identification manuals, or regional floral or faunal summaries, and, thus, the majority of taxonomic products have remained in low-circulation journals hidden in specialists' libraries. Rarely has taxonomic research resulted in accessible and widely useful products. User-unfriendliness of resources is the principal reason why there is not a broad base of public support clamoring for an increase in taxonomy.

BROADER IMPACTS

Renner and Ricklefs (1994) claim that systematists should not see themselves as "service providers", for this will take away from the intellectual validity of the discipline and sap it of it vitality. I disagree and feel that in addition to the academic enterprise of hypothesis driven systematics, the systematics community needs to develop products that have a wider and more practical use across the applied and basic sciences, especially for the protection and management of biological resources. Renner and Ricklefs (1994) are concerned that it is detrimental to the profession for systematists to devote too much time conducting inventories because it requires precious taxonomic expertise to identify the specimens. On the other hand, if systematists facilitate the creation of tools permitting nonspecialists to identify specimens, parataxonomists can ease the burden of identification. Systematists must view species description as more than just putting names in lists. They must view their work as the access point for all users of that piece of the biodiversity puzzle and see their job as making his/her work accessible.

Representation

Inventory provides baseline documentation of natural occurrence of wild species, and is a crucial first step in mapping conservation priorities. This map is required by all who share the aim of preserving the greatest representation of biodiversity in Madagascar. However, the usual taxonomic products — monographs and species lists — are not sufficient to ensure that biodiversity data are incorporated in local and national conservation decision-making processes. Biodiversity planners and decision makers in governments, agencies, and non-governmental agencies (NGOs) are unaware that these data exist and are not accustomed to including data on terrestrial invertebrates. To ensure that our data are used for conservation planning in Madagascar, we tailor our results toward practicality. This required development of strong relations with local conservation and government agencies so we would understand their policy approaches and decision-making needs. Most importantly, this has required understanding the spatial scale of the conservation issue, and the generation of maps and analyses at the appropriate scale. In collaboration with the Jet Propulsion Laboratory in the U.S., we are generating species richness maps of Madagascar based on predicted species distribution, remotely sensed environmental layers and a novel model algorithm allowing to make use of the standard sampling techniques for ants (Fig. 3).

Our ultimate goal is to develop a Biodiversity Center staffed by well-trained Malagasy scientists that will provide short- and long-term benefits to biodiversity and conservation efforts. The Center will promote understanding of the use of biodiversity data in planning land management and conservation systems, and provide baseline biodiversity data for sound conservation and sustainable use planning. The Center will dramatically improve ability to respond to local conservation issues, and to ensure that biodiversity results are disseminated to a broad audience of users. The training of Malagasy nationals and scientists to participate in conservation decision making in their country is an extremely effective way to ensure long-term commitment to conservation on this unique island.

Conclusion

The increasing loss of biodiversity presents a daunting challenge to taxonomists and requires the discovery and analysis of biodiversity at a greatly accelerated pace. If we are really serious about “zero biodiversity loss” in Madagascar and elsewhere, then conservation planning needs to be based more fundamentally on biodiversity data, and this requires taxonomic knowledge. The renovation of systematics, as proposed here, is an extremely ambitious program requiring innovation, and large-scale application of tools in systematic research, from collecting to dissemination of results. In addition, this initiative requires the systematic community to work together at a level never before realized, focusing attention on global revision of select taxa and ensuring the repre-

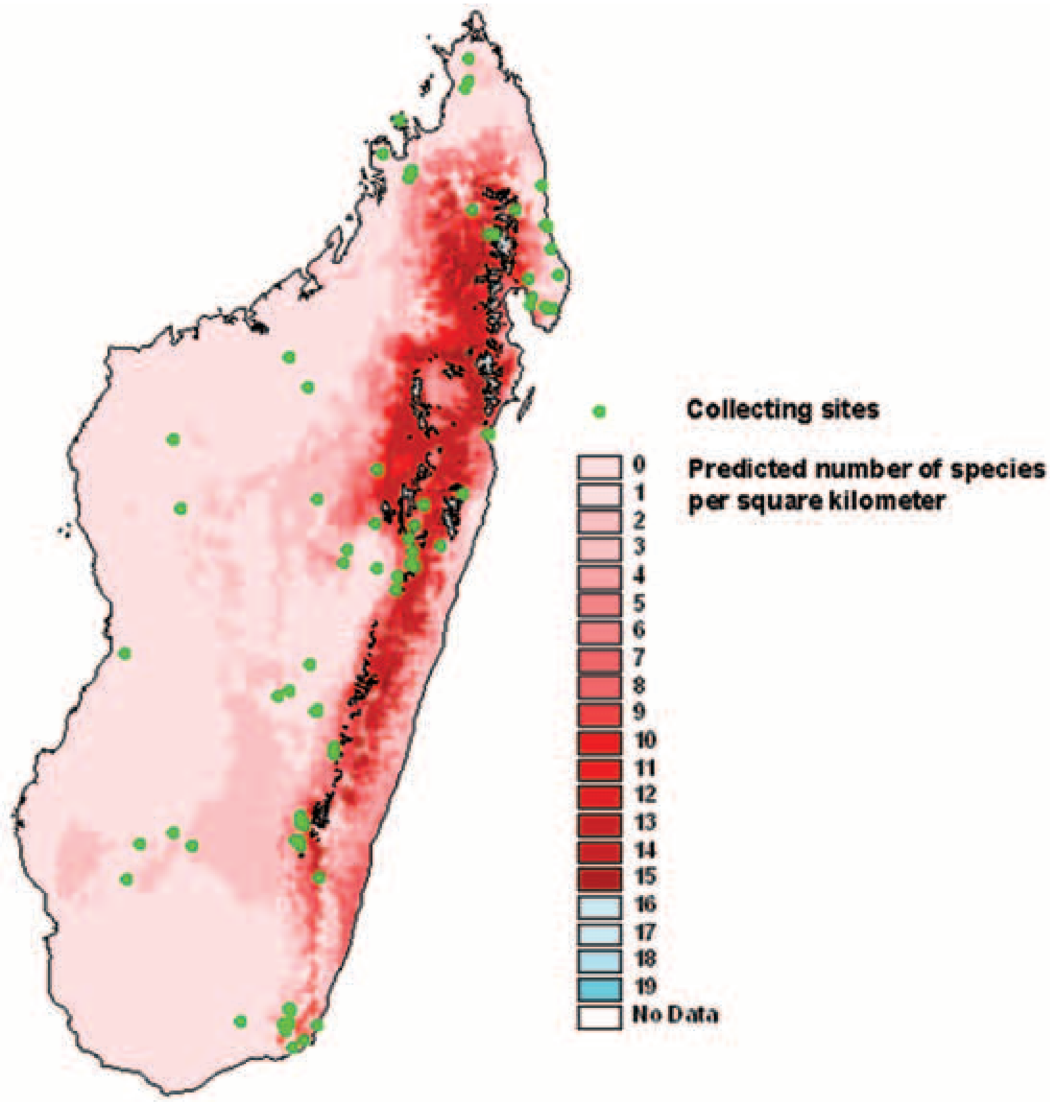

FIGURE 3. Sample species richness map of Madagascar based on predicted species distribution.

sentation of results in the conservation process, thereby enhancing the perceived value of taxonomy.

MANDI has demonstrated the feasibility of rapid collection and processing of ant specimens. This model, combined with innovations in imaging technology, has set the stage for accelerated discovery and documentation of global ant species diversity. The model proposed here can be applied across disciplines and toward other inventory efforts. Little time remains for the documentation of global biodiversity. Taxonomists, equipped with modern tools, have a chance to move systematics to the forefront of conservation and attention of the public. With increased taxonomic output and improved public access and visibility, public support for the discovery of life on this planet should follow.

ACKNOWLEDGEMENTS

Fieldwork could not have been completed without the gracious field support of the people of Madagascar. Our research in Madagascar was authorized by the Direction des Eaux and Forêt (DEF) and the Tripartite Commission. This project was funded in part by the National Science Foundation to B.L. Fisher and C.E. Griswold (DEB-0072713) and to B.L. Fisher and P.S. Ward (DEB-0344731). Special thanks to Aisha Pearl Mayekiso, Leticia Njozela, Madelyn Peters, Balsama Rajemison, Helian Ratsirarson, Jean Claude Rakotonirina, Jean-Jacques Rafanomezantsoa, Chrislain Ranaivo, Randriambololona Tantely Nirina, Hanitriniana Rasoazanamavo, and Nicole Rasoamanana for assistance in field collection, processing and sorting the specimens.

LITERATURE CITED

AGOSTI, D., AND N.F. JOHNSON. 2003. Taxonomists need better access to published data. *Nature* 417:6886.

AGOSTI, D., J.D. MAJER, L.E. ALONSO, AND T.R. SCHULTZ, EDS. 2000. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Smithsonian Institution Press, Washington, DC, USA. 280 pp.

BALMFORD, A. 2003. Conservation planning in the real world: South Africa shows the way. *Trends in Ecology and Evolution* 18:435–438.

BATTISTINI, R., AND G. RICHARD-VINDARD, EDS. 1972. *Biogeography and Ecology of Madagascar*. Monographiae Biologicae, vol. 21. Junk, The Hague, Netherlands. 765 pp.

BLACKMORE, S. 1996. Knowing the Earth's biodiversity: challenges for the infrastructure of systematic biology. *Science* 274:63–64.

BURNEY, D.A. 1987. Late Quaternary stratigraphic charcoal records from Madagascar. *Quaternary Research* 28:274–280.

COLWELL, R.K. 1996. *Biota 2: The Biodiversity Database Manager*. Sinauer Associates, Sunderland, Massachusetts, USA. 860 pp. plus application software.

DALTON, R. 2003. Ants join online colony to boost conservation efforts. *Nature* 424:242.

FISHER, B.L. 1996. Ant diversity patterns along an elevational gradient in the Réserve Naturelle Intégrale d'Andringitra, Madagascar. *Fieldiana: Zoology* (n.s.) 85:93–108.

FISHER, B.L. 1997. *Ant Diversity Patterns and Conservation Planning in Madagascar*. Ph.D. Dissertation, University of California, Davis, USA. 241 pp.

FISHER, B.L. 1998. Ant diversity patterns along an elevational gradient in the Réserve Spéciale d'Anjanaharibe-Sud and on the western Masoala Peninsula, Madagascar. *Fieldiana: Zoology* (n.s.) 90:39–67.

FISHER, B.L. 1999a. Improving inventory efficiency: A case study of leaf litter ant diversity in Madagascar. *Ecological Applications* 9:714–731.

FISHER, B.L. 1999b. Ant diversity patterns along an elevational gradient in the Réserve Naturelle Intégrale d'Andohahela, Madagascar. *Fieldiana: Zoology* (n.s.) 94:129–147.

FISHER, B.L. 2000. The Malagasy fauna of Strumigenys. Pages 612–696 *in* B. Bolton, ed., The Ant Tribe Dacetini. *Memoirs of the American Entomological Institute* 65:1–1028.

FISHER, B.L. 2002. Ant diversity patterns along an elevational gradient in the Réserve Spéciale de Manongarivo, Madagascar. *Boissiera* 59:311–328.

FISHER, B.L. 2003. Ants (Formicidae: Hymenoptera). Pages 811–819 *in* S.M. Goodman and J.P. Benstead, eds., *The Natural History of Madagascar.* University of Chicago Press, Chicago, Illinois, USA.

FISHER, B.L., AND H. ROBERTSON. 2002. Comparison and origin of forest and grassland ant assemblages in the high plateau of Madagascar. *Biotropica* 34:155–167.

GEORGINA, M.M., J.L. GITTLEMAN, AND A. PURVIS. 2003. Preserving the tree of life. *Science* 300:1707–1709.

GILLESPIE, R.G., AND G.K. RODERICK. 2002. Arthropods on islands: colonization, speciation, and conservation. *Annual Review of Entomology* 47:595–632.

GODFRAY, H.C.J. 2002. Challenges for taxonomy. *Nature* 417:17–19.

GOODMAN, S.M., AND B.D. PATTERSON, EDS. 1997. *Natural Change and Human Impact in Madagascar*. Smithsonian Institution Press, Washington DC, USA. xiii + 432 pp.

GOODMAN, S.M., AND J. BENSTEAD, EDS. 2003. *Natural History of Madagascar*. University of Chicago Press, Chicago, Illinois, USA.

HOUSE OF LORDS. 2002. *What on Earth? The Threat to the Sciences Underpinning Conservation*. H.M. Stationery Office, Ltd., London, UK.

JOLLY, A., P. OBERLÉ, AND R. ALBIGNAC, EDS. 1984. *Key Environments: Madagascar*. Pergamon Press, Oxford, England, UK. xviii + 239 pp.

LONGINO, J.T., AND R.K. COLWELL. 1997. Biodiversity assessment using structured inventory: capturing the ant fauna of a tropical rain forest. *Ecological Applications* 7:1263–1277.

LONGINO, J.T., J. CODDINGTON, AND R.K. COLWELL. 2002. The ant fauna of a tropical rain forest: estimating species richness three different ways. *Ecology* 83:689–702.

LOURENÇO, W.R., ed. 1996. *Biogéographie de Madagascar*. Editions ORSTOM, Paris, France. 588 pp.

MARGULES, C., AND R. PRESSEY. 2000. Systematic conservation planning. *Nature* 405:243–253.

OLSON, D.M. 1994. The distribution of leaf litter invertebrates along a Neotropical altitudinal gradient. *Journal of Tropical Ecology* 10:129–150.

RENNER, S.S., AND R.E. RICKLEFS. 1994. Systematics and biodiversity. *Trends in Ecology and Evolution* 9:78.

ROUGET, M. 2003.Measuring conservation value at fine and broad scales: Implications for a diverse and fragmented region, the Agulhas Plain. *Biological Conservation* 112:217–232.

SCHATZ, G.E. 2002. Taxonomy and herbaria in service of plant conservation: Lessons from Madagascar's endemic families. *Annals of the Missouri Botanical Garden* 89:145–152.

STEVENSON, R.D., W.A. HABER, AND R.A. MORRIS. 2003. Electronic field guides and user communities in the eco-informatics revolution. *Conservation Ecology* 7(1):3. <*http://www.consecol.org/vol7/iss1/art3*>

STOREY, M., J.J. MAHONEY, A.D. SAUNDERS, R.A. DUNCAN, S.P. KELLEY, AND M.F. COFFIN. 1995. Timing of hot-spot related volcanism and the breakup of Madagascar and India. *Science* 267:852–855.

SUSSMAN, R.W., G.M. GREEN, AND L.K. SUSSMAN. 1996. The use of satellite imagery and anthropology to assess the causes of deforestation in Madagascar. Pages 296–315 *in* L.E. Sponsel, T.N. Headland, and R.C. Bailey, eds., *Tropical Deforestation: The Human Dimension*. Columbia University Press, New York, New York, USA.

WILSON, E.O. 2000. A Global Biodiversity Map. *Science* 289:2279.

WILSON, E.O. 2003. The encyclopedia of life. *Trends in Ecology and Evolution* 18:77–80.