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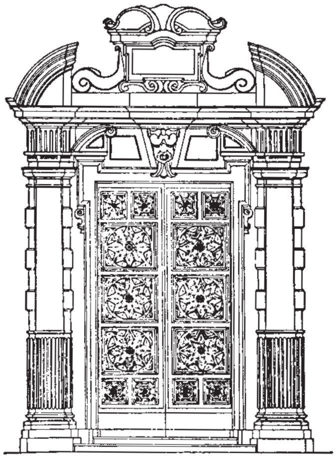
A Conservation Strategy for the Amphibians of Madagascar

Franco Andreone
(Editor)



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A Conservation Strategy for the Amphibians of Madagascar

Idea and project by
Franco Andreone

Foreword by
Russell A. Mittermeier and Claude Gascon

Introduction by
Charles P. Blanc and Rose M. A. Blommers-Schlösser

Contributions by
Franco Andreone, Luciano Andriamaro, M. Nandrianina Andrianasolonjatovo, Gennaro Aprea, Olvier Behra, Richard Berridge, Lise Bock, Parfait Bora, Robert Bourou, Angus I. Carpenter, Ylenia Chiari, Jamie Copse, Angelica Crottini, Kathrin H. Dausmann, Rainer Dolch, Louis Du Preez, Joanna Durbin, Samantha Earle, Rollande Finoana, Karen Freeman, Samuel C. Furrer, Gerardo García, Claudia Gili, Frank Glaw, Julian Glos, Richard K. B. Jenkins, Olga Jovanovic, David H. Knox, Jörn Köhler, K. Eduard Linsenmair, Fabio Mattioli, Joseph R. Mendelson III, Vincenzo Mercurio, Robin D. Moore, Harison Rabarison, Andriamanana Rabearivelo Nirhy Rabibisoa, Falitiana C.E. Rabemananjara, Liliane Raharivololoniaina, Zo Lalaina Rakotobe, Daniel Rakotondravony, Malalan'Ny Aina A. Rakotondrazafy, Noromalala Rasoamampionona Raminosoa, Roseline L. Rampiliamanana, Edouard Randriamitso, Harison H. Randrianasolo, Roma Randrianavelona, Roger-Daniel Randrianiaina, Jasmin E. Randrianirina, Noromalala Rasoamampionona Raminosoa, Olga Ravoahangimalala Ramilijaona, Christopher J. Raxworthy, Tokihery J. Razafindrabe, Onja Robson, Josef Straka, Meike Teschke, Denis Vallan, Miguel Vences, Anselme Toto Volahy, David R. Vieites, Ché Weldon, Katharina, K. Wollenberg, Richard Young

Franco ANDREONE
Sezione di Zoologia
Museo Regionale di Scienze Naturali
Via G. Giolitti, 36
10123 Torino, Italy
franco.andreone@regione.piemonte.it
www.francoandreone.it

Amphibian Specialist Group
Chair for Madagascar
www.sahonagasy.org

SOMMARIO

To Kintana Azzurra,
Serena Crystal Vatosoa,
Marie Olga,
Bruna

A northern tomato frog, *Dyscophus antongilii*, photographed at Maroantsetra. This is maybe one of the best known frogs of Madagascar.

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Franco ANDREONE

FOREWORD

The decline and extinction of amphibians that is sweeping the globe is unlike anything humans have witnessed since our arrival on earth. With almost a third of approximately 6,000 described species listed as Threatened by the IUCN, we teeter on the brink of a mass extinction spasm affecting an entire class of vertebrates. We are truly entering a new era in conservation, in which novel threats such as climate change and emerging disease combine with traditional factors such as habitat loss, pollution and over-harvesting to produce a lethal cocktail of threats that does not respect political or protected area boundaries. To stem the current amphibian extinction crisis, the global community must respond in a truly innovative and multidisciplinary fashion and at an unprecedented scale.

In a bid to catalyze a unified global strategy for amphibian conservation, the IUCN/SSC Amphibian Specialist Group (ASG) recently published the Amphibian Conservation Action Plan or ACAP (available at www.amphibians.org) the proceedings of an Amphibian Conservation Summit convened by IUCN and Conservation International in Washington, DC in September, 2005. The ACAP presents an ambitious but realistic five-year program to combat amphibian declines and extinctions around the world. It is designed to serve as a template for action that can be adopted by a multitude of stakeholders from all scales from global to local.

The ACSAM represents an effort to implement the ACAP at a regional scale and promises to serve as a model for similar initiatives across the globe. The effort is both timely and critically important, being in a top priority region. Madagascar boasts more than 235 described amphibian species, over 99% of which are endemic, and at least as many more await description. As a country it consistently falls in the top dozen in the world for total number of amphibian species (12^{th}), number of threatened species (11^{th} =) and number of endemics (4^{th}). With the new species currently awaiting description, these figures will likely increase dramatically in the near future.

Fortunately, we now have great opportunities to advance amphibian conservation in this country. President Marc Ravalomanana's commitment to triple protected area coverage – the Durban Vision – opens the door to including many new priority areas, including those for amphibian. An emerging fungal disease that has decimated amphibian populations in other parts of the world appears to be absent on Madagascar according to initial tests on Malagasy frogs – at least for the moment, giving us the opportunity to be proactive and get ahead of the curve. The ACSAM provides the perfect vehicle for seizing these and other opportunities for integrating amphibian conservation into national initiatives.

ACSAM is a reflection of what can be achieved by a small number of dedicated and passionate individuals who are committed to making a change, and we are proud to be a part of this globally important effort.

Russell A. MITTERMEIER
President, Conservation International

Claude GASCON
Senior Vice-President, Regional Programs Division,
Conservation International

INTRODUCTION

C'est avec gratitude que nous répondons favorablement à la demande de notre Collègue Franco Andreone de rédiger, de conserve, une brève introduction à son ouvrage sur la conservation des Amphibiens.

L'organisation à Madagascar d'un Workshop dédié à la Conservation des Amphibiens est un évènement scientifique dont nous apprécions toute l'importance. Nous y avons été d'autant plus sensibles que notre position, dans le cours des recherches scientifiques qui se sont déroulées sur ces animaux, nous permet de mesurer l'ampleur du chemin parcouru au cours de ces quarante dernières années. Cette fascinante perspective chronologique montre combien l'inventaire des espèces a progressé. Mais aussi, et peut-être surtout, combien les idées, les concepts, les objectifs de recherche ont changé. Enfin, combien les moyens, humains et matériels, qui leur ont été consacrés se sont accrus.

Dans une première étape, la connaissance des Amphibiens a dépendu essentiellement de l'opportunité de missions de terrain occasionnelles effectuées par des chercheurs, en général européens, et des collectes aléatoires de voyageurs ou de résidents amateurs qui se passionnaient pour telle ou telle composante de la faune malgache lorsqu'ils réussissaient à établir une relation suivie avec un laboratoire susceptible de déterminer et décrire leurs trouvailles.

Dans ces conditions, l'inventaire progressait lentement, irrégulièrement, selon les disponibilités des uns et des autres, au hasard de publications dispersées, parfois difficiles à identifier et à se procurer. Mais les données biologiques ou écologiques restaient fort incomplètes et disparates, limitées assez souvent à des indications aussi vagues que le nom d'un village ou d'une ville voisine du point de collecte, ou même simplement du pays, et parfois entachées d'erreurs quand des collections étaient mélangées par inadvertance.

Dans ce contexte, les problèmes de conservation des espèces n'étaient guère évoqués. Mais ils ne se posaient alors souvent pas avec la même acuité qu'actuellement.

Nous avons eu la chance de résider chacun plusieurs années à Madagascar au cours de la décennie 1962-1973, soit comme chercheur libre à l'ORSTOM (R.B.), soit comme Maître-Assistant dans la toute jeune Université de Madagascar (C.B.).

R.B. a eu l'occasion d'étudier pendant presque trois ans (1970-1973) la biosystématique et l'histoire naturelle des Amphibiens. Tandis que l'analyse des chromosomes et de l'ADN lui a permis de résoudre maints problèmes, accumulés depuis plus de cent années, relatifs à l'identification taxonomique et à l'établissement des affinités phylogénétiques, le succès d'une soixantaine d'élevages, qu'elle a conduits du stade têtard jusqu'au stade adulte, signait le début des connaissances écologiques sur ce groupe riche en espèces endémiques.

Les descriptions des biotopes des deux stades, aquatique et terrestre, des coassements (sonogrammes), des têtards et parfois des subadultes ont été une aide pour les chercheurs lui ont succédé, comme Frank Glaw, Miguel Vences et Franco Andreone. Ce travail a culminé en une thèse.

La création d'enseignements et d'activités pédagogiques adaptés au pays occupèrent la majeure partie du temps et des efforts de C.B. Le reste fut consacré à la réalisation d'une thèse sur les Iguanidés endémiques. Des échantillonnages d'Amphibiens ont pu être réalisés au cours de ses divers séjours sur le terrain, notamment dans le cadre du programme du CNRS sur les écosystèmes montagneux de Madagascar.

L'intérêt scientifique restait alors focalisé sur les progrès nécessaires de la systématique encore imparfaite et très incomplète des Amphibiens, comme en témoigne la synthèse taxonomique, qui intègre l'essentiel des collectes ainsi réalisées, proposée par le Professeur Jean Guibé (1978) dans son ouvrage «Les Batraciens de Madagascar».

La notion de conservation, à cette époque, reposait essentiellement sur la création d'un ensemble d'aires protégées où les activités anthropiques étaient soit proscrites (Réserves naturelles intégrales) soit limitées (Parcs nationaux, Réserves spéciales, Réserves de faune, …), se voulant représentatif des diverses formations végétales originales de la Grande Ile. Les distributions chorologiques et écologiques des espèces étant mal connues, il était implicitement admis que le peuplement animal originel serait lui aussi de ce fait préservé.

Considérant la diversité et l'importance des acquis phylogénétiques et écologiques, il nous apparut nécessaire au cours de la décennie 1980 d'offrir, tant aux chercheurs qu'aux étudiants, une synthèse actualisée des données systématiques d'une part et biologiques dans son sens le plus large d'autre part, relatives aux Amphibiens malgaches. Nous avons donc entrepris la rédaction des deux tomes qui leur sont respectivement consacrés, publiés dans la Faune de Madagascar éditée par Renaud Paulian.

L'essor de ces jeunes disciplines va jouer un rôle majeur dans l'élaboration des conceptions actuelles sur la conservation des espèces animales en général, et des Amphibiens en particulier, dont cette concertation est l'objet.

C'est pourquoi nous fûmes particulièrement heureux d'apprendre qu'une large réunion internationale était consacrée à cette question cruciale. Son organisation exprime qu'un corpus important de données écologiques, biologiques, biogéographiques a été rassemblé au cours des ces dernières décennies. Il complète les progrès notoires et indispensables de l'inventaire systématique, et couronne les efforts des nombreuses équipes nationales qui ont suivi la voie tracée par Marguerite Razarihelisoa, et internationales engagées dans ce projet.

Charles P. BLANC
Laboratoire de Zoogéographie, Université Montpellier 3
Présent addresse: chemin du¨Pioch de Baillos 34980 Montferrier sur Lez, France

Rose M.A. BLOMMERS-SCHLÖSSER
Zoological Museum Amsterdam
Présent addresse: Willibrordweg 6, 3911 CC Rhenen, The Netherlands

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Robin D. Moore[1], Joseph R. Mendelson III[2]

Amphibian conservation at the global, regional and national level

ABSTRACT

Almost a third of amphibians worldwide are threatened with extinction. As a class, amphibians face a variety of threats that are both sadly familiar, such as habitat loss, contamination and overexploitation, as well as threats that are somewhat novel in the history of conservation efforts, such as emerging infectious diseases and climate change. Mitigating these threats at a global scale represents a truly daunting challenge that will require an innovative and multidisciplinary approach. The Amphibian Conservation Action Plan (ACAP) provides a blueprint for actions needed to stem the global extinction crisis. Madagascar lies on the forefront of global priorities for amphibian conservation, ranking consistently in the top 12 countries in the world for numbers of amphibian species, number of threatened species and number of endemics. The ACSAM provides an important opportunity to implement the ACAP at a National scale and serve as a model for expansion to other regions of the world. The Amphibian Specialist Group (ASG) will work with local partners to support efforts to conserve the amphibians of Madagascar. Conservation efforts must include a strategy for habitat protection (incorporating amphibians into plans to increase protected area coverage), targeted research into current and potential threats to amphibians, implementation and enforcement of legislation regulating the movement of amphibians in and out of the country, and building capacity in-country for the establishment and maintenance of captive assurance colonies.

Key words: Amphibian Conservation Action Plan, Amphibian Specialist Group, Global Extinctions.

INTRODUCTION

The phenomenon of global amphibian population declines first received broad scientific and public attention in the late 1980's (Rabb, 1990; Vial, 1990; Wake, 1991). Researchers then spent the 1990's demonstrating that amphibian population declines were real, documenting occurrences, and searching for

[1] IUCN/SSC Amphibian Specialist Group, Arlington.
[2] Zoo Atlanta.

causal agents. After two decades of observing “enigmatic” declines of amphibians and speculating about the causes, a series of recent papers has brought us to the realization that the scale of global amphibian extinctions is massive (Stuart et al., 2004) and that maverick conservation efforts will be required to prevent loss of biodiversity at a level unprecedented in human history (Mendelson et al., 2006).

The Global Amphibian Assessment (GAA) has revealed that almost a third of amphibians are threatened with extinction; this far exceeds the proportion of threatened birds and mammals (12% and 23% respectively). As a class, amphibians face a variety of conservation challenges including threats that are sadly familiar to us (e.g., habitat loss, contamination, overexploitation) as well as threats that are somewhat novel in the history of conservation efforts (e.g., emerging infectious diseases, climate change); complex interactions among these factors are certainly present, but are difficult to assess and mitigate. The program to mitigate global, or local, climate change represents a truly daunting challenge, and there remain far too many unknowns in all of these fields to understand complex synergies that likely underlie the interactions between factors such as environmental contamination, disease spread, and climate change. Tackling these threats will require an innovative and multidisciplinary approach.

A realization of the scale of the global amphibian extinction crisis prompted the establishment in 1991 of the IUCN/SSC Declining Amphibian Populations Task Force (DAPTF). DAPTF succeeded in greatly advancing our knowledge as to the extent and potential causes of amphibian declines worldwide. While we continue to improve our understanding of the problem, however, the crisis has not abated, and amphibian populations continue to decline and disappear at an alarming rate, prompting a response from the global community to tackle the problem at a scale larger than ever before.

Amphibian Conservation Action Plan

In September of 2005, a Summit was convened in Washington, DC by the IUCN-SSC and Conservation International to bring together over 60 world leaders in amphibian research and conservation; the purpose, to develop a global strategy to halt amphibian declines. The Summit produced a Declaration and an ambitious Amphibian Conservation Action Plan (ACAP) with an associated estimated budget of USD 400 million, representing a preliminary road-map of the programs and funds that would be required if we are to have any hope of abating the current amphibian extinction crisis. The summit found consensus amongst stakeholders that the scope of the problem is large and global, and familiar and novel threats are to blame. It was also concluded that science-as-usual and conservation-as-usual are both insufficient. Four main actions were proposed as urgent priorities for global amphibian conservation: (1) expanded understanding of the causes of declines and extinctions; (2) ongoing documentation of amphibian diversity, and how it is changing; (3) development and implementation of novel long-term conservation programs; (4) emergency responses to immediate crises.

The implementation of the ACAP, and securing the funds necessary to do so, is an ambitious task, and one that is beyond the scope of a Task Force. Indeed, DAPTF was never intended to tackle the problem at this level. The decision was therefore made to combine the expertise and experience of DAPTF, the Global Amphibian Specialist Group (GASG) and the GAA into a body devoted to advancing amphibian conservation through the implementation of the ACAP: The IUCN/SSC Amphibian Specialist Group (ASG www.amphibians.org). The ASG works to catalyze a global response through the coordination and support of a global network of expertise. The ASG network is composed of global conservation/research professionals organized around geographic nodes to ensure a "bottom up" body of influence to guide the implementation of the ACAP.

The ASG is coordinated through a Secretariat comprising two Co-Chairs (Claude Gascon and James Collins), who are charged with implementing staff and appointments in the following capacties: an Executive Officer, an Advisory Board, and Directors of four divisions: Conservation, Research and Assessment, Development, and Communications. The ASG will use a constantly updated website and the bimonthly newsletter Froglog to disseminate the latest amphibian news from around the world and facilitate communication among amphibian researchers and conservation practitioners.

Implementing ACAP at local, national, regional and global scales

The ACAP represents a unified global strategy for amphibian conservation. It has been designed with the intention of providing a template that can also be applied at regional, national and local scales. Issues affecting amphibians vary according to region, and some issues-such as trade, invasive species and disease-transcend national boundaries and need to be addressed at local, national and international levels to be effective. The implementation of the ACAP will therefore necessarily be a collaborative effort working synergistically at all levels from local to global; the ASG strives to facilitate the development of such synergistic partnerships. It is hoped that the ACAP will serve as a working template for the development of regional and national Action Plans, such as the ACSAM, that address local issues in the context of the global amphibian crisis. The ACSAM represents an important step in the implementation of the ACAP at a national level and promises to serve as a model for other countries and regions of the world.

Global significance of Madagascar

Madagascar is a country with global significance for amphibian conservation. According to the GAA, it ranks number 12 in the world for number of species (over 220 described); however with so many species remaining to be described in Madagascar this is likely an underestimate. Based on those species that have been described, Madagascar ranks 4th in the world for number of endemics (over 99% of the species found there are endemic) and 11th equal in the world for number of threatened species. Madagascar is a region that has experienced a particularly steep rise in the numbers of recognized amphibian species, an increase of 42 percent (from 143 to 203) in the period 1992-2003 (Köhler et al., 2005), and many more species are likely to be discovered. At the time of writing, 150 species await description. Madagascar ranks as one of the top biodiversity hotspots (Myers et al., 2000) and with predictions suggesting that by 2025 forests will only exist in the most remote parts of Madagascar (Green & Sussman, 1990), novel conservation strategies are required to save much of its biodiversity.

Threats to amphibians in Madagascar include 'traditional' threats such as habitat loss and collection of animals for the pet trade-however more 'novel' threats such as climate change are likely to become more significant. Introduced species, such as crayfish from the genus *Procambarus* which has recently invaded Madagascar, may also pose a threat through predation and potentially serving as a vector for disease. Disease does not currently appear to be a major threat to the amphibian fauna of Madagascar; initial tests for the amphibian fungus chytridiomycosis, which has been implicated in dramatic declines in Latin America, Australia and Europe, have shown up negative. However, this does not warrant complacency, and patterns observed elsewhere indicate that a disease outbreak could potentially be catastrophic. We must therefore regard this as an opportunity to be proactive in preventing amphibian chytrid fungus from reaching Madagascar, and contingency plans should be developed should an outbreak occur. Suggested measures include stringent control of the movement of animals in and out of Madagascar through the implementation and enforcement of appropriate policies, careful adherence to protocols for minimizing the risk of spread, research into those species which may be particularly susceptible to the disease, and establishing captive assurance colonies for those species deemed to be at risk.

Some amphibian species in Madagascar are heavily collected for the International pet trade. The CITES database first recorded CITES listed amphibian species being traded from Madagascar in 1994, and between 1994 and 2006 a total of nearly 162,000 individuals were traded in 18 species. The CITES data shows that nearly 38% of the trade is accounted for by *Mantella aurantiaca* followed by *M. madagascariensis* (13%) and *Mantella* spp (12%). Similarly, *Mantella aurantiaca* has recorded the highest number of years in the trade (10 years) with four other *Mantella* spp each recording 9 years in the trade. Further research is required to assess the impact that this trade has on wild populations, and appropriate measures must be taken to minimize this impact. This may be achieved at the international level, by ensuring appropriate policies regulate export, as well as at the national and local level, by enforcing legislation and exploring the development of sustainable harvesting protocols and, potentially, captive breeding to supply animals for the pet trade.

It is worth reiterating that habitat loss remains the most significant threat to amphibians globally, impacting 9 out of 10 threatened species, and efforts to protect critical amphibian habitat are central to any conservation efforts in Madagascar and elsewhere. The ambitious goals set by the Malagasy government to significantly increase protected areas within the country provide an important opportunity to advance amphibian conservation. It is important that the needs of amphibians are incorporated into plans to establish new protected areas and the Key Biodiversity Areas (KBAs) concept be used to prioritize those areas that are important for conservation.

The ASG will support efforts to devise and implement an Action Plan for the amphibians of Madagascar by working closely with local partners to implement conservation actions, including habitat protection and establishment of captive assurance colonies, in addition to providing financial support for critical research into current and potential threats, continuing the Assessment process through the GAA, and influencing policies relating to the trade of amphibians. We also will work to identify and protect critical habitats for amphibians.

Madagascar represents an important opportunity for amphibian conservation. The country contains a rich diversity of species found nowhere else-a high percentage of which are threatened-and we have the opportunity to address many of these threats before it is too late. The ACSAM is an important milestone in advancing amphibian conservation in Madagascar and globally and may serve as a model to be adopted by other nations around the world.

RESUMÉ

Conservation des amphibiens au Niveau Global, Régional, National.

Presque un tiers des amphibiens sont menacés d'extinctions. Comme catégorie, les amphibiens font face à diverses menaces qui sont à la fois tristement familières, comme la perte de l'habitat, la contamination et la surexploitation, ou des menaces qui ont quelque chose de nouveau dans l'histoire de la conversation, telles les maladies infectieuses ou le changement climatique. Modérer ces menaces à une échelle globale représente un réel et intimidant défit qui demandera une approche innovante et multidisciplinaire. Le Plan d'Action de Conservation des Amphibiens (ACAP) (The Amphibian Conservation Action Plan) fournit des schémas pour des actions qui doivent faire cesser les crises d'extinctions globales. Madagascar se trompe sur le front des priorités globales de la conservation des amphibiens, classée dans le top 12 des pays mondiaux pour le nombre d'espèces d'amphibiens, nombre d'espèces menacées et nombre d'espèces endémiques. L'ASCAM fournit une importante opportunité de se servir de l'ACAP à une échelle nationale et sert de modèle d'expansion à d'autres régions du monde. Le Groupe de Spécialistes des Amphibiens (Amphibian Specialist Group, ASG), travaille avec des partenaires locaux pour soutenir les efforts de conservation des amphibiens de Madagascar. Les efforts de conservation doivent inclure une stratégie de protection de l'habitat (incorporant les amphibiens dans des plans qui accroissent la couverture de zones protégées), des recherches ciblées sur les menaces actuelles et potentielles des amphibiens, une mise en œuvre et un renforcement d'une législation régularisant le mouvement des amphibiens dans et à l'extérieur du pays, et d'exercer son aptitude dans l'établissement et la maintenance de colonies garanties en captivité.

Mots clés: Plan d'Action de Conservation des Amphibiens, Amphibian Conservation Action Plan; Groupe de Spécialistes des Amphibiens; Amphibian Specialist Group; Extinctions Globales.

Robin D. Moore
IUCN/SSC Amphibian Specialist Group
Conservation International
2011 Crystal Drive, Suite 500, Crystal City
Arlington, Virginia 22202, USA
Email rdmoore@conservation.org

Joseph R. Mendelson III
Department of Herpetology,
Zoo Atlanta, 800 Cherokee Ave
Atlanta, Georgia, 30315, USA
Email jmendelson@zooatlanta.org

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Franco Andreone[1]

Frogging Madagascar: a free chat on frogs and frog conservationists across the Red Island

ABSTRACT

A short history of amphibian conservation of Madagascar is provided, passing through a history of conservation batrachologists.

Key words: Amphibians, Conservation, Madagascar.

The amphibian crisis and Madagascar

Amphibians are indeed at the forefront of the current biodiversity crisis, and the recent analysis through Global Amphibian Assessment (GAA) showed that at least a third of the world's species are in danger of becoming extinct (IUCN et al., 2006; http://www.globalamphibians.org/). Now widely referred to as the "amphibian crisis", there is an overall agreement in the conservation, scientific, and zoo community that conservation actions are urgently needed to prevent the pending extinctions of many species.

In the world there are some true "hot spots" for amphibian diversity, such as Sri Lanka, Brazil, and Madagascar. The amphibian radiation of Madagascar is characterized by a high species diversity: a summary from the GAA shows that when considering the countries with the highest number of amphibian species, Madagascar ranks 12th. Moreover, when looking at endemism patterns, Madagascar ranks 4th with 230 endemic frogs (other 150 wait to be described and – hopefully – protected). The GAA points out that among countries with large numbers of amphibian species, Madagascar (along with Australia) stands out with the highest level of endemicity at 99.6%.

Furthermore, it is obvious that the status of Madagascar's amphibians must be carefully monitored for several compelling reasons:

1) The most relevant threat to amphibians, habitat loss, is a significant and evident problem in Madagascar;

[1] Museo Regionale di Scienze Naturali, Torino.

2) New taxa are continuously discovered in Madagascar, and many new species will likely make the overall species number double (Hance, 2008);
3) Research detailing the distribution and density of frog populations is still in its infancy (apart from taxonomic studies very little is known on behaviour, ecology and life history of most species);
4) Although the amphibian chytrid fungus has not been found in Madagascar, the possibility of this or another emerging disease entering Madagascar could lead to a major wave of extinctions, which would result in a significant loss of the world's amphibian diversity.

The current volume is a "product" of this concern and represents, for the ACSAM organizers and for me in particular, not only a sound "bible" for amphibian conservation, but a real "pole position" from where we all could start to develop together a common strategy. These priorities were all in the mind of a small circle of friends (and herpetologists) who, in the last years, have conducted an intense action of zoological surveys and awareness increase in Madagascar. It has been an honor for me to share experience with some of the most renewed and famous scientists of the moment, persons who will certainly be remembered in the future as the "Malagasy frog scientists". With Frank Glaw, Chris J. Raxworthy, Miguel Vences, Denis Vallan, and all those composing the team who wrote a paper published on *Conservation Biology* (Andreone et al., 2005 a) I had the chance to discuss on several occasions about the need to do something more for the herpetofauna of Madagascar in terms of conservation, and especially for its amphibians.

Of course, this idea was something of unprecedented and – in many ways - absolutely "new", keeping in consideration the overall difficult and "hard" political and economic situation of Madagascar. Being one of the last countries in the world in terms of GDP, and with many structural and socio-economic obstacles, it was a real challenge to speak about the conservation of a "lesser fauna", like the amphibians are. Notwithstanding, the high biodiversity of Madagascar made it already a space where a high number of conservation agencies (just to quote a few: Conservation International, Wildlife Conservation Society, WWF), and Madagascar is a real "melting pot", where researchers meet and compare their ideas, studies and projects on many occasions. For all these reasons, the idea of a workshop to be held in Antananarivo on the Malagasy amphibians, although awkward, soon became a reality, and it would have become the first step of the ACSAM Initiative.

The decision point was on the occasion of the meeting of the ACAP (the *Amphibian Conservation Action Plan;* see Gascon et al., 2007), held in Washington in 2005. Two important "CI people", Russ Mittermeier and Olivier Langrand, expressed there the desire of Conservation International to support and encourage a similar project. Of course, I considered and still believe that a meeting and scientific symposium should never be a mere finality. For this, the ACSAM Initiative had to give the possibility to meet and discuss, and, moreover, to propose a strategy of conservation.

Around one year after this crucial meeting, the ACSAM Initiative was ready to be held in Antananarivo, 18-21 September 2006. Indeed now I see it as a great event and a success. More than 100 persons/scientists met and many others discussed about the peculiar frogs of Madagascar (Fig. 1). The action plan produced after this meeting will indeed an important document that will be hopefully integrated in the MAP (Madagascar Action Plan; http://www.madagascar.gov.mg/MAP/), and represents an important offshoot. Finally, the papers published in this book are in many points the most updated information regarding the conservation of the amphibians of Madagascar, and, especially, they present original ideas on how to deal with the future of these animals.

In this paper, that is also a sort of "expanded" introduction for the book, comment, and summary of all the history and actions, I would also like to enlighten the main conservation events that accompanied the formation of a true interest in the safeguard of amphibians in Madagascar. This is also the occasion of making a long story short and describe the profile of the major actors in this process.

Fig. 1. The inauguration of the ACSAM meeting held at Antananarivo, 18-21 September 2006. from left to right: Russell A. Mittermeier (President of Conservation International), Ferdinand Andriamihaja (Director of the "Cabinet" of Ministry of Environment, of Waters and Forests), Harison Edmond Randriarimanana (Former Minister of Agriculture, of Breeding and Fishing (currently Minister of Waters and Forest, Environment and Tourism), Joelisoa Ratsirarson (General Secretary of Ministry of Environment, of Waters and Forests), Herilala Randriamahazo (Marine and Coastal Program Director in Madagascar for the Wildlife Conservation Society and Chair, Amphibian Specialist Group).

A short conservation story

When I first arrived in Madagascar, in 1988, on the occasion of a sort of naturalistic holiday, rather little was already known on the life history traits and the conservation status of its frogs. At that time I was pushed to go to Madagascar after having read the papers by Peracca (1892, 1893) and having admired, in the important herpetological collection of the University of Turin, some of Peracca's types (e.g., those of *Guibemantis liber*, *Mantidactylus opiparis,* and *M. alutus*) (Gavetti & Andreone, 1993). Further energy to my Madagascar travel came from the occasional reading, when revising the herpetological collection, of Blommers-Schlösser's (1979a, b) important work on the biosystematics of mantelline frogs: the color plates really hit me and stimulated my imagination of a naturalist explorer. A lot of studies had already been carried out, but they were mainly focused on taxonomic aspects, as the most important priority was to know what is present there. Anyhow, despite the great efforts of "mytical" herpetologists like Boulenger, Peracca, Angel, Guibé, Mocquard, and Boettger, we are still far from a final taxonomic and nomenclatorial stability, considering that beyond the currently known 238 species, about an equal number still waits to be discovered, described and named.

By the way, the priority of taxonomic discoveries and revisions, that featured and still characterizes most of the zoological studies in Madagascar, has anyhow prevented and somehow "obscured" the need to go "beyond", and analyse more in depth the species and community ecology and threats. A lot of work still remains to be done, especially if we consider that many of the species are still known for a limited series number (some are known only for the type specimens), and that despite the gigantic efforts of Vences' team (e.g., Raharivololoniaina et al., 2006; Randrianiaina et al., 2007), many tadpoles still remain to be described.

The trend of the herpetological conservation studies and published papers is represented in Fig. 2. Amphibians and reptiles are calculated together for commodity, and also because many contributions dealt with both the vertebrate classes together.

The first indications for a major interest in the overall aspect of amphibian biology and conservation were already visible in the pioneer studies by Rose M. Blommers-Schlösser (Fig. 3). It was evident that, oppositely to the mostly morphological and taxonomic work carried out by J. Guibé (1978), Rose's work was also often addressed to unveil the biology of the species. She was also one of the first herpetologists to live in that country, and thus to meet and describe the species and their behaviour and ecology basing upon direct observations. For the first time colour photographs often accompanied her work. Rose also published the first popular papers on the amphibians (e.g., Blommers-Schlösser & Blommers, 1984). In collaboration with Charles P. Blanc (Fig. 4) she also realized the first real monographs destined to enlighten and widen the knowledge of Malagasy amphibians. When the first volume of the Faune of Madagascar devoted to amphibians saw the light

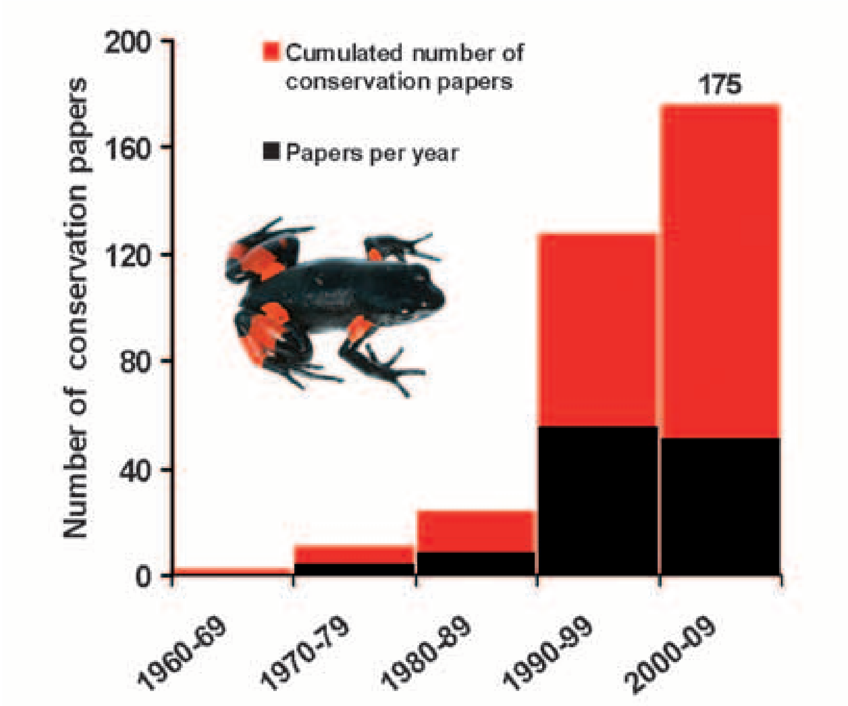

Fig. 2. Trend in the publication of conservation papers (scientific and popular contributions pooled together) for amphibians and reptiles.

(Blommers- Schlösser & Blanc, 1991) it soon became a stepstone in bibliography. I still remember one of my first visits to the rainy forest of Nosy Mangabe Island, accompanied by this "grey book". Most of the frogs that before were very mysterious for me, and very difficult to recognize, became something real. Before, I was obliged to send my photographs either to Rose Blommers Schlösser, or to Christopher J. Raxworthy. Chris in those years was already a "personality", (see for this purpose a portrait made by Holmes, 1997) (Fig. 5). Although Chris' main interest is oriented to reptiles, he also wrote, together with the French herpetologist Olivier Behra, one of the first papers devoted to amphibian conservation and pet-trade (Behra & Raxworthy, 1991).

Later on, Blommers-Schlösser and Blanc published the second volume of the "Faune" (Blommers- Schlösser & Blanc, 1993). While the first one was mainly based on Blommers-Schlösser's published and unpublished papers (mainly on species description and taxonomic revisions), the second volume was focused on biogeography. This volume, amazingly not yet sufficiently

Fig. 3. Rose M. A. Blommers-Schlösser, the first European researcher having conducted field surveys in Madagascar, at the quest of amphibians.

known and often missing in several libraries and university departments of Madagascar, contained most of Blanc's still unpublished observations, and surely it represented an unprecedented attempt to provide ecological notes that would have been extremely useful in terms of conservation biology.

It was for a fortunate combination that some of the most passionate young herpetologists met in Madagascar, and formed one of the most active working groups. The nineties and early years of the 21st century were particularly important for the study and conservation of Malagasy frogs. I was especially interested and oriented to amphibians (more than to reptiles), and with a sufficiently strong interest in life history, distribution, and conservation of these vertebrates. It was the encounter with the two "German guys", Frank Glaw and

Miguel Vences to boost my interests and studies (Figs. 6-7). Glaw and Vences, soon after the publication of Blommers-Schlösser & Blanc's book, published the first fieldguide on the amphibians (Glaw & Vences, 1992). While this first edition was still rough and with part of the observations not yet corroborated by first-hand field notes, and also included reptiles, it was the first and real field guide on the herpetofauna of Madagascar, later much improved with the second edition (Glaw & Vences, 1994), and now with the ultimate field guide, the third edition that will be difficultly overpassed in the future (Glaw & Vences, 2007). Frank and Miguel also shared a marked love for amphibians: with a titanic action they gathered an impressive information bulk on the amphibians, their recognition in the field, and their conservation. They also included a set of beautiful colour photographs that turned out to be among the most important factors in allowing the determination of the Malagasy frogs. While they continue to describe new frogs they also give a special emphasis to conservation too, by providing indications on their status. Although criticized (Nussbaum & Raxworthy, 1995), "the" fieldguide allowed a whole generation of herpetologists to discover the wonderful cold-blooded creatures of Madagascar!

As already stated, new data were also provided by the team of Chris J. Raxworthy and Ronald A. Nussbaum, with the collaboration of several Malagasy students, in particular Achille P. Raselimanana, Jean-Baptiste Ramanamanjato, and Nirhy Rabibisoa. The activity of this Anglo-American-Malagasy team was particularly intense in conducting extended field-surveys in

Fig. 4. Rose M. A. Blommers-Schlösser and he French zoogeographer and herpetologist Charles P. Blanc, during a working meeting, while preparing the "Faune de Madagascar".

Fig. 5. The British Herpetologist Chris Raxworthy with Prof. Daniel Rakotondravony and University of Antananarivo herpetology students (front to back) Paule Razafimahatratra, Nirhy Rabibisoa, and Andrianja Fiadanantsoa Ranjanaharisoa. planning a survey at Tsaramandrosa in 2006.

all the corners of Madagascar, in rain and dry forests, in open habitats and in deep canyons, by providing for the first time almost exhaustive species lists, especially for key protected areas of Madagascar. Most of these papers were accompanied by important conservation considerations. Especially Raxworthy's sensibility in terms of conservation and safeguard was evident in the publication of some papers, such as a pioneer work on reptiles and rainforests (Raxworthy, 1988), and a remarkable analysis of the montane amphibian and reptile communities and an overall excursus on the conservation problems (Raxworthy & Nussbaum, 1996, 2000).

Another key frog-person is Denis Vallan (Fig. 8), who started his studies on the amphibian communities by accompanying me during survey work to Andohahela (Andreone & Randriamahazo, 1997), and then by developing a conservation-oriented PhD research theme. Denis was particularly keen to know the effect of forest fragmentation on frog communities - an argument formerly touched by me at Ranomafana (Andreone, 1994) - and by looking at the effect of forest fragmentation. His studies soon became true classics in terms of amphibian conservation (Vallan, 2000, 2002, 2003; Vallan et al., 2004).

Finally, it is important to quote the activity of the American John E. Cadle. Especially oriented on snake studies, John provided some incisive amphibian studies (Cadle, 1995) or in collaboration with others (Vallan et al., 1998). John's style of describing new species and their behaviour still remains difficult to be reached: full of details and very precise, it provides important issues helpful to conservation.

Further conservation works were also carried out more recently by Ramanamanjato et al. (2002) and Lehtinen & Ramanamanjato (2006), who conducted research especially on the herpetological communities of southern Madagascar, and studied the effect of forest fragmentation and reduction on the herpetological communities.

It has always been my deep conviction that only through a collaborative effort we could do something for the conservation of Malagasy frogs. The contacts I kept on one side with the team of Frank and Miguel, and on the other with Chris and Ron convinced me that only with a multidisciplinary approach it would have been possible to boost frog conservation. Thus, I carried out field works following the methods recommended by Raxworthy and Nussbaum, but always giving a special attention to the taxonomic aspects of amphibians, as suggested by Glaw and Vences. My work was carried out with the assistance of the Parc Botanique et Zoologique de Tsimbazaza (PBZT). At the beginning of my visits in Madagascar I collaborated with Felix Rakotondraparany and Herilala Randriamahazo, now at the University

Fig. 6. The German herpetologist Frank Glaw at Andohahela.

Fig. 7. Miguel Vences, while frogging and fishing tadpoles.

Fig. 8. Denis Vallan while photographing.

of Antananarivo and at the Wildlife Conservation Society, respectively, the latter being eventually my co-chair for DAPTF and ASG (Fig. 9). It was also in this framework that Jasmin E. Randrianirina (now curator in PBZT) has been formed. By the way, it was just this collaborative effort that represented the starting point to organize the ACSAM Initiative, and making Madagascar a crucial point for frog conservation.

The Malagasy initiatives

A part from the foreign teams conducting frog research and promoting conservation, an important role in the research is plaid by the scientific Malagasy community. University professors and researchers, zoo curators, and many other professionals are continuously involved in many biodiversity projects. It would be very difficult to remind all the key-persons involved in this. First and still important researches were conducted by Marguerite Razarihelisoa, who published a series of contributions on the life history traits of many frog species (e.g., Razarihelisoa, 1977, 1988). Other remarkable studies are those on the alkaloid skin contents in Mantella species made by Marta Andriatsiferana in collaboration with the American researcher J.W.

Daly (Andriamaharavo et al., 2005). Several other professors the University of Antanananarivo (Department of Animal Biology), among which Daniel Rakotondravony, Olga Ramilijaona Ravohangimalala and Noromalala Raminosoa (to report only a few ones), have been indeed the most important supervisors for the active student community and are closely collaboratoring with many foreign teams. At the Parc Botanique at Zoologique de Tsimbazaza Felix Rakotondraparany (now at the University), Herilala Randriamahazo (now at WCS) and Jasmin E. Randrianirina collaborated with some research teams and also carried out studies on some threatened species (e.g., Randrianirina, 2005). The University students are being formed by the two major foreign teams. Achille P. Raselimanana (now at University of Antananarivo and Vahatra), and Jean-Baptiste Ramanamanjato (now at QITFER Madagascar) worked with Raxworthy, and then carried out many autonomous field researches (Fig. 10). Nirhy Rabibisoa and Malalan'Ny Aina Rakotondrazafy recently collaborated with Raxworthy in studies in N. Madagascar, and published several papers, some of which given in the current volume: Rabibisoa et al. (2008) on the Mantidactylus sugenus Ochthomantis; and Rakotondrazafy & Raxworthy (2008) on Guibemantis (Pandanusicola) biogeography. In the last years Vences and Glaw assisted the thesis and PhD preparation of many students. Among these we remind Falitiana Rabemananjara, Parfait Bora and Tokihery J. Razafindrabe (working on Mantella species), and Roger Daniel Randrianiaina and Liliane Raharivololoniaina (working on tadpoles) (Fig. 11). Other researches on

Fig. 9. Herilala Randriamahazo and Jasmin E. Randrianirina at Anjanaharibe-Sud (1996).

Fig. 10. Field herpetologists with Christmas dinner at Ampamakiesiny Pass, Andohahela, in 1990. Far left Jean-Baptiste Ramanamanjato, Achille Raselimana, far right Chris Raxworthy.

Mantella species were carried out largely independently and autonomously within the framework of the FADES (Fonds d'Appui au Développement de l'Enseignement Supérieur) program (Rabemananjara et al., 2007). Most recently, Nirhy Rabibisoa was named "Amphibian Executive Secretary", and is currently working together the Amphibian Specialist Group's chairs to make amphibian conservation a reality (see later). Finally, many of these students (or former students) are present in this book in quality of authors or coauthors: it has been (and will also be in the future) with their help that the frog conservation will be developed in Madagascar.

The CAMP, the DAPTF, and the GAA initiative

An important and crucial momentum for the conservation status of the amphibians of Madagascar occurred in 2001 at Mantasoa, during the CAMP (Conservation Assessment and Managing Planning). The workshop, sponsored by the Madagascar Fauna Group and by the Captive Breeding Specialist Group of IUCN, allowed an evaluation of the status of the vertebrate species, including the amphibians. This also made it possible to identify some endangered species, and to draw the attention on these species (Andreone et al., 2001). The list included five species, which were *Mantella aurantiaca*, *M. cowani*, *M. bernhardi*, *M. expectata*, and *Scaphiophryne gottlebei*. Although the selection modalities were not yet fully standardized, and the results had to be considered preliminary, it is worth stating that all these species were subsequently (during the GAA) classified as Critically Endangered, and only one (*M. bernhardi*) was classified as Vulnerable, but only after the discovery of further populations not yet known at that time.

A further and important step for amphibian conservation was the appointment of a chair for the *Declining Amphibian Populations Task Force* (DAPTF/IUCN). This task force of the IUCN – recently metamorphosed into *Amphibian Specialist Group* – helped in identifying the conservation key factors for the amphibians of Madagascar, and promoted important actions.

Then, the Global Amphibian Assessment (GAA) allowed prioritizing all the amphibians of the world. In terms of Malagasy species, an overview was done on the occasion of a meeting held in Gland in 2003 (Andreone et al., 2004). This meeting between F. Andreone, J.E. Cadle, D. Vallan, F. Glaw, C.J. Raxworthy, S. Stuart, N. Cox, and M. Vences allowed to comment a first draft written by R. A. Nussbaum and thus drawing the distribution of all the 220 species known at that time (Andreone & Luiselli, 2003). The results were that an overall number of 55 species was considered as "threatened", including 9 critically endangered, 21 endangered, and 25 vulnerable species (Andreone et al., 2005 a, b). We may in fact consider the GAA project as the most important recent keystone for

Fig. 11. A group of herpetologists on the Ankaratra summit (2006) The photo shows (from the left) Parfait Bora, Tokihery J. Razafindrabe, a local assistant, Roger Daniel Randrianiaina, and David Vieites.

amphibian conservation. Together with the *Amphibian Conservation Action Planning* (ACAP) it allowed to identify the most important action axes and boosted the conservation actions (Gascon et al., 2007). The results of GAA also allowed to show that none of the over 220 species of frogs known in Madagascar went extinct. This is a very important information and a very powerful indication, taken into account that the considerable deforestation rate for Madagascar, and the fact of having only 10% of the original rain and dry forests, could have, as a logical consequence, the result that at least some species would have already gone extinct.

While it cannot be excluded that some frog species went extinct much before the starting of a specific study activity on amphibians (early nineteenth century), and thus that the current frog fauna is only a part of the original one, it is clear that, at least during the the last decades no species became extinct. Anyhow, considering the above mentioned deforestation, general habitat degradation and climate change, we can assume that the original distribution areas have shrunk and/or become isolated. This could produce many major problems in the future, also in front of the announced climatic changes and subsequent species distribution effects. In spite of this, we are not aware of any extinction, and this contrasts with data obtained from other continents, where species extinctions have been documented. Likely, this could be the effect of the non-presence (or non-virulence) of the amphibian chytrid fungus in Madagascar.

Conservation-oriented projects for the amphibians

While the attention for amphibians has always been present mostly since Boulenger's works, it is only recently that a series of projects started and aimed to save and study some particular species. Following the GAA, a special attention was recently drawn on species considered as "threatened", thus including those assessed as "vulnerable", "endangered", or "critically endangered".

For this purpose it is not possible to ignore the importance given to the golden frog, *Mantella aurantiaca*, as an iconic species. Together with the tomato frog (*Dyscophus antongilii*) it is likely the most known Malagasy frog: almost all the terrarium journals and books, when speaking of the peculiar amphibians of Madagascar, know and show the golden mantella. For this reason, it is clear that this species has always been among the "most wanted" Malagasy frogs for pet-trade. According to a recent evaluation of the *Mantella* trade (Rabemananjara et al., 2007), the number of exported individuals has reached a peak in 2001 (Carpenter & Robson, 2008). The high commercial interest is also witnessed by the fact that this has been the first *Mantella* species to be included in the CITES listing. *Mantella aurantiaca* was included in CITES II in 1995, while the remnant species (and the genus as a whole) in 2000 (see http://www.cites.org/eng/cop/11/prop/46.pdf). *Mantella aurantiaca* is also one of the easiest captive bred species, with several reproductive nuclei held by public aquariums and private people (Mattioli et al., 2005; Garcia et al., this book).

The great interest is also mirrored by the fact that *M. aurantiaca* was indeed one of the first species to be studied in terms of conservation. For this purpose, it is worth reminding the several actions of the The Foundation for Tropical Nature and Species Conservation (NAT) with a series of actions and proposals aimed at the conservation of the species' most typical habitats and the inclusion in 2005 of the Torotorofotsy marsh within the Ramsar convention. (http://digitalmedia.iespana.es/diariodelastablas/ramsar.pdf) (Zimmermann, 1992, 1996).

The relevant study project on the harlequin mantella, *Mantella cowani*, was started in 2003, although some data were already collected in the past (Fig. 12). The study aimed to define more precisely the species' distribution, until then quite uncertain, and allowed to gather some natural history data. Thus, it turned out that *M. cowani* is present in some high altitude sites around the Antoetra village and at least in a site not far from Ankaratra (Andreone & Randrianirina, 2003; Andreone et al., 2007). Tissue and bone samples obtained by toe-clipping allowed to carry out a phylogeographic analysis (Chiari et al., 2005), and to obtain data on the age structure (Tessa, 2006; Guarino et al., 2008). Interestingly, the trade of *M. cowani*, indeed one of the major concerns together with habitat alteration, was stopped by Malagasy authorities in 2004. This study will be re-launched in 2007, with the crucial support of the Van Thienhoven Foundation (http://www.vantienhovenfoundation.com).

Fig. 12. *Mantella cowani.* The harlequin mantella is the top priority for frog conservation. Still present at a few altitude sites, it suffered for the pet-trade (currently stopped) and for habitat alteration.

Studies of distribution and mitochondrial variation in *Mantella bernhardi* also revealed that the populations of this species are arranged into two conservation units that need particular attention (Rabemananjara et al., 2005) (Fig. 13).

Important projects are currently carried out by the team of Vences and Glaw. In particular, it should be mentioned: (1) the development of effective tools for rapid assessments of Malagasy amphibians: use of mtDNA sequences, bioacoustics, and tadpole morphology in conservation-oriented species inventories. (funded by the Volkswagen Foundation); (2) the biodiversity inventory and conservation priorities of the limestone formation of the Montagne des Francais region in northern Madagascar (funded by EAZA); (3) the realisation of the Malagasy Field Guide to Amphibians and Reptiles - an efficient monitoring tool in a biodiversity hotspot (funded by World Bank/Netherlands partnership Program; (4) the conservation and sustainable use of amphibians in Madagascar: integrating species and area priority assessments with a standardization of monitoring techniques (funded by the Volkswagen Foundation).

A conservation study was recently conducted in the arid Isalo Massif, south-central Madagascar (Fig. 14). This study, funded by the Nando Peretti Foundation, DAPTF, WAZA, and Zurich Zoo, had the finality to collect data on two poorly known CR species, *Mantella expectata* and *Scaphiophryne gottlebei*. Both species are indeed actively searched and collected for pet-trade

Fig. 13. *Mantella bernhardi*, one of the species frogs object of conservation studies.

Fig. 14. Franco Andreone while checking the drift-fence and pitfall trapping at Betampona (2007).

(Andreone et al., 2006). Beside this, life history data were gathered and new species were described (Mercurio & Andreone, 2007), together with data on the amphibian community and their conservation (Mercurio et al., 2007). Part of the same project was also destined to analyze more in detail the distribution of *Mantella viridis*, providing at the same time information on the population and age structure (Tessa, 2006; F. Andreone & V. Mercurio, in prep.).

A relevant survey work that had important conservation fallouts has been the analysis of Ankarana, Tsingy de Bemaraha and other arid western areas. Similarly to what happened for Isalo, the inventories conducted there revealed several still undescribed and endemic frog species (Mercurio & Andreone, 2007). In particular, the discovery of *Plethodontohyla fonetana* and *Tsingymantis antitra* (Fig. 15) gave new impulse to the conservation of frogs from western Madagascar.

While this paper is in press other research is in act, and is mainly reflected by the papers presented in this book. Notably, study work by Raxworthy and colleagues will allow to identify the risk connected to climate change in Madagascar, while Glaw's team is trying to valorize the rich and little known herpetofauna of the Montagne des Français area in N. Madagascar. The latter initiative was financed by the EAZA campaign on Madagascar (http://www.eaza.net/). EAZA also supported the study work on *Dyscophus*

Fig. 15. A female of *Tsingymantis antitra.* This recently discovered and enigmatic frog found at Ankarana is indeed one of the most relevant conservation priorities of Madagascar, since it shows a peculiar basal phylogenetic position (Glaw et al., 2006).

antongilii, led by F. Andreone in collaboration with BIOPAT and the local NGO Antongil Conservation (Tessa et al., 2007). For the first time a land was purchased just to assure the conservation of a frog species (Fig. 16).

The creation of the "Village Saogongogno" within the town of Maroantsetra, and the support to the environmental actions and environmental song and singer activity of A. Sarovy, the local NGO "Antongil Conservation" and the folk group "Antongil Vert" will likely become important conservation tools for this iconic frog (http://www.maroantsetra.com/pages/antongil_conservation.html).

Awareness initiatives

Other important conservation studies and initiatives currently carried out concern the increase of public awareness. The pioneer works in this sense are again due to the activity of Blommers-Schlösser and Blanc, who published important notes on books destined to the scientific community (Blommers-Schlösser & Blommers, 1984; Blanc & Blommers-Schlösser, 1987). Other remarkable initiative focussed on amphibians and reptiles have been the realisation of photographic posters (Andreone, 1997, 2006), and the publication of nature parts in a guide destined to tourists (Andreone & Randrianirina, 2001).

The activity of Vences, Glaw, and coworkers led to the realization of three editions of the well-known fieldguide. The first two were printed in 1992 and

1994, respectively, while the third edition was published in October 2007. Most remarkably, the third edition was printed in Malagasy too, and this project was supported by the World Bank.

Together with the publication of a series of three CDs with the calls of most frogs of Madagascar (Vences et al., 2005), the field-guide initiative represents indeed one of the most important actions supporting the valorization of Malagasy frogs. On the same wavelength it is worth quoting the publication of a popular booklet entitled "Threatened amphibians of Madagascar" (Andreone et al., 2007 a). This booklet, written in English, French, Italian and Malagasy was also aimed to reach a wide public and provide basic information on the importance of the amphibians for the biodiversity valorization in Madagascar. More recently, through the initatives of *Conservation International,* a leaflet on the identification of *Mantella* frogs was published by Jovanovic et al. (2006). Together with

Fig. 16. The Malagasy conservationist, guide and environmental singer Augustin Sarovy, while releasing a pit of *Dyscophus antongilii.*

popular papers published on Orchid, the journal of the Madagascar flight company, Air Madagascar (Andreone, 2006), and in other journals, as well as in a touristic guide (Andreone & Randrianirina, 2001) the activity of awareness valorization represents indeed one of the most important education tool.

Last but not least I wish to remind the initiatives led by two of the major European zoos and aquariums. The Acquario di Genova conducted a series of surveys in collaboration with Andreone and Vences (Mattioli et al., 2005), and realized an important portion of its exhibit dedicated to Madagascar (Gili, 2008). The Zürich Zoo realized the impressive “Small Masoala”, a very big exhibit where the Masoala Rainforest has been recreated (Andreone, 2005; Graf, 2005; Rübel & Furrer, 2006.).

Which future for amphibian conservation?

The importance of the conservation actions for the frogs of Madagascar has been stressed by the recent establishement of an Amphibian Executive Secretary of the Amphibian Specialist Group in Antananarivo. The two co-chairs, F. Andreone and H. Randriamahazo still continue their coordination activity. But the recruitment of N. Rabibisoa as Amphibian Executive Secretary, with the financial support of Conservation International represents indeed a novelty in the panorama of amphibian conservation.

Madagascar is an optimal place where to carry out “experiments” in terms of amphibian management and amphibian conservation. In fact: (1) it is an island (and thus is separated from any other land mass, a condition that limits the possibility of contamination and penetration of emerging pathogens), (2) it has a very rich and almost totally endemic batrachofauna, (3) the amphibian chytrid fungus has not yet been detected (and, hopefully, is really absent), (4) a diversified system of protected areas is currently under expansion, (5) there is a clear and evident interest of the Malagasy Government and the herpetological scientific community to act for species and habitat conservation. Seen this, the results obtained during the ACSAM, most of which have been presented and commented in the present book, could represent a solid base for a real conservation action.

The “Sahona Gasy Action Plan (Andreone & Randriamahazo, 2008) is an indispensable tool for obtaining an official recognition of the importance plaid by amphibians in terms of biodiversity assessment. The coming few years offer an unprecedented opportunity for working with the Malagasy Government to establish conservation priorities, and may possibly represent the last chance to make large-scale progress in the designation of protected areas. There is a keen interest among Malagasy officials to prioritize regions of the country in need of protection, and these priorities will be largely based upon basic biological knowledge relating to species diversity and distribution.

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RÉSUMÉ

Grenouillant à Madagascar: histoire de la conservation des amphibiens et des conservationists de l'Ile rouge.

Nous reportons une courte histoire de la conservation des amphibiens à Madagascar, en passant à travers une histoire parallèle de scientifiques de la conservation.

Mots clés: Amphibiens, Conservation, Madagascar.

Franco Andreone
Museo Regionale di Scienze Naturali
Via G. Giolitti, 36, I-10123 Torino, Italy
Email franco.andreone@regione.piemonte.it

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 47-58

Miguel VENCES[1], Olga JOVANOVIC[1], Frank GLAW[2]

Historical analysis of amphibian studies in Madagascar: an example for increasing research intensity and international collaboration

ABSTRACT

An analysis of a list of almost 1400 publications focused on Malagasy amphibians and reptiles revealed a clear trend of increasing research intensity, both in herpetological research in general, and in publications dealing with amphibians. Altogether, research on Malagasy amphibians has been less intensive as compared to reptiles, with 396 papers focusing on amphibians, 874 on reptiles, and 113 on both groups. Amphibian research intensity, measured as the number of publications dealing with these organisms (exclusively or together with reptiles) per decade, strongly increased from the 1970s on and reached maximum levels of 175 and (interpolated) 169 for the periods of 1990-1999 and 2000-2009. Most papers dealt with taxonomy, but phylogeny, biogeography and ecology/conservation are becoming increasingly important. The average number of authors per amphibian publications was 1 over most of historical times, and reached 3.3 in the current decade, with a current maximum number of nine authors in one paper. Malagasy authors increasingly participate in the research and publication process, with an average number of Malagasy authors per publication of 0.26 in the current decade. We suggest strengthening the increasingly collaborative nature of research on Malagasy amphibians by approaches that speed up data availability via appropriate cyber-infrastructure, and by further capacity building, in Madagascar, for the field of amphibian biology.

Key words: Amphibians, Collaboration, Conservation, Historical findings, Literature, Madagascar.

INTRODUCTION

As summarized by Andriamialisoa & Langrand (2003), the exploration of Madagascar's fascinating flora and fauna has since long attracted the interest of numerous explorers and scientists. For the amphibians, early works were taxonomic almost in their entirety, and started with the description of *Boophis*

[1] Technical University of Braunschweig.
[2] Zoologische Staatssammlung München.

goudoti in 1838 (Tschudi, 1838). Until 1870 only eight frog species were described from Madagascar, but the subsequent years saw a large increase of research intensity, with the descriptions of 95 species by 1900, mainly by George Albert Boulenger from the British Museum in London, and Oskar Boettger in Frankfurt. After an intensified research activity in the 1970s, mainly due to the works of Jean Guibé and Rose Blommers-Schlösser, monographic accounts focusing on the Malagasy amphibians were published by Guibé (1978), Blommers-Schlösser & Blanc (1991), Glaw & Vences (1992, 1994, 2007), and Vences et al. (2006).

Historical analyses of herpetological research in Madagascar have so far used the number of species descriptions per decade as indicator for research intensity (Glaw & Vences, 1994, 2000). These works detected an extreme rise in research intensity since the 1990s, with more species described from 1990-1999 than in any decade before, both for amphibians and reptiles (Glaw & Vences, 2000). In fact, at least for amphibians, there is reason to assume that this high rate of species discoveries will be maintained or will even further increase. The trends in study intensity in other fields of amphibian biology, e.g., ecology, behaviour, physiology, biogeography, phylogeny comma and conservation, have so far remained unstudied. However, from collaborative efforts and meetings such as the Global Amphibian Assessment workshop for Madagascan amphibians in Geneva in 2003, and the ACSAM (A Conservation Strategy for the Amphibians of Madagascar) workshop in Antananarivo in 2006, both focusing exclusively on amphibian conservation in Madagascar, it is clear that also aspects beyond systematics are now receiving a high international attention.

For a long time, the participation of Malagasy researchers in the exploration work and publications of Madagascar's flora and fauna remained marginal, largely reflecting colonial history. However, this trend has been reversed, and the contributions of a flourishing generation of Malagasy scientists, especially to the exploration of remote areas of Madagascar, have strongly contributed to the enormous advances in knowledge on Madagascar's biota.

In this paper, we analyze the historical trends of faunal research in Madagascar from an amphibian perspective. We compiled a largely complete database of literature and analyze number of publications, numbers of authors per publication, and international collaboration over the decades and centuries, with the aim of detecting general trends and inferring suggestions for future research strategies.

MATERIALS AND METHODS

The basis for the analyses in this paper was the first version of a list of references prepared by two of us (FG and MV) for inclusion in the third edition of the "Field Guide to the Amphibians and Reptiles of Madagascar" (Glaw & Vences 2007; for the first and second editions, 1992, 1994). This list of references contains by far most historical and recent publications that focus on Malagasy amphibians. It is certain that the list is not complete, and we will have missed both a number of historical publications of difficult access, and certainly some recent publications which use Malagasy amphibians and reptiles as model groups, especially in the fields of ecology, physiology and behaviour. Nevertheless, it is unlikely that the results of our analysis and our conclusions would be affected in any relevant way by the inclusion of these papers which certainly represent a minor proportion only.

All references were classified into a number of exclusive thematic categories: (1) taxonomy, (2) phylogeny, (3) biogeography, (4) ecology and behaviour, (5) physiology, and (6) monographic accounts and books. We furthermore noted the year of publication, language, number of authors, and (as far as discernible) number of different nationalities of the authors. Data were summarized for decades, from year 0 to 9 of each ten years; e.g., works published in the 1890s would be those with publication dates from 1st January 1890 to 31 December 1899. Publications on Malagasy amphibians, as summarized in the following, comprise two categories, namely (1) papers focusing only on Malagasy amphibians plus (2) papers focusing on Malagasy amphibians as well as reptiles. When talking about all herpetological publications, we refer to amphibian publications as defined above, plus those focusing exclusively on Malagasy reptiles.

RESULTS

Our database contained a total of 1383 herpetological references. Of these, 396 had as main focus Malagasy amphibians, 874 focused on Malagasy reptiles, and 113 were equally focused on Malagasy amphibians and reptiles.

The historical trends of research intensity on Malagasy amphibians (Fig. 1) indicate a constantly low number of publications from the 1830s to the 1960s, with 1-21 amphibian publications per decade, thus maximum average numbers of 2 published papers per year. A fast increase is visible since, with 39, 46, 175 and 110 publications in the 1970s, 1980s, 1990s and 2000s. Interpolating the value for the current decade (only publications until mid-2006 were considered in our database) gives an estimate of 169 amphibian publications, thus a publication intensity similar to that in the previous decade. The corresponding values for reptile research, as a whole, show similar trends, with average values of less than 20 publications per decade until 1960, 292 publications in the 1990s, and a drop to 148 papers (interpolated estimate: 227) in the current decade.

For an analysis of research categories of the published works, we first considered all herpetological papers together. The bulk of these dealt with taxonomy: altogether 736 (53%). Papers with a main focus on ecology, biogeography, physiology and phylogeny were almost not represented before 1960. Since then, these themes have gained importance, and in the present decades, ecological research is highly represented in the publications analyzed. The strongest categories, in this period, are still taxonomy (38%), and, newly, phylogeny and biogeography (together 35%). Ecology makes up for 29% of all

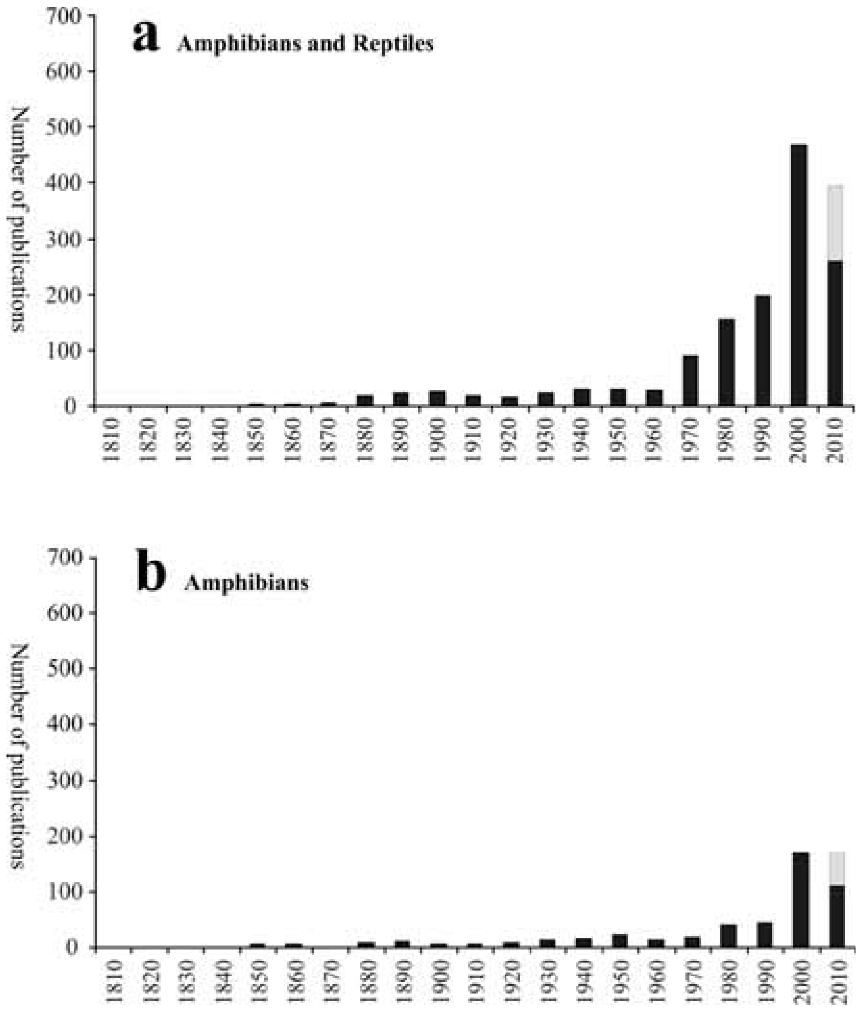

Fig. 1. Historical trends of herpetological research in Madagascar, indicated by numbers of scientific publications per decade focusing mainly on (a) either amphibians or reptiles, or both, and (b) on amphibians only, or on amphibians and reptiles. The grey bars are interpolated estimates for the period from 2000-2009. Each year given on the x-axis corresponds to the scale bar to its right, respectively.

herpetological papers published since 1960. A very similar situation is found if only publications on amphibians are considered: out of 396 publications, 190 dealt with taxonomy and systematics (48%). This proportion is similar for the period since 1960: 41% of amphibian papers published in this period deal with taxonomy and systematics; the categories of next highest representation are phylogeny and biogeography (together 16%), and ecology (10%).

The language of the herpetological publications, as well as of the amphibian publications analysed, was relatively equally distributed among English, German and French until 1930. From 1930 to 1980, French was the predominant language, making up for the largest proportion of publications (from 87% in the 1940s to 43% in the 1970s for all herpetological publications and from 100% in the 1950s to 41% in 1980s for amphibian publications). From the 1980s on, English became the predominant language, and in the current decade, 74% of all herpetological publications were in English, 23% in German, and only 3% in French, with an even stronger bias if only amphibian publications were considered: 94% of these were in English.

The average number of authors per amphibian publications was about one over most of historical times, and started to continuously increase from the 1980s on (Fig. 2a), reaching 3.3 in the current decade, with a current maximum number of 9 in the paper of Andreone et al. (2005). In parallel, also the number of authors of different nationalities increased strongly since 2000, to an average of 1.7.

Malagasy researchers were not involved as authors in any amphibian publication before the 1960s and 1970s, when M. Razarihelisoa, partly in collaboration with J. Arnoult, provided some work on the larval stages of Malagasy frogs (e.g. Arnoult & Razarihelisoa, 1966, 1967; Razarihelisoa, 1969, 1970). A sharp rise of the number of publications with Malagasy participation is noticeable in the 1990s, with 16 papers, and since 2000, with already 19 papers. The proportion of papers with Malagasy participation was 17% and 10% in the 1960s and 1970s, at a time of altogether few publications dealing with amphibians, dropped steeply to 2% in the 1980s, and is since then rising, with 9% in the 1990s and 17% in the current decade. The average number of Malagasy authors per publication was 0.16 in the 1990s and is 0.26 in the current decade.

DISCUSSION

On a global scale, the number of yearly published scientific papers is known to increase constantly (e.g., Mabe & Amin, 2001). The overall publication output between 1981 and 1992 increased by 41.5%, i.e. by 3% annually (Okubo et al., 1998). However, the enormous increase in research intensity on Madagascar's fauna and flora certainly represents more than just a reflection of this global trend. The intensified research activities have led to a relatively advanced state of knowledge on the Malagasy amphibian fauna with respect to their morphology (Blommers-Schlösser & Blanc, 1991; Glaw & Vences, 1994, 2007), advertisement

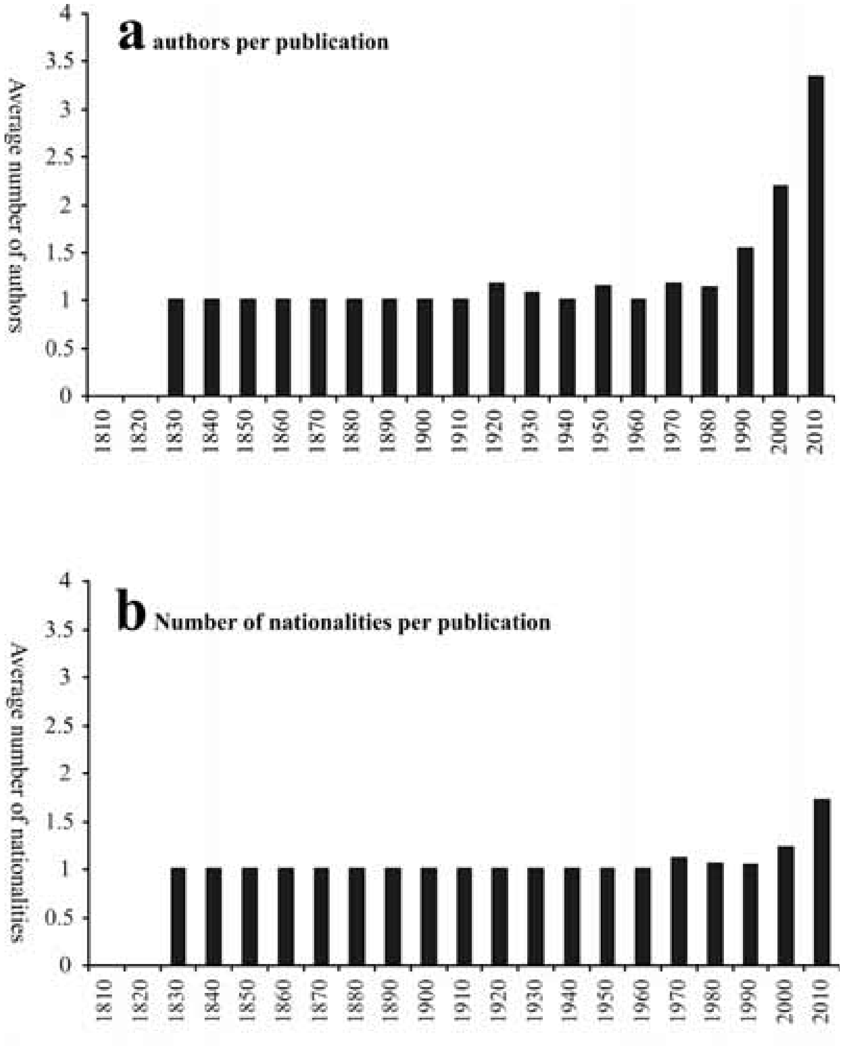

Fig. 2. Historical trends of collaboration in herpetological research in Madagascar, indicated by (a) the average number of authors per publication in each decade, (b) the average number of different nationalities of co-authors per decade, and (c) the number of publications with participation of at least one Malagasy co-author. Each year given on the x-axis corresponds to the scale bar to its right, respectively.

calls (Vences et al., 2006), conservation status (Andreone et al., 2005) and genetic divergences (Köhler et al., 2005). Most importantly, due to the intensive exploration work of Madagascar's habitats, all species of Malagasy amphibians have been confirmed in the wild during the past 15 years (Andreone et al., 2005), indicating that probably no extinctions have occurred in recent times.

Continuation of fundamental survey activity in concert with taxonomic and phylogenetic studies is crucial to identify priorities for conservation of biodiversity. Our analysis gives a number of indications for future developments of a research strategy on Malagasy amphibians.

A first crucial step could be to foster the participation of Malagasy researchers in the process of actually publishing research results. Our results indicate an increasing trend in this respect, but still more than 80% of all studies on Malagasy amphibians are published without participation of Malagasy researchers. This agrees with a general trend in science: publications in high-profile journals are dominated by authors from developed countries who in 1997 produced 88% of all scientific and technical publications registered by the Science Citation Index (UNESCO, 2001). In the time period 1981-1992, 48 countries or regions with the highest publication output covered over 97.9% (6,582,457 publications) of the total world production (Okubo et al., 1998). One key factor may be that more local journals from developed regions are listed by the SCI than similar journals from developing regions (Gibbs, 1995). Consequently, there are more high-profile regional publication opportunities available to scientists from the developed region, whereas much of the research published locally in the developing world is overlooked. However, it appears critical for the developing world to promote, through research and publications, those areas of concern that are having a proportionally greater scientific and social impact upon them (Holmgren & Schnitzer, 2004).

According to our own observations, many excellent and highly relevant results, often obtained by Malagasy researchers and students, remain buried in unpublished reports. The publication series “Recherches pour le Developpement - Serie Sciences Biologiques” and the recent creation of the new journals “Malagasy Nature” and “Madagascar Conservation and Development” represent encouraging steps to overcome this situation. Further potential actions could involve the creation of a series of rapid online publications in the field of the natural history of Madagascar which would, on one hand, allow for the publication of short notes on novel distribution records or behavioural or ecological observations, and on the other hand, allow for the publication of monographical reports and surveys, including lists and photos of voucher specimens to increase verifiability of results.

Several authors have, in the past years, argued for the need of a general change of approach in research in the field of taxonomy, and, in general, biological sciences (e.g., Schram, 2004; Wheeler et al., 2004). Rhee (2004) proposes a seamless connection of community databases, public repositories and journals. A crucial component is to make results of research timely available by appropriate cyber-infrastructure and building a digitally connected network of knowledge rather than isolated, specialized and difficult-to-find papers. Data would be published electronically and made instantly available. Databases of names and conservation status of species, geo-referenced distribution records, DNA barcode sequences, images of specimens, and real-time satellite surveys of habitat changes could provide a direct feedback of research into conservation. Working towards this vision requires a high degree of collaborative effort, as exemplified by a recent initiative to elucidate taxonomy and phylogeny of southern African reptiles for conservation purposes (Branch et al., 2006). Whether such concepts can be applied to research on Malagasy amphibians will depend on the interest of all involved researchers. The increasing number of authors and nationalities involved in the publication analyzed here (Fig. 2) shows that research on Malagasy amphibians is becoming a collaborative endeavour. Continuing these first steps would likely be of benefit for all involved researchers and, above all, for the conservation of the amphibians of Madagascar.

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RÉSUMÉ

Analyse historique des études sur les amphibiens à Madagascar: un exemple pour l'amélioration de l'intensité de la recherche et la collaboration internationale.

Une analyse sur une liste de presque 1400 publications orientées sur les amphibiens et les reptiles malgaches révèle une claire tendance à l'augmentation de l'intensité des recherches, en recherches générales d'herpétologie et en publications qui traitent des amphibiens. Globalement, la recherche sur les amphibiens malgaches a été moins intensive comparée aux reptiles, avec 396 articles sur les amphibiens, 874 sur les reptiles, et 113 concernant les deux groupes. L'intensité de la recherche sur les amphibiens mesurée en tant que nombre de publications traitant ces organismes (exclusivement ou avec les reptiles) par décennie, est fortement en hausse à partir des années 70, atteignant un volume de 175 et (interpolés) 169 sur les périodes 1990-1999 et 2000-2009. Beaucoup d'articles traitent de la taxonomie, mais la phylogénie, la biogéographie et l'écologie/conservation commencent à augmenter fortement. La moyenne du nombre d'auteurs par publication sur les amphibiens était de plus ou moins 1 sur l'ensemble de la période historique, avant d'atteindre 3,3 pour la décennie actuelle, avec actuellement un nombre maximum de neuf auteurs pour un article. Les auteurs malgaches participent de plus en plus à la recherche et au processus de publication, avec un nombre moyen d'auteurs malgaches par publication de 0,26 pour la décennie actuelle. Nous suggérons d'intensifier l'augmentation de la nature collaborative des recherches sur les amphibiens malgaches par des approches qui accélèrent la disponibilité des données à travers des infrastructures cybernétiques, et par la conduite de capacités accrues, à Madagascar, dans le champ de la biologie des amphibiens.

Mots clés: Amphibiens, Collaboration, Conservation, Données Historiques, Littérature, Madagascar.

Miguel Vences
Olga Jovanovic
Zoological Institute
Technical University of Braunschweig
Spielmannstr. 8
38106 Braunschweig, Germany
Email m.vences@tu-bs.de

Frank Glaw
Zoologische Staatssammlung
Münchhausenstr. 21
81247 München, Germany
Email Frank.Glaw@zsm.mwn.de

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 59-66

Olga RAMILIJAONA RAVOAHANGIMALALA[1]

Rôle du Muséum du Département de Biologie Animale de l'Université d'Antananarivo dans la conservation de la biodiversité de Madagascar, avec spéciale référence aux amphibiens

ABSTRACT

The museum of the Animal Biology Department is a museum for the natural history of Malagasy fauna. Its principal mission is research, the formation to research and the conservation of scientific collections. The final goal is to make collection data available to the scientific community. The national collection is the fruit of collect of national and international researchers issued of different institutions (university, Museum, center of research, etc.). There are 30000 to 50000 species with 17954 amphibians. The 4 families, 9 subfamilies and threatened species of Amphibians are represented with many types.

Key words: Amphibians, Endemism, Herpetological collection, Madagascar, Museum.

INTRODUCTION

Créé depuis une quinzaine d'année, le Muséum du Département de Biologie Animale de l'Université d'Antananarivo (MDBA) constitue un répertoire muséologique et scientifique des espèces faunistiques de Madagascar. Par conséquent, il représente aussi un centre de documentation de l'histoire naturelle de la biodiversité malgache.

Ses missions principales sont le développement et le renforcement de la recherche fondamentale et appliquée, l'amélioration du système de l'enseignement et de la pédagogie. Par ailleurs, ce Muséum contribue à l'initiation à la recherche, à la gestion et à la conservation des collections scientifiques référentielles travers l'encadrement scientifique des étudiants et

[1] Département de Biologie Animale, Université d'Antananarivo.

des jeunes chercheurs. Le Muséum s'adresse en particulière aux étudiants du 2ème cycle et doctorants du 3ème cycle par l'intermédiaire de l'école doctorale.

Les collections préservées du Muséum sont utilisées également par les chercheurs (soit nationaux qu'étrangers) comme support d'études scientifiques ou comme témoins de la biodiversité dans le cadre d'études biologiques, écologiques et/ou environnementales. A ce propos nous rappelons que, dans le cadre des amphibiens, une publication concernant la redécouverte et la redescription de *Mantella manery* a été faite par Vences et al. (2004) grâce aux spécimens conservés dans ce Muséum.

Les spécimens conservés au Muséum servent aussi de base essentielle aux expertises dans le secteur du patrimoine naturel. Rappelons aussi que ces matériels proviennent des investigations biologiques menées dans les différents milieux écologiques de la Grande île, ceci depuis l'extrême Nord à l'extrême Sud et de l'Ouest à l'Est. (Glaw & Vences, 1994).

L'activité de recherche du Muséum consiste surtout à inventorier, à documenter, et à comprendre la diversité biologique et écologique de Madagascar. En fait, l'étude de la dynamique et des rôles joués par cette biodiversité ainsi que ses valeurs et potentialités font l'objet des divers sujets de recherches, afin de contribuer à une gestion durable de cette diversité (Glaw et al., 2007). Des recherches plus approfondies sur la biogéographie et la phylogéographie prennent également une importante dimension au sein du Muséum dans le but de mieux comprendre le pattern de cette biodiversité unique. La gestion, l'entretien et la conservation des collections scientifiques tiennent une place centrale dans les activités statutaires du Muséum. Les partenariats avec différentes institutions de recherches, des ONGs et des Associations constituent la base stratégique adoptée pour mieux gérer, entretenir et enrichir la collection.

Deux collections existent actuellement: la première est celle du MDBAet la deuxième est hébergée au Parc Botanique et Zoologique de Tsimbazaza. Les deux collections ont des origines, des finalités et des vocations différents. Le MDBA a une orientation nationale pour la recherche et celui du PBZT pour l'éducation. La collaboration pour la gestion commune de ces collections est incontournable afin d'aboutir aux objectifs communs (protection, conservation et valorisation de ces Amphibiens)

RESULTATS

Origine des spécimens collectionnés dans le Muséum

Les amphibiens ont été collectés surtout lorsque des activités de valorisation de la biodiversité menées par les grandes équipes de recherche ou par l'activité continu de petits groupes de recherche. En général, les inventaires biologiques consistent à conduire des inventaires «rapides» d'environs 5 jours dans un site donné, afin d'avoir une idée globale du contenu du site et d'orienter dans la suite les thèmes de recherche suivant ces résultats. Cinq spécimens par site

(Aires protégés ou autres) et par espèces capturées ont été ramenés au Muséum suivant l'autorisation de recherche octroyée par l'entité responsable (la Direction Générale des Eaux et Forets au Ministère de l'Environnement et des Eaux et Forets). Les individus ont été anesthésiés dans un solution de chlorotone. Tous les tissus sont conservés (dans des eppendorfs) contenant de l'alcool éthylique 90°, tandis que les spécimens de référence sont conservés à l'alcool 70° après avoir les anesthésiés et fixés.

Une identification préliminaire a été faite sur terrain suivi par une plus approfondie au muséum ou dans des autres laboratoires Des études comparatives avec les individus typiques dont la plupart se trouvent à l'extérieur sont souvent effectuées afin d'assurer une bonne détermination du spécimen. Dans ce cas, une exportation à titre de prêt se fait et les spécimens sont envoyés aux spécialistes du groupe concerné, le rapatriement s'effectue après l'identification du spécimen Cette condition est nécessaire pour continuer la collaboration entre les partenaires responsables de la collecte.

D'une manière générale, dans le cadre de collaboration avec des institutions de recherches dans un laboratoire étranger, la moitié des spécimens sera exportée, et après les travaux de détermination, une partie doit retourner à Madagascar pour servir d'étalon. Dans le cas de découverte de nouvelle espèce, la description sera faite ensemble avec le spécialiste qui a fait la détermination et les chercheurs nationaux (enseignants ou thésards) suivant le cas. C'est le cas d'une nouvelle espèce de *Mantella manery* (Vences et al., 2004), groupe *Boophis rappiodes* (Vences & Glaw, 2002) et *Scaphiophryne boribory* (Vences et al., 2003.

Quelques collectes sont effectuées au cours des études et suivis de la biodiversité études quand les chercheurs disposent de permis adéquats. L'objectif est de profiter toutes les occasions pour enrichir autant que possible la collection de référence du MDBA. Par exemple, le suivi des espèces de *Mantella* fortement commercialisées est entretenu par diverses équipes (F. Andreone, M. Vences, R. Jenkins, etc.).

Des études biologiques et écologiques des différents stades d'un cycle biologique sont collectionnés pour faire des comparaisons en vue des études ultérieures, ou encore des études sur des variations de taille entre différents sites, ou étude ostéologique, les structures et les formes des palmures (cf. Glaw et al*.,* 2000; Hayek et al*.,* 2001; Rabibisoa et al., 2008).

Stockage et gestion des spécimens

Le Muséum est actuellement formé par trois salles: une salle d'exposition, une salle de préparation et une salle de stockage des spécimens non étudiés et non catalogués.

Les spécimens sont conservés par groupe taxinomique, Suivant le groupe, le mode de conservation est différent. Il existe en effet des spécimens en liquide, conservés dans de l'éthanol dont la concentration varie suivant le groupe taxinomique. Ils sont préservés dans des bocaux contenant de l'alcool. Ces matériels sont offerts par les partenaires du Muséum.

Le Muséum n'a pas un financement propre pour son fonctionnement, chaque chercheur contribue à la bonne marche de la gestion et de la conservation des animaux conservés. Ceci constitue un handicap pour le bon fonctionnement du Muséum car les chercheurs n'apportent pas le même niveau de contribution et un sentiment de non confiance existe entre les responsables de chaque équipe. Un seul curateur bien formé et pouvant gérer et entretenir ce muséum est idéal

Par ailleurs, certains partenaires ont laissé à la disposition du Muséum des ressources humaines pour travailler pendant une période déterminée pour travailler et arranger les collections. C'est le cas de Sabine Fellowship de l'Ecology Training Programme du WWF en 2003 qui a financé deux chercheurs malgaches pour arranger et entretenir les spécimens. Des chercheurs étrangers, tels que M. Vences (Université de Braunschweig, Allemagne) et Raxworthy (American Museum of Natural History, New York, US) ont soutenu pendant plusieurs année des étudiants ou thésards pour les mêmes activités (Cramer et al., Rabibisoa et al. in prep.).

Malgré cette gestion par équipe, des registres rassemblant la liste des divers spécimens par groupe faunique existent. L'enregistrement des spécimens dans une base de données globale identique au contenu des registres (logiciel Excel) se fait sur un ordinateur offert par l'un de nos partenaires le WWF, Madagascar en 2002.

Taille et entretien de la collection

Les collections disponibles au Muséum se chiffrent à plus de 80,000 spécimens de références dont environs 17,594 spécimens d'Amphibiens catalogués Il reste encore des milliers de spécimens qui ne sont pas encore enregistrés pour différentes raisons entre autre, la détermination des spécimens collectés non terminés, le non retour des spécimens envoyés à l'étranger. Il y a également les problèmes techniques tels que le manque d'alcool ou des bocaux ou encore des étiquettes. Les collections proviennent des chercheurs nationaux et internationaux ou des institutions et organismes de recherche, des universités ou des établissements d'enseignement ou des autres muséums. L'enrichissement se poursuit actuellement dans le cadre des conventions entre les instituts de recherche publics ou privés et des universités. La contribution individuelle des chercheurs nationaux et internationaux lors des expéditions scientifiques effectuées avec le Département de Biologie Animale de l'Université d'Antananarivo est également non négligeable.

Type de collection

Les spécimens sont issus des différents endroits de l'île aussi bien dans les aires protégées que hors aires protégées. Les Aires Protégées à Madagascar sont gérées par l'Association Nationale de la Gestion des Aires Protégées (ANGAP) sous l'égide du Ministère des Eaux et Fôrêts et Environnements. Toutes demandes de collectes doivent d'avoir l'aval de cette association et suivie de près par ces agents.

Potentialités et valeurs de la collection

Les spécimens de collection des amphibiens sont utilisés par les chercheurs, spécialistes, doctorants et étudiants pour leur propre étude en tant que matériels de base. Des spécimens sont destinés pour des travaux de reconnaissance en travaux pratiques dans l'enseignement académique du Département dans les différentes années d'étude sur la classification des Amphibiens à partir de la morphologie externe. Des études d'Anatomie sont menées mais à partir d'Amphibiens d'espèces communes vendues dans les marchés locaux (*Hoplobatracus tigerinus*).

En moyenne, 800 étudiants en première année, 250 en deuxième année suivent les Travaux Pratiques sur la classification animale. En troisième et quatrième année, une centaine d'étudiants participent aux études plus approfondies entre autre sur l'anatomie. Le nombre d'étudiants suivants des études en troisième cycle (DEA + Doctorat) sur les Amphibiens sont repartis entre les differentes équipes.

Initiation à la recherche scientifique

Les matériels disponibles sont d'une importance capitale pour initier les étudiants qui s'intéressent à la systématique zoologique à manipuler par exemple une clé de détermination pour identifier un spécimen. Par ailleurs, ils constituent un matériel de choix pour apprendre aux étudiants la technique de mensuration et la biométrie en général en disposant des spécimens entier ou d'un squelette.

D'autres étudiants venant de différentes institutions viennent consulter cette collection en cas de besoin. Il s'agit d'étudiants nationaux ou étrangers participant dans des projets de conservation et qui souhaitent connaître ou approfondir leur connaissance sur les espèces d'Amphibiens menacées par exemple. Le Muséum n'est pas ouvert à tout public, ceci est plutôt le rôle de PBZT.

Plus de 40 000 spécimens de références sont déjà cataloguées actuellement dans ce muséum dont environs 28 952 spécimens herpétofauniques. Des centaines de spécimens appartenant à ce groupe demeurent encore non enregistrés et sont conservés dans la salle de stockage temporairement. Les différents genres de reptiles et amphibiens connus jusqu'à maintenant à Madagascar sont représentés dans la collection. Il existe des formes qui ne sont pas encore connues par la science et qui sont en train d'être décrites par des chercheurs travaillant au sein même du Département (Rabibisoa et al., 2008; Glaw et al., 2007).

Les spécimens de batrachofaune déjà enregistrés sont au nombre de 17 574 (août 2006) Ils sont issus des différents coins de Madagascar. C'est la plus grande collection de référence jamais existée à Madagascar pour ce groupe de Vertébrés. Actuellement, le Muséum abrite quelques types (holotypes et paratypes) des espèces nouvellement décrites. Pour les Amphibiens, *Mantella manery, Boophis tasymena* et *Scaphiophryne boribory* sont représentés Les spécimens conservés représentent des espèces endémiques de Madagascar.

DISCUSSION

Il n’y a pas de Ressources humaines disponibles pour assurer le maintien et la gestion de la collection (Collection Manager). Par ailleurs, le Musée ne dispose par de Curateur qui constitue un handicap pour la coordination et la gestion même de la collection.

Differents types taxinomiques sont dispersés dans différents musées du monde (Muséum national d'Histoire naturre de Paris, Natural History Museum, etc.). Ceci contribue a une bonne conservation des specimens de reference malagasy dans differents musées internationaux. La gestion des Données reste à l’état embryonnaire en particulier: l’informatisation des données qui n’applique pas des logiciels adéquats et la création de bases de données suivent cette forme et nécessitent une nette amélioration.

En termes d’infrastructures, les conditions existantes ne correspondent pas aux normes exigées pour un véritable Muséum. Outre l’insuffisance des infrastructures adéquates, il y les problèmes d’électricité, de l’eau et d’aération, Il est ainsi nécessaire de faire la normalisation des conditions de stockage (température, humidité, aération etc.,). Les matériels de recherche comme les binoculaires, microscopes si ils existent sont non performants, insuffisants et obsolètes. Le renouvellement des équipements des matériels pour la détermination et pour des recherches et études spécifiques (stéréo microscopes, microscopes à caméra numérique, trousse à dissection) est nécessaire ainsi que l’équipement en nouveaux matériels pour des études moléculaires et les outils informatiques performants équipés des logiciels pour des analyses spécifiques. Malgré les nombreuses recherches menées sur la biodiversité malgache, très peu des publications et d’ouvrages relatifs à ces études sont disponibles à Madagascar Le renforcement des ouvrages et des manuels de détermination trop anciens mérite une attention particulière avec accès à l’Internet.

L’approvisionnement en matériels de terrain pour la collecte de spécimens (matériels de camping et matériels de collecte et conservation des spécimens) est idéal afin de compléter les données en cas de besoins.

Les collections du Muséum sont utilisées à des fins de recherche scientifique, culturelles et pédagogiques. Elles sont utilisées par les chercheurs comme support d’études scientifique (références) ou comme témoins de la biodiversité dans le cadre d’études écologiques ou environnementales. Malgré la vétusté des locaux et l’inexistence de financement pour le maintien de ces locaux, beaucoup d’efforts ont été et sont déployés par les responsables locaux et ces partenaires afin que ce musée puisse suivre la norme requise.

RÉSUMÉ

Le Musée du Département de Biologie Animale est un musée consacré a l’histoire naturelle des espèces faunistiques malgaches. Ses missions principales sont la recherché, la formation a la recherche et la conservation de collections scientifiques. Les collections du Musée sont utilisées a des fins de recherches scientifiques et pédagogiques dans le domaine de la science de la vie. Les espèces conservées au Musée servent de base essentielle aux expertises dans le secteur du patrimoine naturel. Les collections disponibles actuellement proviennent des chercheurs nationaux et internationaux issus de differentes institutions. Ce musee abrite 17594 spécimens de référence d'Amphibiens, des paratypes (*Mantella manery*) et les espèces en danger. Malgré la vétusté des locaux, beaucoup d'efforts sont déployés par les responsables locaux et ces partenaires afin que ce musée puisse suivre le norme requis.

Mots clés: Amphibiens, Collections, Endémisme, Madagascar, Spécimens de référence.

Olga Ramilijaona Ravoahangimalala
Université d'Antananarivo
Département de Biologie Animale
BP 906, Antananarivo 101, Madagascar
Email oramilij@yahoo.fr

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Christopher J. RAXWORTHY[1]

Global warming and extinction risks for amphibians in Madagascar: a preliminary assessment of upslope displacement

ABSTRACT

Recently, the Malagasy amphibian fauna was assessed for extinction vulnerability, as part of the larger Global Amphibian Assessment (GAA) Program. However, at this time, no assessment was made regarding potential distribution shifts produced in response to global warming, despite growing evidence for warming and species displacement to higher elevations. Tropical montane species are potentially vulnerable to extinction, through loss of habitat from upslope displacement, because species may be endemic to single massifs and confined to areas close to summits. The Malagasy amphibians exhibit both these biogeographic features, but their vulnerability to extinction from upslope displacement has never been investigated. This study presents a preliminary assessment of this potential vulnerability for all 226 species listed in the GAA for Madagascar. A total of 39 species are identified that are confined to mid and high elevation habitats, and that appear to be locally endemic. These species are distributed in the following nine regions: Tsaratanana, Anjanaharibe-Sud/Marojejy, Ambohitantely, Andasibe-Fierenanana, Ankaratra, Antoetra, Ranomafana, Andringitra, and Anosy. An elevational displacement analysis, which assumes that species track the temperature envelope that they occupy, finds increases in total habitat loss occurring with upslope elevational displacements greater than 500 m, with an upslope displacement of 700 m potentially resulting in total habitat loss for 18 of 39 species. Using a more severe scenario, which allows for no elevational dispersal (e.g. the situation for forest-obligate species in completely fragmented forest landscapes) finds 26 of 39 species potentially experiencing total habitat loss with upslope displacements of 300 m. Applying a standard moist adiabatic lapse rate, and assuming species will: 1) disperse, and 2) tolerate displacements up to half that required for total habitat loss, finds that amphibian extinctions in Madagascar would potentially increase substantially with warming above 1.5°C and upslope displacements greater than 250 m. Recent temperature data and regional mid-range climate model projections indicate that this warming threshold could be reached before the end of the 21st Century in Madagascar. To permit maximal upslope displacement for amphibians, high conservation priority should therefore be given to

[1] American Museum of Natural History, New York.

protecting broad elevational transects of continuous primary habitat within the existing and proposed reserves and corridors. In addition, surveys of amphibians are also needed to track potential upslope displacements. Preferably, these surveys should establish transects, for the long-term monitoring of amphibian populations, at all nine of the regions identified here to have significant regional endemism.

Key words: Amphibia, Climate Change, Conservation, Distribution Change, Elevational Displacement, Extinction, Global warming, Madagascar, Montane endemism.

INTRODUCTION

Recently, the entire Malagasy amphibian fauna was assessed for extinction vulnerability using the IUCN categories on threats (Andreone et al., 2005), as a part of the larger Global Amphibian Assessment (GAA) Program (Stuart et al., 2004). However, at this time, no assessment was made regarding potential distribution shifts that might be produced in response to global warming, although there has been growing evidence for global warming and it's biological consequences (Hughes, 2000; IPCC, 2001, 2007ab; Walther et al., 2002; Parmesan & Yohe, 2003; Root et al., 2003; Karoly & Wu, 2005). These biological responses include predictions of species extinctions through loss of habitat (e.g. Peterson et al., 2002; Williams et al., 2003; Thomas et al., 2004, Thuiller et al., 2005) and empirical observations that directly link warming to extinctions (e.g. Pounds et al., 1999, 2006).

Upslope distribution displacements represent one of the biological fingerprints of global warming, with species distributions shifting to higher elevations in direct response to increasing temperature (Parmesan & Yohe 2003, Root et al., 2003), or in combination with other changes such as mist frequency (Pounds et al., 1999; Still et al., 1999) or the availability of new habitats (Seimon et al., 2007). Upslope displacements have now been reported for multiple temperate studies (e.g. Grabherr et al. 1994; Parmesan, 1996; Pauli et al., 1996; Kullman, 2001; Erasmus et al., 2002; Epps et al., 2003; Konvicka et al., 2003; Pauli et al., 2007), but currently, there is still very little information available for tropical regions (IPCC, 2007b). However, a frog population census in Ecuador, made between1967-2003, did find increases in the upper elevation limit in 6 of 76 surveyed species (Bustamante et al., 2005).

Tropical mid-elevation and montane regions, such as those found in Madagascar, typically exhibit high levels of local endemism, which may also include species confined to narrow elevational zones close to summits (e.g. Jenkins, 1987; Myers et al., 2000; Ricketts et al., 2005). Although some of the high montane communities of Madagascar have been subject to periods of intense research (see Andriamialisoa & Langrand 2003; Raxworthy, 2003), the vulnerability of these and indeed most other tropical montane communities to extinction from upslope displacement is not yet well documented (Rull & Vegas-Vilarrúbia, 2006).

Concerning tropical amphibians, the Global Amphibian Assessment (GAA) has found for montane species a high incidence of ‘enigmatic’ declines (declines or disappearances in apparently intact primary habitats), which has been suggested as a potential consequence of climate change and emerging diseases (Stuart et al., 2004). And more recently, *Atelopus* frog extinctions have been linked to warming temperatures that are thought to promote a pathogenic chytrid fungus (Pounds et al., 2006). Other enigmatic declines have been linked to emerging disease (Lips et al., 2006), but more generally, tropical montane amphibian declines remain poorly understood, and to date, none have yet been reported for Madagascar.

Although the evidence for global warming is well established (IPCC, 2001), no observations for changes in physical or biological systems have been noted for Madagascar in the most recent IPCC summary report (IPCC, 2007b). Concerning Madagascar, Jury (2003) reports an increase in coastal sea surface temperatures around Madagascar of ~1°C over the past century (see also Karoly & Wu, 2005) and Heiss et al. (1998) detected a general warming trend (with oscillations) from 1930 onwards from a 350 year old coral core taken from the SW coast of Madagascar. The widespread bleaching of coral reefs in Madagascar during 1988 has also been linked to the exceptionally high (33°C) ocean temperatures of this period (Wilkinson et al., 1999), and it has been predicted that the vegetation cover of Madagascar will show negative responses to the expected increasing frequency of El Niño Southern Oscillation (ENSO) phenomenon that is associated with global climate change (Ingram & Dawson, 2005). Most recently, Raxworthy et al., (2008) have summarized recent temperatures records for Madagascar, finding evidence for warming between 1993 and 2003 of 0.10 to 0.37°C per decade (gridded data for Northern Madagascar taken from CRUTEM3, HadCRUT3, ERA-40, NCEP and NCEP2) and corresponding upslope displacements of 19 – 51 m for 30 resampled species of amphibians and reptiles at the Tsaratanana Massif in northern Madagascar.

The objective of this study is to provide a preliminary assessment of extinction vulnerability of the Malagasy amphibians, resulting from potential upslope displacement from warming. The elevational distributions of all species are examined to identify the most vulnerable mid-altitude and montane regionally endemic species. For these species a simple elevational range displacement analysis is then applied, based upon elevational distribution, regional topographic constraints, a standard moist adiabatic lapse rate, and scenarios of both dispersal and no dispersal.

MATERIALS AND METHODS

All species listed in the Global Amphibian Assessment (GAA) for Madagascar were evaluated to provide a comprehensive review of the most vulnerable Malagasy taxa. This database can be accessed at: http://www.globalamphibians.org/. A total of 226 species were listed for

Madagascar at the time of this study (14 June 2007). For each species the following data was evaluated: minimum and maximum elevational range, estimate of distribution range based on a minimum area polygon (extent of occurrence), and IUCN status. All GAA data and evaluations are based on published sources cited in the GAA database (see also Glaw & Vences, 1994, 2003), with additional field data provided by the GAA Madagascar members during the species assessments. Further details about the Madagascar GAA are provided by Andreone et al. (2005).

For this analysis two criteria were used to select species considered at greatest risk to extinction from upslope displacement: 1) minimum known elevation 800 m; and 2) extent of occurrence with a maximum linear length < 200 km. The first criterion was used to exclude species that occupy low elevation habitats, which in the vast majority of cases will have substantial higher elevation topographic areas available to them. The 800 m elevation threshold is also the boundary widely used to separate low and mid-elevation forest (e.g. Jenkins, 1987; ANGAP, 2001). The second criterion was used to select species endemic to single massif systems, and those species that appear to be regionally endemic (no commonly recognized massif in Madagascar exceeds 200 km in linear length). By contrast, the more widespread species will occupy regions offering greater elevational variation. Using these two criteria resulted in the selection of 39 species representing 17.3% of the Malagasy amphibian fauna as listed in the GAA database.

The highest elevation area considered available to each of the selected species was based on the highest summit found either from within their extent of occurrence, or up to 50 km of a known recent locality, with summits identified based on the Foiben Taosarintanin'I Madagasikara (FTM) 1:500,000 topographic maps. Not surprisingly, for most species, the highest elevation areas coincided with the summits of the major massifs in Madagascar. For each species, the upslope displacement required for total habitat loss (UDHL) was calculated based on the difference between the minimum known elevation occupied by the species and the highest elevation area available. Under this scenario the species is assumed to freely disperse upslope and thus extinction occurs when no more suitable habitat exists for the species.

In addition, the upslope displacement for total distribution loss (UDDL) was calculated based on the difference between the lowest and highest elevation known to be occupied by the species. Under this scenario, the species is assumed to be unable to disperse upslope and thus extinction occurs when no more suitable habitat exists for the species within its current (static) elevational range.

To estimate the magnitude of temperature warming required to displace a species upslope, a standard moist adiabatic lapse rate was used, which describes the relationship between air temperature and elevation. The more conservative lapse rate of 6°C per 1000 m was applied, which has also been routinely used by other researchers (e.g. Wright et al., 2004; Rull & Vegas-Vilarrúbia, 2006). This elevational range displacement analysis assumes that species track the spatial shifts of the temperature envelopes that they occupy (i.e. the changes in isotherm height).

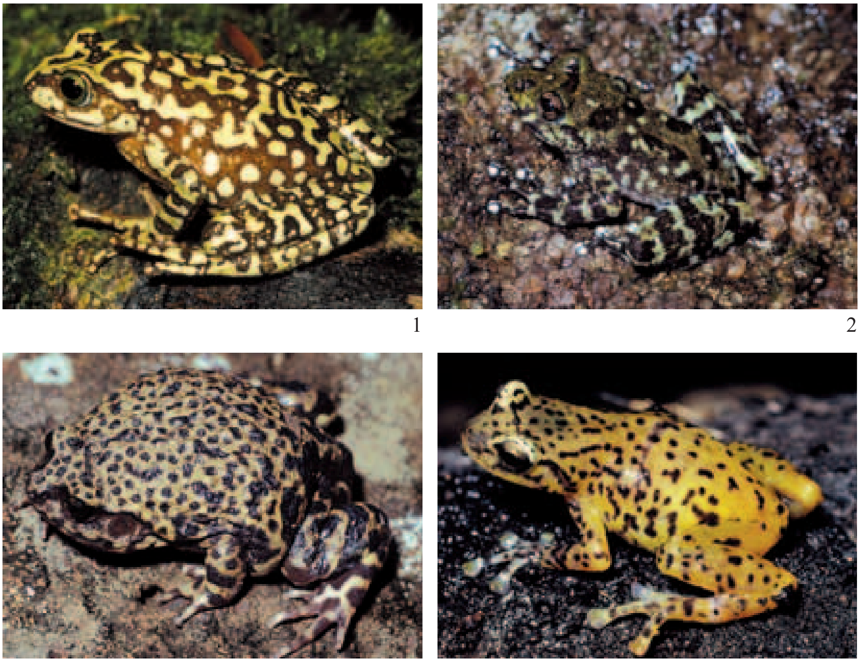
RESULTS

A total of 39 species were found to be regional endemics (as defined here, see methods), and confined to mid or higher level elevational habitats 800 m. These species are listed in Tab. I (see also Figure 1 for example species), which includes their known elevational distribution, IUCN status, and the calculated upward displacements required for both total habitat loss (assuming dispersal) and total distribution loss (assuming no dispersal). These species are distributed in just nine endemic regions: Tsaratanana, Anjanaharibe-Sud/Marojejy, Ambohitantely, Andasibe-Fierenana, Ankaratra, Antoetra, Ranomafana,

Species	IUCN	Endemism region	Min. elev.	Max. elev.	Max topo.	UDHL	UDDL
MICROHYLIDAE							
Anodonthyla montana	VU	Andringitra	2000	2658[1]	2658	658	658
Anodonthyla rouxae	EN	Anosy	1900	1900	1959	59	0
Platypelis alticola	EN	Tsaratanana	2350	2600	2876	526	250
Platypelis mavomavo	EN	Anjanaharibe-Marojejy	875	975	2133	1258	100
Platypelis tsaratananensis	VU	Tsaratanana	2600	2600	2876	276	0
Plethodontohyla brevipes	EN	Ranomafana	900	1100	1874	974	200
Pletho. guentherpetersi	EN	Tsaratanana	1450	2700	2876	1426	1250
Pletho. serratopalpebrosa	VU	Tsaratanana	900	2100	2876	1976	1200
Plethodontohyla tuberata	VU	Ankaratra	1600	2400	2643	1043	800
Scaophiophryne boribory	EN	Andasibe-Fierenanan	950	950	1548	598	0
Stumpffia helenae	CR	Ambohitantely	1500	1500	1646	146	0
MANTELLIDAE							
Boophis anjanaharibeensis	DD	Anjanaharibe-Marojejy	800	1000	2133	1333	200
Boophis burgeri	DD	Andasibe-Fierenanan	815	900	1548	733	85
Boophis elenae	DD	Ranomafana	900	1000	1874	974	100
Boophis feonnyala	DD	Andasibe-Fierenanan	900	900	1548	648	0
Boophis laurenti	DD	Andringitra	1500	2650	2658	1158	1150
Boophis liami	DD	Andasibe-Fierenanan	850	900	1548	698	50
Boophis periegetes	DD	Andringitra	800	1100	2658	1858	300
Boophis schuboeae	DD	Ranomafana	900	1000	1874	974	100
Boophis sibilans	DD	Andasibe-Fierenanan	900	900	1548	648	0
Boophis solomaso	DD	Andasibe-Fierenanan	850	850	1548	698	0
Boophis williamsi	CR	Ankaratra	2100	2100	2643	543	0
Blommersia sarotra	DD	Andasibe-Fierenanan	900	1200	1548	648	300
Brygoomantis madecassus	EN	Andringitra	1500	2500	2658	1158	1000
Brygoomantis ambohimitombi	DD	Antoetra	1100	1100	2052	952	0
Brygoomantis pauliani	CR	Ankaratra	2200	2200	2643	443	0
Mantidactylus albofrenatus	DD	Andasibe-Fierenanan	850	950	1548	698	100
Gephyromantis cornutus	DD	Andasibe-Fierenanan	850	1200	1548	698	350
Gephyromantis eiselti	DD	Andasibe-Fierenanan	800	1200	1548	748	400
Gephyromantis schilfi	VU	Anjanaharibe-Marojejy	1200	1200	2133	933	0
Gephyromantis thelenae	DD	Andasibe-Fierenanan	900	900	1548	648	0
Gephyromantis zavona	DD	Tsaratanana	800	1000	2876	2076	200
Mantella aurantiaca	CR	Andasibe-Fierenanan	920	960	1548	628	40
Mantella cowani	CR	Antoetra[2]	1000	2000	2052	1052	1000
Mantella crocea	EN	Andasibe-Fierenanan	800	1057	1548	748	257
Mantella microtympanum	CR	Andasibe-Fierenanan	900	1000	1548	648	100
Mantidactylus zolitschka	DD	Andasibe-Fierenanan	850	850	1548	698	0
Spinomantis guibei	EN	Anosy	1200	1800	1959	759	600
Spinomantis microtis	EN	Anosy	800	1400	1959	1159	600

[1] The GAA gave the maximum elevation, in error, as 2700 m.
[2] No recent records have been confirmed for other regions.

Tab. I. An elevational range displacement analysis for the selected 39 regionally endemic amphibian species distributed ≥ 800 m elevation. Distributional data from the GAA (see methods). IUCN categories: CR, Critically Endangered; EN, Endangered; VU, Vulnerable; DD, Data Deficient. Min. elev., Minimum elevation; Max. elev., Maximum elevation; Max. topo., Maximum topographic elevation in the endemism region; UDHL, upslope displacement for total habitat loss (assuming upslope dispersal), UDDL, upslope displacement for total distribution loss (assuming no upslope dispersal). All elevations and upward displacements given in meters.



1 2 3 4

Fig. 1. Examples of montane endemic species vulnerable to decline from potential upslope displacement (all the photos by C.J. Raxworthy).
1. *Boophis laurenti* from Andringitra.
2. *Spinomantis microtis* from Col d'Ampamakiesiny, Anosy.
3. *Plethodontohyla tuberata* from Ankaratra.
4. *Platypelis pollicaris* from Tsaratanana.

Andringitra, and Anosy (Fig. 3, Fig. 2). Of these 39 species, 18 species are classed as Data Deficient using the IUCN categories (in many cases because of suspected poorly-known distributions) while the other 21 species are classed with categories of threat: 6 Critically Endangered, 10 Endangered, and 5 Vulnerable.

The calculated upward displacement required for total habitat loss (UDHL) ranged between 59 m for *Anodonthyla rouxae*, to 2076 m for *Gephyromantis zavona*, with the mean 869 m, and the median 733 m. Cumulative plots for the number of species experiencing total habitat loss for increasing upslope displacement are shown in Fig. 4. All 39 species are included in the first plot (Fig. 4A), while in the second plot (Fig. 2B) only the IUCN threatened species are included (18 Data Deficient species excluded). For both plots an S-shaped curve is evident, with maximum rates of total habitat loss occurring with

Fig. 2. Examples of montane habitats vulnerable to modification from potential upslope displacement (all the photos by C.J. Raxworthy).
1. Stunted lichen forest with heathland ground cover at 2550 m elevation, Tsaratanana.
2. Grass-dominated wetland and lichen forest margin at 2500 m elevation, Tsaratanana.
3. Heathland at 2400 m elevation, Ankaratra.
4. Heathland with streams at 2000 m elevation, Andringitra.

upslope displacements of 600-800 m for all species, and 500-800 m for threatened species. Total habitat loss for species incrementally increases over almost all magnitudes of upslope displacement, but for an upslope displacement of 700 m, 18 of these 39 species experience total habitat loss. Using the 6°C per 1000 m lapse rate results in the following numbers of species experiencing total habitat loss (assuming dispersal) for each degree of warming temperature: 1°C, 2 species; 2°C, 3 species; 3°C, 4 species, 4°C 13 species; 5°C, 24 species; 6°C, 29 species.

The calculated upward displacement required for total original distribution loss (UDDL) ranged between zero for 13 species (only recorded for a single elevation) to 1250 m for *Plethodontohyla guentherpetersi* with the mean 292 m, and the median 100 m. All 39 species are included in Fig. 4C, and in Fig. 4D only the IUCN threatened species are included (18 Data Deficient species

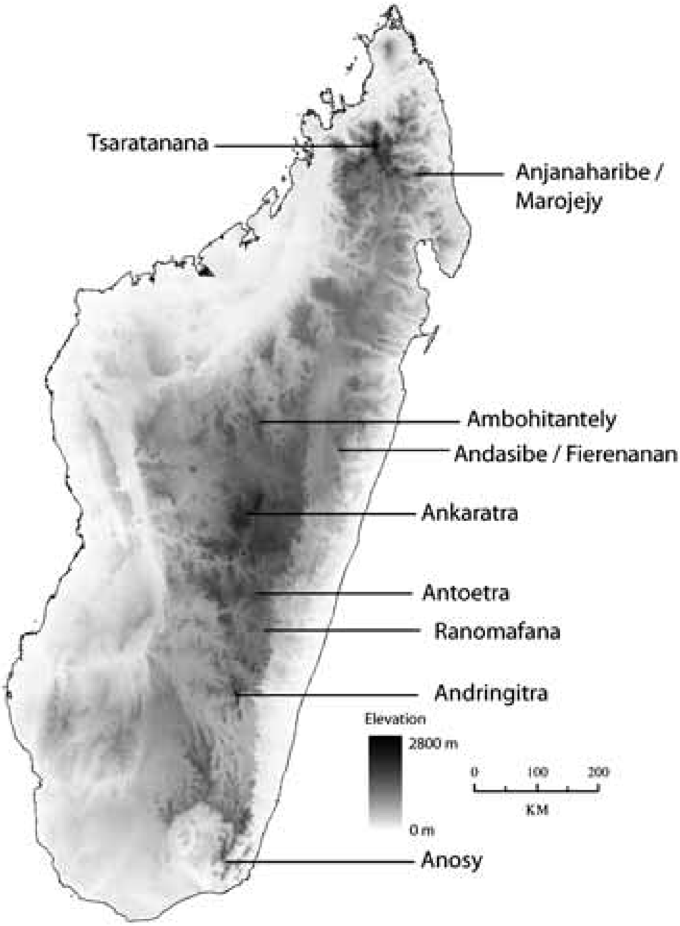


Fig. 3. Topographic map of Madagascar showing the eight regions identified as having locally endemic amphibians restricted to 800 m elevation.

excluded). For both plots a linear trend is evident, with the exception of displacements below 200 m for the plot including all 39 species. In this case, many Data Deficient species have zero or low elevational range distributions that are probably artefacts of insufficient field data. Consequently, when the Data Deficient species are removed, this results in a linear trend for species distribution loss being exhibited across the entire upslope displacement range. For an upslope

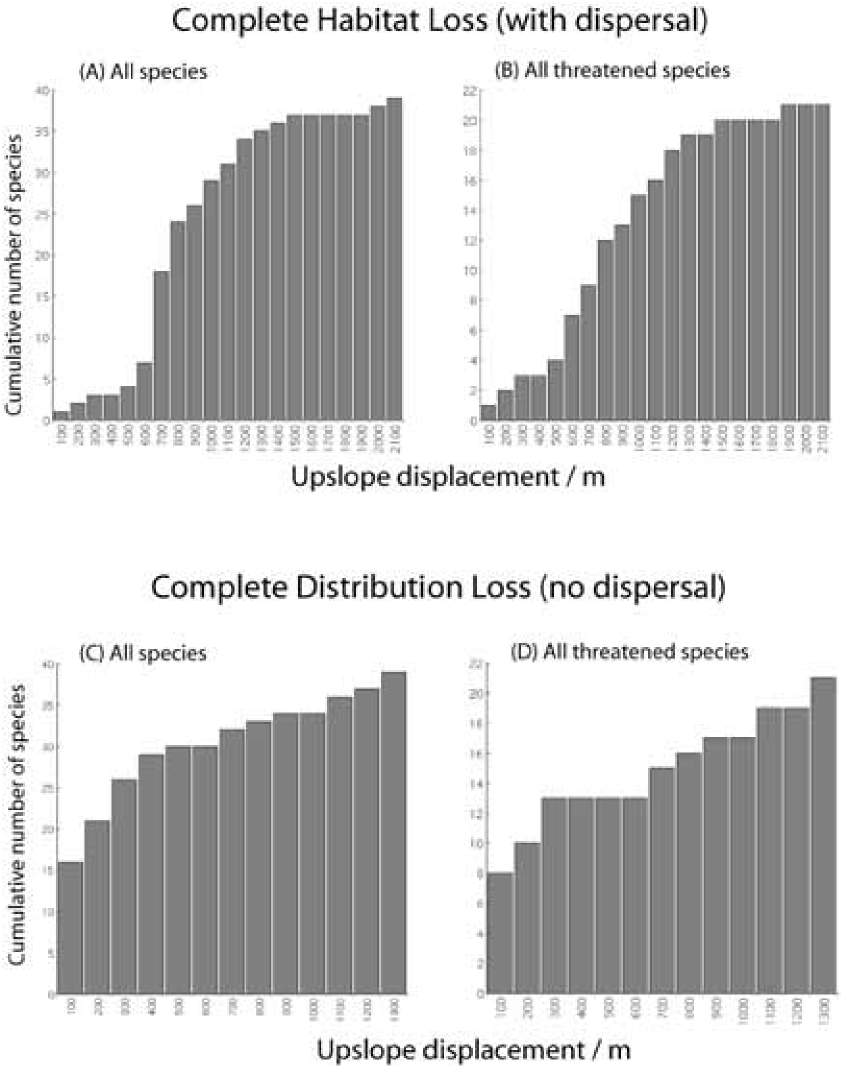


Fig. 4. The influence of upslope displacement on cumulative species loss through either complete habitat loss (assuming complete dispersal), or complete distribution loss (assuming no dispersal). (A) All 39 species (see Tab. I) for complete habitat loss (UDHL); (B) All threatened species (see Tab. I) for complete habitat loss (UDHL); (C) All 39 species for complete distribution loss (UDDL); (D) All threatened species for complete distribution loss (UDDL).

displacement of 300 m, 26 of these 39 species experience total distribution loss. Using the 6°C per 1000 m lapse rate results in the following numbers of species experiencing total original distribution loss (assuming no dispersal) for each degree of warming temperature: 1°C, 21 species; 2°C, 29 species; 3°C, 30 species, 4°C 32 species; 5°C, 34 species; 6°C, 36 species.

DISCUSSION

Current uncertainties and areas for further investigation

Assumptions and sources of errors associated with this preliminary analysis are discussed here to highlight the current limitations concerning assessing threats of potential upslope extinction from warming, and to also help orientate further field research work. Although the species elevational distributions provided by the GAA are assumed to accurately describe the actual species distribution, some of the rare species (especially the Data Deficient) are unlikely to have been sampled across their full elevational range. Incomplete distributional sampling inflates the apparent vulnerability to extinction, and it is probable that at least some of these 39 species also occur at lower elevations, and are thus at lower risk to potential upslope extinction. It is also likely that the current Madagascar GAA includes some elevational and regional biases concerning the historical context of how species were discovered and sampled in the field. For example, many Data Deficient species were collected from the more heavily surveyed Andasibe and Ranomafana regions. Because many of these species are easily confused with other species, additional field surveys are thus still needed to establish their true distribution limits. The highest elevation areas of some the major massifs in Madagascar (e.g. North Anosy) may also be relatively under-surveyed compared to mid elevation sites, because of the logistic problems associated with surveying these areas during the rainy season.

Applying a simple elevational range displacement analysis assumes species track their temperature envelope, and that temperature represents a limiting factor on distribution. Although this is not yet established for Malagasy amphibians, more generally, temperature gradients have been found to greatly influence herpetological species distributions, and species niches are frequently modelled to include multiple temperature-related dimensions (e.g. see Graham et al., 2004; Pearson et al., 2006; Raxworthy et al., 2003, 2007). The predictive power of these niche models, when projected into geographic space, supports the substantial influence of temperature variables on limiting species distributions.

Almost certainly, however, the greatest uncertainty concerns the dispersal abilities of individual species. This study uses two scenarios: species readily disperse to higher elevations, or that no dispersal is possible. Because the vast majority of Malagasy amphibians are restricted to natural forests, the fragmentation of forests for anthropogenic purposes (e.g. Green & Sussman, 1990; Dufiles, 2003) has the potential to create habitat barriers that prevent vertical dispersal upslope (Walther et al., 2002). Thus, in the future, some species may have dispersal limitations imposed upon them as a result of deforestation. For the regions of endemism identified in Tab. I, the elevational transects of forest most heavily fragmented occur at Andasibe-Fierenanan, Antoetra, and Ranomafana, and thus species endemic to these regions are probably the most vulnerable to dispersal constraints. Limitations on vertical dispersal will lower UDHL, and thus increases the vulnerability of a species to potential complete habitat loss from warming. Because future deforestation trends in Madagascar will be heavily influenced by the design of the new protected area network for Madagascar, it remains uncertain at this time, as to which Malagasy amphibians will be most influenced by vertical dispersal constraints.

Extinction risks from potential upslope displacement

These results suggest a substantial increase in total habitat loss for species, when potential upslope displacements exceed 500 m. For potential displacements of 700 m, total habitat loss occurs in 18 of the 39 assessed species. It is especially noteworthy that the Figure 4A S-shaped curve shows a maximum rate of species total habitat loss occurring between potential upslope displacements of 500-800 m: this result is also identical to that found by Rull & Vegas-Vilarrúbia (2006) for locally endemic plants in the Neotropical Guayana Highlands. These congruent findings are intriguing because they suggest the possibility of a common elevational pattern shared between diverse tropical montane communities.

From a conservation perspective, maintaining viable populations of amphibians requires conserving sufficient areas of suitable habitat, rather than just preventing total habitat loss. The UDHL (upslope displacement for total habitat loss) clearly represents too extreme a displacement to be used for conserving populations for the long term. And conversely, assuming a zero tolerance to any degree of upslope displacement also appears to be unrealistic. Here I assume that a displacement of 50% of the UDHL to represent the maximum displacement for stable long-term populations to persist. This assumption should be considered a starting point for evaluating extinction threats from upslope displacement; it is used here due to the absence of more detailed studies available at this time.

Consequently, with 500 m upslope displacement representing the threshold for potential escalating amphibian total habitat loss (Figure 4), the maximum target for upslope displacement to ensure the long-term conservation of populations is 250 m. Applying the 6°C per 1000 m lapse rate, this represents 1.5°C of warming, which is similar to the 2°C threshold of 'dangerous warming' that has been recently proposed by the ISSC (2005). By comparison, the IPCC (2007b) recently reported warming temperatures exceeding 1.5 – 2.5°C increases the risk of extinction for 20-30% of the species assessed by the panel.

Are warming trends in Madagascar sufficiently strong to suggest that amphibians could be vulnerable to upslope displacement extinction? The warming tends reported by Raxworthy et al., (2008) equal or exceed the global averages (IPCC, 2001, 2007ab; Karoly & Wu, 2005): for the periods 1984-1993 and 1994-2003 in northern Madagascar, gridded temperature data show this region experiencing warming between 0.10 and 0.37°C per decade which is also similar in magnitude to the warming reported for other weather stations outside this area (e.g. Maintirano, Tulear, and Antananarivo). These regional warming trends are also consistent with the IPCC warming simulations that include anthropogenic forcings (greenhouse gas emissions) for the same area (Raxworthy et al., 2008; see also Stott, 2003, for similar results for Africa). Should future warming continue at the mid-range rate, this preliminary assessment thus suggests that by the end of the 21st century, substantial habitat loss could potentially be well underway for about half of the mid- and upper elevation regionally endemic amphibians in Madagascar.

Alternatively, the no dispersal scenario (e.g. see Thomas et al., 2004) results in potentially more serious consequences from warming. Excluding Data Deficient species (which appear to be generally under-sampled for their full elevation range, see results), the no dispersal scenario finds that 13 of 21 threatened species (62%) regionally endemic mid- to high elevations could potentially go extinct with an upslope displacement of 300 m, resulting from warming of 1.8°C. However, because the elevational transects still appear to include continuous primary habitat, it seems unlikely that these species would not be able to disperse upslope. This extinction scenario thus currently appears unrealistic. Nevertheless, it will be important to track fragmentation trends for primary forest, to identify potential future barriers to upslope dispersal.

This analysis identifies three species of special concern, all microhylids: *Anodonthyla rouxae* from Anosy, *Platypelis tsaratananensis* from Tsaratanana, and *Stumpffia helenae* from Ambohitantely. Based on current distribution data in the GAA, all three species could potentially suffer complete habitat loss with upslope displacements of less than 300 m. *Platypelis tsaratananensis* has not been seen since Paulian collected it in 1949 at 2600 m (Guibé, 1974), despite more recent surveys. Both the other species appear to be endemic to their respective massifs, and confined to areas in close proximity to summits. The isolation of the relict forests of Ambohitantely make it likely that *Stumpffia helenae* is now confined to just this site (Andreone et al., 2005). *Anodonthyla rouxae* remains poorly known, but based on prevalent amphibian endemism at Anosy, it is likely to also be restricted to high elevation forest around the Anosy summits.

By comparison, montane reptiles in Madagascar show similar potential upslope displacement vulnerability, with the following species restricted to massifs and elevations less than 600 m below the highest summits: Montage d'Ambre (Raxworthy & Nussbaum, 1994a, Raxworthy & Nussbaum, 2006), *Calumma amber*, *Pseudoxyrhopus ambreensis*; Tsaratanana (Raxworthy et al., submitted), *Calumma tsaratananense, Phelsuma l. punctulata*; Marojejy (Raselimanana et al. 2000; Raxworthy & Nussbaum, 2006), *Calumma peyrierasi, Calumma jejy*; Ankaratra (Guibé, 1974, Raxworthy & Nussbaum 1994b), *Lygodactylus mirabilis*; Itremo (Pasteur, 1991), *Lygodactylus pauliani*; Ibity (Pasteur, 1967), *Lygodactylus arnoulti*, *L. blanci*; and Andohahela (Nussbaum et al., 1999), *Calumma capuroni*. These distributions suggest a more widespread vulnerability for the Malagasy fauna to potential upslope extinction from warming.

CONCLUSIONS

Based on the temperature trends reported by recent studies (Karoly & Wu, 2005; IPCC, 2007ab; Raxworthy et al., 2008) it may be prudent to anticipate potential upslope displacements of 300-500 m elevation for amphibians in Madagascar. Provided that elevational transects of intact primary habitat are maintained, potential species displacements less than 250 m do not appear likely to lead to the substantial loss of habitat for the vast majority of amphibians in Madagascar. However, for potential upslope displacements above 250 m, monitoring of vulnerable species populations may need to be considered, especially for those species identified here with low UDHL elevational ranges.

The expansion plans being developed for the protected areas in Madagascar (Durban Vision Program) offer an excellent opportunity to mitigate against potential upslope displacement by protecting large elevational transects (see ANGAP, 2001; Randrianandianina et al., 2003; Hannah et al., 2001). The concentration of regional amphibian endemism at the major massifs in Madagascar makes conserving these elevational transects especially important (see Tab. I). However, at Andasibe-Fierenanan, Antoetra, and Ranomafana, additional elevational transects will also be needed. The massif of Andrabetany (1548 m) could be especially important for inclusion in the Andasibe-Fierenanan region, and the chain of peaks than run north south between Antoetra and the Ranomafana National Park (1606 - 1874 m) will be important for this region. Forest corridors between reserves should also include as broad an elevational transect as possible, and steep sided escarpments (also less desirable for cultivation) offers excellent opportunities in this regard. For amphibians, the continuity of primary habitats within elevational transects is also critical because barriers such as areas of cultivation may otherwise prevent the vertical dispersal of species upslope. In cases where deforestation has already occurred on elevational transects, it may be possible to enhance connectivity between elevational zones by encouraging the growth of secondary forest. Detailed studies of amphibian utilization of secondary forest have not yet been undertaken in Madagascar, however at least some endemic species are known to occupy secondary forest (Glaw & Vences, 1994; Raxworthy, pers obs.).

Additional surveys of amphibians are also needed to monitor populations and provide distributional data to track potential upslope displacement. Obvious candidate transects for long-term monitoring are the trails to the summits at Tsaratanana, Marojejy, and Andohahela, and the trail network within the Ranomafana National Park, but ideally, transects should be established at all nine endemic regions identified here. Should any species reach a point where upslope displacement is leading to complete habitat loss, then *ex-situ* captive breeding programs will have to be considered (see Mendelson et al., 2006). However, for the short-term at least, the results of this preliminary analysis indicate that as a result of warming, this option will not yet be needed for the vast majority of Malagasy amphibian species.

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RÉSUMÉ

Réchauffement global et risques d'extinction des amphibiens à Madagascar: une estime préliminaire des déplacements vers l'haut.

Récemment, l'amphibien malagasy a été considéré comme faisant partie du programme d'Evaluation des statuts des amphibiens (GAA), vu leur vulnérabilité d'extinction. Cependant, aucune étude n'a été faite jusqu'à maintenant concernant la modification potentielle de la distribution des espèces amphibiennes en réponse au réchauffement climatique global, et ceci malgré l'évidence de déplacement des espèces vers les plus hautes altitudes et de réchauffement. Les espèces tropicales des hautes montagnes sont potentiellement vulnérables d'extinctions par la perte d'habitat résulter de le déplacement en haut, parce qu'elles sont endémiques d'un seul massif et surtout confinées aux sommets. Les amphibiens malagasy présentent ces deux aspects biogéographiques, mais leur vulnérabilité à l'extinction résulter de le déplacement en haut n'a été jamais étudiée. Cette étude présente une évaluation préliminaire de cette vulnérabilité potentielle pour chacune des 226 espèces énumérées dans le GAA pour Madagascar. On identifie au total 39 espèces qui sont localement endémiques des habitats de moyenne et haute altitudes. Elles sont distribuées dans les neuf régions suivantes: Tsaratanana, Anjanaharibe-Sud/Marojejy, Ambohitantely, Andasibe-Fierenanana, Ankaratra, Antoetra, Ranomafana, Andringitra, et Anosy. Une analyse de déplacement altitudinale suppose que les espèces sont spécifiquement acclimatées à leur température ambiante. Les résultats obtenus présentent un accroissement général de la perte d'habitat pour un mouvement altitudinale plus de 500 m en haut. Ainsi pour 700 m on assiste à une perte d'habitat potentielle des 18 de 39 espèces. Utilisant un scénario encore plus grave avec une absence de capacité pour des espèces changer des distributions altitudinales (par exemple cas des espèces complètement isolés dans des fragmentations forestières), les 26 des 39 espèces présentent une perte potentielle de leur habitat avec un déplacement altitudinale de 300 m en haut. Appliquer un taux de changement de température avec l'altitude (d'adiabatic humide), et en supposant que les espèces: 1) migrent, et 2) tolérer des déplacements en haut à la moitié qui a exigé pour la perte d'habitat totale, les découvertes que les extinctions amphibiens de Madagascar augmenteraient potentiellement substantiellement avec chauffe au-dessus 1.5°C et des déplacements altitudinale plus grands que 250 m en haut. Les données récentes et les projections régionales climatiques indiquent que ce seuil de réchauffement pourrait être atteint avant la fin du 21ème siècle à Madagascar. Pour protéger au maximum le mouvement altitudinales des amphibiens, la conservation d'une bande large d'altitudes est une haute prioritaire dans les aires protégés et les corridors. En outre, des inventaires des amphibiens seront nécessaires pour dépister les changements des distributions altitudinales aux sommets des montagnes. Des transects seront établis pour un suivi à long terme des populations d'amphibiens sur les neuf régions identifiées qui ont un endémisme régional significatif.

Mots clés: Amphibia, Changement de climat, Changement de distribution, Conservation, Déplacement d'altitude, Endemisme des montagnes, Extinction, Madagascar, Réchauffement climatique global.

Christopher J. RAXWORTHY
American Museum of Natural History
Central Park West at 79th Street, New York
New York 10024-5192, USA
Email rax@amnh.org

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Katharina C. WOLLENBERG[1], David R. VIEITES[2], Miguel VENCES[1]

Annual temperature data for two Malagasy sites of high anuran diversity

ABSTRACT

We present microclimatic temperature data for two Malagasy rainforest sites with high amphibian diversity. Our data show that daily, monthly and annual temperature ranges in these microhabitats are relatively narrow and, as expected, temperatures are much more buffered in streams than in the leaf litter. A successful ex-situ conservation of many species may require adaptation to the reported thermal conditions. Because many Madagascan amphibians seem to be restricted to certain elevations and hence climatic conditions, global warming could endanger stenothermic amphibian species adapted to these narrow climatic envelopes, which highlights the need for more detailed monitoring, and for an assessment of temperature tolerances and preferences.

Key words: amphibians, ex-situ conservation, Madagascar, temperature variation, ecology.

INTRODUCTION

Species' fundamental ecological niches are determined by both biological and physical environmental conditions. Among those conditions, microclimatic data are critical to understand species activity rhythms and annual phenology, especially in ectothermic vertebrates like amphibians. Large-scale global warming has already been related to amphibian declines in Neotropical areas (Pounds et al., 2006). If this turns out to be a global phenomenon, microclimatic data and long-term comparative studies on amphibian declines in other tropical areas of the world are urgently needed. Although temperature and rainfall data are available from the global network of meteorological stations and can be interpolated to develop climate surfaces (Hijmans et al., 2005), those data usually do not reflect actual microclimatic conditions for most amphibian habitats.

[1] Technical University of Braunschweig.
[2] University of California, Berkeley.

Despite the recent technological advances in field temperature recordings (i.e. miniaturized data loggers), few studies report their use in this group of vertebrates, being normally employed for a short period of time (Kusano et al., 2006). Long-term data-logging of temperature in local amphibian microhabitats will not only provide the dynamics and range of microclimatic conditions where species live, but can also be of great interest in developing protocols for captive breeding of endangered species.

For Madagascar, temperature data are available from many meteorological stations, and data on general Madagascan climate zones have been published (e.g., Donque, 1975), yet to our knowledge no data exists about annual temperatures in microhabitats relevant for anurans, such as leaf litter or small streams. Therefore, annual temperature curves from leaf litter and streams in Madagascar can be helpful to fill in these gaps, and provide preliminary data on these microhabitats critical for both adult and larval stages of amphibians.

Current studies suggest that highest values of amphibian diversity in Madagascar are concentrated in the primary rainforests of the central-east and south-east (Lees et al., 1999; Andreone et al., 2005; own, unpublished data). Microclimatic data for the above mentioned localities are especially interesting in the context of ex situ conservation because they are applicable to captive breeding of multiple species, especially those that live mainly on the forest floor or in streams. Here we present data about microhabitat temperatures gathered during 2006-2007 at two sites of high amphibian species diversity in Madagascar: Andasibe and Ranomafana.

METHODS

In total, five data loggers (ibutton DS1921G-F5, Dallas Technologies) were set for one year (2006-2007) in Andasibe and Ranomafana. These data loggers can record temperature data from -40°C to 85°C at 0.5°C precision, and can record data in different time periods. We set them up to record data every 4 hours, providing three measurements during the night and three during the day. In Andasibe, one data logger was placed in the vicinities of the "Station forestiére" in the leaf litter on a slope, about 200 m from the nearest stream. In Ranomafana, we placed each two data loggers at two localities, Sahamalaotra and Talatakely. Both these sites are located in Ranomafana National Park. At each site, one data logger was set in the water of a permanent stream and the second one in the leaf litter (2-5 cm underground) near the stream (Tab. I). All loggers were placed in primary rainforest under a closed canopy. At all three sites, diverse amphibian communities occur, which mostly comprise stream-breeding species of *Boophis* and *Mantidactylus*, but also various leaf-litter dwelling cophyline microhylids (*Stumpffia* and *Plethodontohyla*) and mantellids (*Gephyromantis*, Glaw & Vences, 2007). In general, from both the Ranomafana and Andasibe areas, high amphibian diversities of about 100 species occurring within a few square kilometers have been recorded.

Locality		Data acquisition time	Coordinates
Andasibe	"Station forestière", leaf litter under *Ravenala* palm	03/25/2006 - 2/24/2007	Altitude = 939m S = 18°56.169' E = 48°24.734'
Sahamalaotra	Leaf litter	02/25/2006 - 02/22/2007	Altitude = 846m S =21°14.282' E =47°23.753'
	Submerged in small stream	02/25/2006 - 02/22/2007	Altitude = 846m S =21°14.282' E =47°23.753'
Talatakely	Leaf litter	03/01/2006 - 02/24/2007	Altitude = 846m S =21°15.8' E =47°25.8'
	Submerged in small stream	03/01/2006 - 02/24/2007	Altitude = 846m S =21°15.8' E =47°25.8'

Tab. I. Locality information, data acquisition time and coordinates of the sampled sites.

RESULTS AND DISCUSSION

Our data show the typical temperature patterns for a tropical climate, with relatively small temperature ranges and only two seasons during the year. In figures 1, 2 and 3, a temperature curves typical for Malagasy rainforests can be observed; mean annual temperatures in the leaf litter range between 15.8°C (Sahamalaotra leaf litter) and 17.2°C (Andasibe leaf litter). Mean annual temperatures in the two sampled streams were 16.0°C and 16.9°C (Tab. II). In the dry season from April to September, temperatures are lower than their annual mean in all sampled localities, and in the rainy season (October to March) the mean temperatures increase (see Tab. II).

Comparison of the annual temperatures in water and leaf litter shows that temperatures in the streams are generally more constant than leaf litter temperatures. In Sahamalaotra, the annual leaf litter temperatures shift between +2.0°C (rainy season) and -1.9°C (dry season) compared to annual means; the water temperature shifts only between +1.0°C (rainy season) and -1.0°C (dry season). In Talatakely, the annual leaf litter temperature shifts between +1.3°C (rainy season) and -1.3°C (dry season) compared to annual mean; the water temperature shifts only between +0.7°C (rainy season) and -0.6°C (dry season). For Andasibe, no data for stream temperatures could be obtained. However, leaf litter temperatures in Andasibe were the highest among the three sampled localities. Information on temperature fluctuations between daytime and night can be seen in Tab. III (and are visualized in Fig. 4). Characteristically, the mean temperature shifts between daytime and night are small (≤0.2°C) in rainy and dry season, respectively. Also, temperature differences between rainy and dry season are generally smaller in streams than in the leaf litter at daytime and at night.

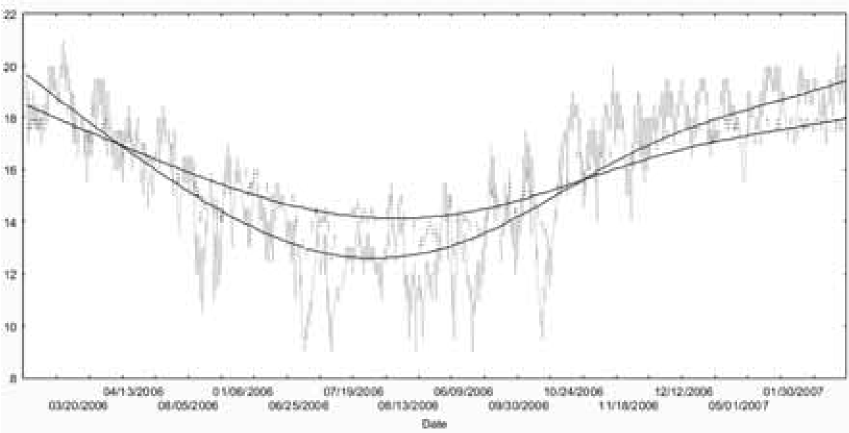

Fig. 1. Annual temperature curves for stream and leaf litter data in Sahamalaotra. Leaf litter temperature is indicated by a continuous line, stream temperatures are indicated by a broken line. Line fit: Distance weighted least-squares.

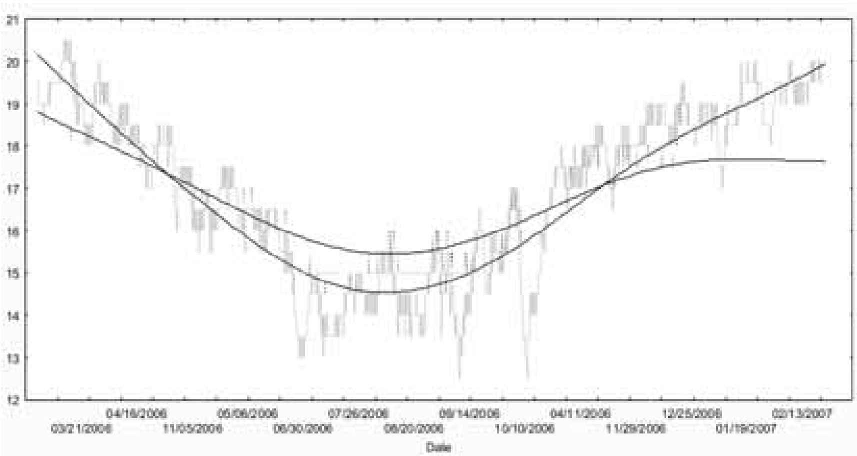

Fig. 2. Annual temperature curves for stream and leaf litter data in Talatakely. Leaf litter temperature is indicated by a continuous line, stream temperatures are indicated by a broken line. Line fit: Distance weighted least-squares.

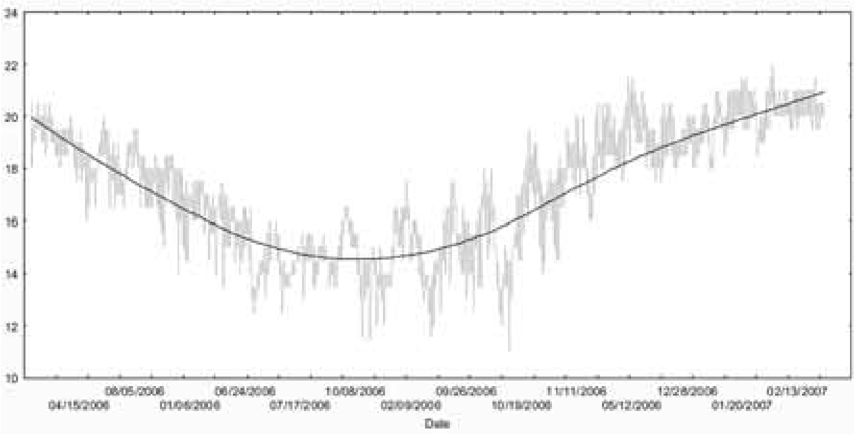

Fig. 3. Annual temperature curves for temperature data for the leaf litter in Andasibe. Line fit: Distance weighted least-squares.

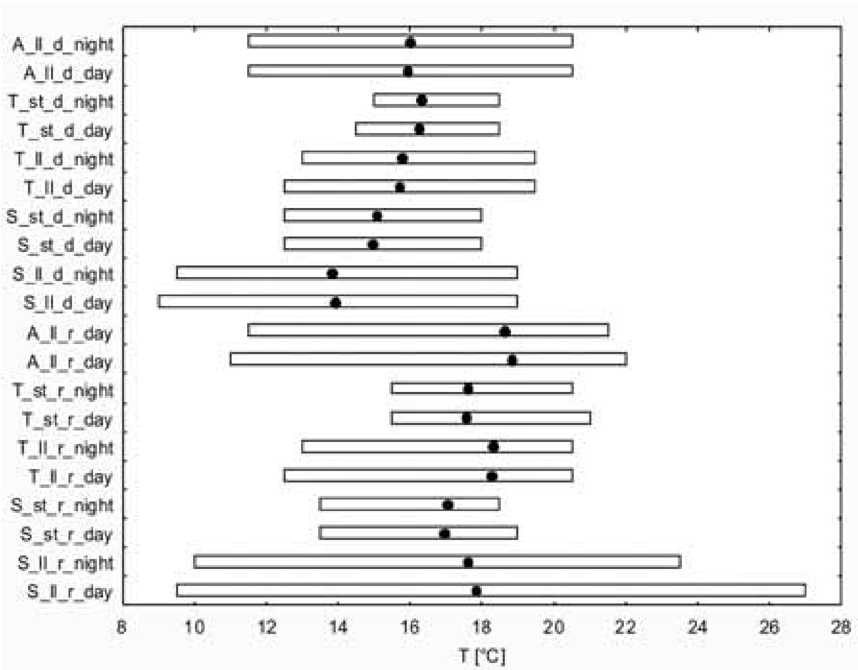

Fig. 4. Mean temperatures at day and night time, and their minimal and maximal values. Values are shown for dry and rainy season separately. A = Andasibe, T = Talatakely, S = Sahamalaotra, st = stream, ll = leaf litter, r = rainy season, d = dry season.

Whole period	T [°C]	Dry season	T [°C]	Rainy season	T [°C]
Sahamalaotra leaf litter					
mean	15.8	mean	13.9	mean	17.7
sd	2.8	sd	2.0	sd	1.9
max	27.0	max	19.0	max	27.0
min	9.0	min	9.0	min	9.5
Sahamalaotra stream					
mean	16.0	mean	15.0	mean	17.0
sd	1.5	sd	1.2	sd	1.0
max	19.0	max	18.0	max	19.0
min	12.5	min	12.5	min	13.5
Talatakely leaf litter					
mean	17.0	mean	15.7	mean	18.3
sd	2.0	sd	1.6	sd	1.4
max	20.5	max	19.5	max	20.5
min	12.5	min	12.5	min	12.5
Talatakely stream					
mean	16.9	mean	16.3	mean	17.6
sd	1.2	sd	1.1	sd	0.7
max	19.0	max	18.5	max	19.0
min	14.5	min	14.5	min	15.5
Andasibe leaf litter					
mean	17.2	mean	16	mean	18.6
sd	2.3	sd	1.9	sd	1.9
max	22.5	max	20.5	max	22.5
min	11.0	min	11.5	min	11.0

Tab. II. Summary statistics of the obtained temperature data for all sites. The arithmetic mean, standard deviation, minimal and maximal values are given for (a) the whole sampling period, (b) the dry season (04/01/2006 - 10/01/2006) and (c) the rainy season (10/02/2006 - begin of sampling in February / March, see Tab. I).

Our data indicate that natural microclimatic conditions for a large number of Malagasy frog species involve relatively low minimum temperatures around 9-11°C (Tab. III), and that temperature changes are much more buffered in streams. Adjusting tank temperatures as well as water temperatures (for tadpole rearing) to the observed conditions may at least in some cases be a premise for successful captive breeding (e.g., in the context of ex-situ conservation) of these frogs. Furthermore, our data suggest that the temperature range in the sampled microhabitats is relatively narrow, both on a daily, monthly and annual scale. This may be relevant to the potential decline of amphibian species under future global warming scenarios, as these narrow climatic envelopes could be largely affected by a global increase in temperature (Williams et al., 2007). Climate change has naturally occurred over millions of years, and most Malagasy species of amphibians have a strong genetic differentiation and hence an old age (Köhler et al., 2005), and therefore must have survived past climate shifts. However, under the present conditions of largely fragmented and destroyed forests in Madagascar, species may not always be able to adequately respond to such shifts by moving into habitats at different elevations. Therefore, long-term monitoring efforts should also include measurements of other environmental parameters like humidity or temperatures at various heights above the ground which are relevant to anurans, to understand possible changes in these parameters.

Rainy season	**T [°C]**	**Dry season**	**T [°C]**		**T [°C]**
Sahamalaotra stream					
mean day	16.9	mean day	14.9	Δ mean day r/d	2.0
sd day	1.0	sd day	1.2	Δ sd day r/d	0.2
max day	19.0	max day	18.0	Δ max day r/d	1.0
min day	13.5	min day	12.5	Δ min day r/d	1.0
mean night	17.0	mean night	15.1	Δ mean night r/d	2.0
sd night	1.0	sd night	1.2	Δ sd night r/d	0.2
max night	18.5	max night	18.0	Δ max night r/d	0.5
min night	13.5	min night	12.5	Δ min night r/d	1.0
Δ mean day/night	0.1	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.0	Δ min day/night	0.0		
Sahamalaotra leaf litter					
mean day	17.8	mean day	13.9	Δ mean day r/d	3.9
sd day	1.9	sd day	2.1	Δ sd day r/d	0.2
max day	27.0	max day	19.0	Δ max day r/d	8.0
min day	9.5	min day	9.0	Δ min day r/d	0.5
mean night	17.6	mean night	13.8	Δ mean night r/d	3.8
sd night	1.9	sd night	2.0	Δ sd night r/d	0.2
max night	23.5	max night	19.0	Δ max night r/d	4.5
min night	10.0	min night	9.5	Δ min night r/d	0.5

Δ mean day/night	0.2	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.1		
Δ max day/night	3.5	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.5		
Talatakely stream					
mean day	17.5	mean day	16.0	Δ mean day r/d	1.3
sd day	0.7	sd day	1.1	Δ sd day r/d	0.4
max day	21.0	max day	18.5	Δ max day r/d	2.5
min day	15.5	min day	14.5	Δ min day r/d	1.0
mean night	17.6	mean night	16.3	Δ mean night r/d	1.3
sd night	0.7	sd night	1.1	Δ sd night r/d	0.4
max night	20.5	max night	18.5	Δ max night r/d	2.0
min night	15.5	min night	15.0	Δ min night r/d	0.5
Δ mean day/night	0.1	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.0	Δ min day/night	0.5		
Talatakely leaf litter					
mean day	18.3	mean day	15.7	Δ mean day r/d	2.6
sd day	1.4	sd day	1.6	Δ sd day r/d	0.2
max day	20.5	max day	19.5	Δ max day r/d	1.0
min day	12.5	min day	12.5	Δ min day r/d	0.0
mean night	18.3	mean night	15.8	Δ mean night r/d	2.5
sd night	1.4	sd night	1.6	Δ sd night r/d	0.2
max night	20.5	max night	19.5	Δ max night r/d	1.0
min night	13.0	min night	13.0	Δ min night r/d	0.0
Δ mean day/night	0.0	Δ mean day/night	0.0		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.0	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.5		
Andasibe leaf litter					
mean day	18.8	mean day	15.9	Δ mean day r/d	2.9
sd day	1.9	sd day	1.9	Δ sd day r/d	0.0
max day	22.5	max day	20.5	Δ max day r/d	1.5
min day	11.0	min day	11.5	Δ min day r/d	0.5
mean night	18.6	mean night	16	Δ mean night r/d	2.6
sd night	1.9	sd night	1.9	Δ sd night r/d	0.0
max night	21.5	max night	20.5	Δ max night r/d	1.0
min night	11.5	min night	11.5	Δ min night r/d	
Δ mean day/night	0.2	Δ mean day/night	0.1		
Δ sd day/night	0.1	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.0		

Tab. III. - Daily temperature ranges and the absolute differences between day/night and rainy/dry season values (in °C, indicated by Δ). See Figure 4.

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RÉSUMÉ

Température annuelle pour deux sites malgaches sur une grande diversité d'anuran.

Nous présentons des données de températures microclimatiques de deux sites malgaches de forêts pluvieuses avec une grande diversité d'amphibiens. Nos données montrent que les gammes de températures, quotidiennes, mensuelles et annuelles dans ces micro habitats sont relativement proches, et comme on pouvait l'attendre, les variations de température sont bien plus marquées dans les rivières que entre les litières de feuilles. Une conservation ex-situ réussie pour de nombreuses espèces nécessite une adaptation à ces conditions thermiques rapportées. En effet, beaucoup d'amphibiens malgaches semblent être limités par certaines altitudes et donc par les conditions climatiques. Le réchauffement global pourrait mettre en danger les espèces d'amphibiens sténo thermiques adaptés dans ces étroites enveloppes climatiques, ce qui souligne le besoin de plus de détails de suivi.

Mots clés: Amphibiens, Conservation, Écologie, Madagascar, variation de température.

Katharina WOLLENBERG
Miguel VENCES
Zoological Institute
Technical University of Braunschweig
Spielmannstr. 8
38106 Braunschweig, Germany
Email m.vences@tu-bs.de

David R. VIEITES
Museum of Vertebrate Zoology and Department of Integrative Biology
3101 Valley Life Sciences Bldg.
University of California
Berkeley, CA 94720-3160. USA
Email vieites@berkeley.edu.

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 95-106

Ché WELDON[1], Louis DU PREEZ[1], Miguel VENCES[2]

Lack of detection of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) in Madagascar

ABSTRACT

The global fungal disease chytridiomycosis can have catastrophic effects on amphibian populations leading to declines and even extinctions. Madagascar with its highly endemic and diverse amphibians is particularly vulnerable to emerging infectious diseases. In this study we report on a histological survey of chytridiomycosis at multiple localities in eastern Madagascar. The amphibian chytrid fungus was not detected in 527 frogs that altogether were examined. A more comprehensive survey involving all biogeographic zones on the island is urgently needed before a conclusion can be made about the chytridiomycosis classification of Madagascar. Suggestions on future research aimed at managing the disease are also made.

Key words: Amphibians, Chytrid, Histopathology, Madagascar.

INTRODUCTION

The amphibians of the world are currently facing an extinction crisis that calls for major conservation efforts at all levels of research, law and policy (Mendelson et al., 2006). The magnitude of the proportion of taxa that are either declining or presumed extinct make amphibians the most threatened vertebrate class (Stuart et al., 2004). The greatest contributors to amphibian declines include habitat loss, environmental contamination, exotic predators, climate change and disease. One of the most virulent diseases of amphibians is

[1] North-West University, Potchefstroom.
[2] Technical University of Braunschweig, Braunschweig.

chytridiomycosis caused by the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* (Berger et al. 1998; Collins & Storfer 2003). Two factors in particular contribute to the potency of chytridiomycosis; the ability to affect entire amphibian assemblages and a rapid rate of spread (e.g., Berger et al., 1998; Lips et al., 2006). Chytridiomycosis has been associated with amphibian population declines and extirpations from the Australian and American tropics, western North America, Europe and East Africa (Berger et al., 1998; Bosch et al., 2001; Weldon & Du Preez, 2003; Rachowicz et al., 2006). In contrast, evidence from southern Africa indicates that *B. dendrobatidis* is an endemic infection with no apparent adverse effects on amphibian communities at large (Weldon et al., 2004).

A highly diverse and almost exclusively endemic amphibian assemblage is found on the island of Madagascar, one of the world's biodiversity hotspots (Glaw & Vences, 2000; Myers et al., 2000). The Madagascan batrachofauna includes approximately 23% threatened taxa (including all vulnerable, endangered and critically endangered taxa) mainly because of a small distribution area, habitat destruction, and exploitation for the pet trade (IUCN, 2004; Andreone et al., 2005). Forest ecosystems are disappearing at an alarming rate (Ganzhorn et al., 2001), which could be potentially devastating, because they sustain the highest frog diversity. Furthermore, the high numbers of frogs being exported for the pet trade locally threaten some species such as *Dyscophus, Mantella* and *Scaphiophryne* (Behra & Raxworthy, 1991; Jenkins & Rakotomanampison, 1994). Chytridiomycosis has not been included as a threat to Madagascan batrachofauna, because the likelihood was not investigated until now (see an appraisal of threats by Andreone & Luiselli, 2003). Taxa particularly prone to extinction include those with limited geographical distribution and low reproductive rate (McKinney, 1997: Purvis et al., 2000; Cardillo, 2003) of which Madagascar has many. The moment that the live animal trade is involved in an infectious disease system, the risks of pathogen dispersal within the system (Madagascan frogs) and beyond (export countries) increases considerably (Daszak et al., 2000, Hanselmann et al., 2004). Dealing in the international pet trade implies that Madagascar is a high-risk country for disseminating associated disease agents. Because the frog trade via Madagascar is unidirectional (exports only; e.g., Rabemananjara et al., 2008) the biggest risk for frog-to-frog transmission between countries is exporting potential pathogens from Madagascar.

Given the high conservation profile of Madagascar's frogs and augmented by the trade in live frogs, classification of *B. dendrobatidis* at regional, species and population level is both warranted and timely. Here we present the findings from a preliminary survey in eastern Madagascar as part of a larger initiative to survey the whole of Madagascar's frog diversity, and suggest future research directions. The results from here and the survey, once completed, will provide researchers and policy makers with information that can aid the management of *B. dendrobatidis* either pro-actively or responsively. Chytridiomycosis in this paper is the designation for infection of frogs by *B. dendrobatidis*.

MATERIAL AND METHODS

Month-long surveys of Madagascan frogs were conducted in January 2005 and February 2006 to determine if *B. dendrobatidis* was present on the island. The regions surveyed included Maroantsetra in the north-east, Andasibe, An'Ala and Ranomafana in the central east, and Ambohitantely, Antananarivo, Ambatolampy and Ankaratra in the central highlands (Fig. 1).

There were no prior reports of enigmatic declines that could help direct survey effort. Therefore our study sites were selected either for their high biodiversity and unique frog assemblages (Andasibe, An'Ala, Ranomafana, Ambohitantely), because they have been in the center of previous studies on threats of fragmentation and deforestation on Madagascan amphibians (Ambohitantely, An'Ala), because they are in areas of major tourist destinations (Andasibe, Ranomafana) or close to laboratories where in the past clawed frogs may have been kept (gardens of Institut Pasteur and of Parc de Tsimbazaza in Antananarivo) and where chytrid introduction would therefore be most likely. Clawed frogs have been identified as a high-risk species for disseminating the amphibian chytrid fungus through the trade in this species from South Africa (Weldon et al., 2004). The selected locations as summarized in Tab. I span a wide range of biogeographic regions and elevations, including some specimens from high elevations above 2000 m in the Ankaratra Massif, various mid-altitude to high-altitude sites (900-1700 m) and one coastal site, virtually at sea level.

Post-metamorphic and adult frogs were collected by hand at night and placed in separate, clean plastic bags to minimize the risk of potential disease transmission. All footwear and equipment were thoroughly cleaned and air dried between locations. Frogs were examined for any clinical symptoms associated with chytridiomycosis including loss of fear, abnormal body posture, excessive sloughing, loss of righting reflex and fitting when handled. All frogs were anaesthetized with chlorobutanol and a representative subset was sampled for chytridiomycosis. Two phalanges from the fifth toe of the left hind foot were clipped and preserved in vials of 70% alcohol for histopathology. Dissecting instruments were wiped clean and alcohol flamed between animals. Collected specimens were fixed in 70% ethanol and will be deposited in the herpetological collections of the Université d'Antananarivo, Département de Biologie Animale, Madagascar, and the Zoologische Staatssammlung München, Germany.

Toe clips for histological sectioning were dehydrated in an alcohol series (70, 96 and 2 x 100% alcohol), elucidated with xylene, decalcified with Perreni's fixative and impregnated with paraffin wax at 60°C. Following the wax impregnation the tissue samples were embedded in paraffin wax blocks using a SLEE MPS/P2 embedding center and sectioned at 6 µm with a Reickert-Jung 2050 automated microtome. Slides were stained with Erlich's haematoxylin, counter stained with eosin and examined using a Nikon Eclipse E800 compound microscope for the presence of *B. dendrobatidis* using the criteria described in Berger et al. (1999).

Fig. 1. Map showing study sites that were surveyed for chytrid infection using histological methods, based on samples collected in 2005 and 2006.

RESULTS

Collectively 527 frogs representing a minimum of 79 species were collected and screened during the two surveys (Tab. I). Among these were a number of new species that await description. The sample represented all four families known from Madagascar: Mantaellidae, Microhylidae, Ranidae and Hyperoliidae (Vences & Glaw, 2001). Sample sizes broken up between the two surveys varied between 20 and 178 per locality (Tab. II) and are a reflection of the time spent at different localities and of species richness.

We did not encounter any frogs that demonstrated any clinical symptoms usually associated with chytrid fungus infections. All sections were carefully examined, but no indication of chytridiomycosis was detected in any of the specimens that were screened through histopathology.

DISCUSSION

Our results demonstrate that histologically detectable chytridiomycosis was not present in any of the 74 species screened from Maroantsetra, Andasibe, Ranomafana, An'ala, Ambohitantely, Antananarivo, Ambatolampy and Ankaratra. Although molecular confirmation is still missing, we see this as a very strong indication that in fact *B. dendrobatidis* was absent from the

Family	**Genus**	**N species**	**% Infected**
Hyperoliidae	*Heterixalus*	3	0
Mantellidae	*Aglyptodactylus*	1	0
	Blommersia		0
	Boophis	22	0
	Gephyromantis	6	0
	Guibemantis	7	0
	Mantella	7	0
	Mantidactylus	21	0
	Spinomantis	1	0
Microhylidae	*Dyscophus*	1	0
	Platypelis	2	0
	Plethodontohyla	5	0
Ptychadenidae	*Ptychadena*	1	0

Tab. I. Summary of families and genera sampled.

Locality	Altitude	Collection date	N	% infected
Maroantsetra	10	2006, Feb	34	0
Andasibe	910	2005, Jan	28	0
Andasibe	920	2006, Feb	42	0
An'Ala	840	2006, Feb	178	0
Ranomafana	600-1100	2006, Feb	115	0
Ambohitantely	1580	2005, Jan	27	0
Antananarivo	1290	2006, Feb	20	0
Ambatolampy	1650	2006, Feb	32	0
Ankaratra	1700-2500	2005, Jan	29	0
Ankaratra	1700-2500	2006, Feb	22	0

Tab. II. Localities and outcome of chytrid survey of frog samples included in this study.

specimens sampled. This outcome is encouraging for several reasons: (1) the survey took place in three major biogeographic zones (Glaw & Vences, 1994), (2) these zones include regions known for their high amphibian species richness (Andreone, 1994; Vences et al., 2002), (3) these are the zones from which most of the pet trade collecting takes place (Behra & Raxworthy, 1991; Jenkins & Rakotomanampison, 1994). In addition the sample included species which conform to eight of nine parameter ranges selected by Andreone & Luiselli (2003) as indicators of population survival among Madagascan frogs namely: environmental adaptability, habitat breadth, arboreality, reproductive mode, activity type, altitudinal distribution, number of findings and extent of occurrence. The only parameter that was not completely represented by our sample was geographic distribution, because our survey did not include western and northern Madagascar, both of which are areas of considerable endemic and threatened amphibian diversity (Andreone et al., 2005). However, this study is by no means a conclusive indication of the chytridiomycosis classification of Madagascar nor does it suggest that chytridiomycosis is not a threat. Evidence is accumulating that climate change could under particular conditions foster the outbreak of chytridiomycosis (Pounds et al., 2006). Moreover, compelling evidence from Panama indicated how *B. dendrobatidis* arrived and spread like an epidemic wave through the country (Lips et al., 2006). As a consequence, even regions so far not affected by the disease could become so in the near future. Ron (2005) indicated that large parts of Madagascar have a favorable climate for *B. dendrobatidis* based on a prediction model developed on distribution data from the New World. Besides obvious advantages for conservation, Leung et al. (2002) determined that an approach at preventing biodiversity loss could be less costly and more effective than future control and eradication measures.

A limitation of the data from this study can be expressed as an order of magnitude in terms of sample size and diagnostic sensitivity. Sample sizes for the 2005 surveys of Andasibe and Ambohitantely, as well as the 2006 surveys of Antananarivo and Ankaratra were too small to detect disease at an estimated prevalence of 10%. However when we combine the number of specimens during the two surveys, only Ambohitantely and Antananarivo did not have large enough sample sizes for this estimated prevalence. Although histology has been used to great effect in other surveys as primary technique for detecting *B. dendrobatidis* (Lips et al., 2003; Carnaval et al., 2006), detection through quantitative polymerase chain reaction (qPCR) has been demonstrated as the most sensitive assay for chytridiomycosis (Boyle et al., 2004; Kriger et al., 2006). The results presented from this survey should therefore be considered reliable yet preliminary until sufficient samples from all regions of Madagascar have been surveyed for chytridiomycosis through assays of higher sensitivity.

The speed with which chytridiomycosis has spread to naïve populations causing extinctions or declines may be forewarning of the problems to be caused by this disease in the future in countries that are currently chytrid free. A rapid assessment of the vectors and mechanisms contributing to the global spread of amphibian chytrid is therefore essential, and should be conducted in especially countries involved in the amphibian trade. A call for pro-active conservation action towards protecting Madagascar's frogs from habitat loss and amphibian chytrid was recently voiced (Andreone et al. 2008). A more detailed and comprehensive study in Madagascar is of the utmost importance. We propose that a dichotomous approach should be followed to address the research and policy issues relating to *B. dendrobatidis* in Madagascar depending on the final outcome of the survey (Fig. 2). If *B. dendrobatidis* is detected the first objective should be to determine the extent of the infection in Madagascar to classify areas as *B. dendrobatidis* infected or *B. dendrobatidis* free. This can be done by continuing to survey frogs across taxonomic and geographic ranges. Detailed information about the occurrence of *B. dendrobatidis* can then aid in conducting a risk assessment involving threats and spread of the disease. It will also be important to establish long-term monitoring sites as part of a management strategy. Concurrently with conducting the survey, attempts should be made to isolate and culture the fungus using described criteria from Longcore (2001). The cultured Madagascan strains can then be used to determine their relatedness to other strains in an attempt to find a genetic basis for the region of endemism of *B. dendrobatidis* (see Morehouse et al., 2003). Knowing whether *B. dendrobatidis* is endemic or introduced in a region determines how biosecurity strategies should be designed. If *B. dendrobatidis* is not detected a risk assessment that focuses on the likelihood of introduction and subsequent spread of the amphibian chytrid should be conducted. Part of this risk assessment should involve exposing Madagascan frogs to *B. dendrobatidis* strains outside of Madagascar to determine susceptibility to infection and disease. Such challenge experiments, although replicated, have to consider dose and ecological parameters that most accurately simulate exposure under natural conditions.

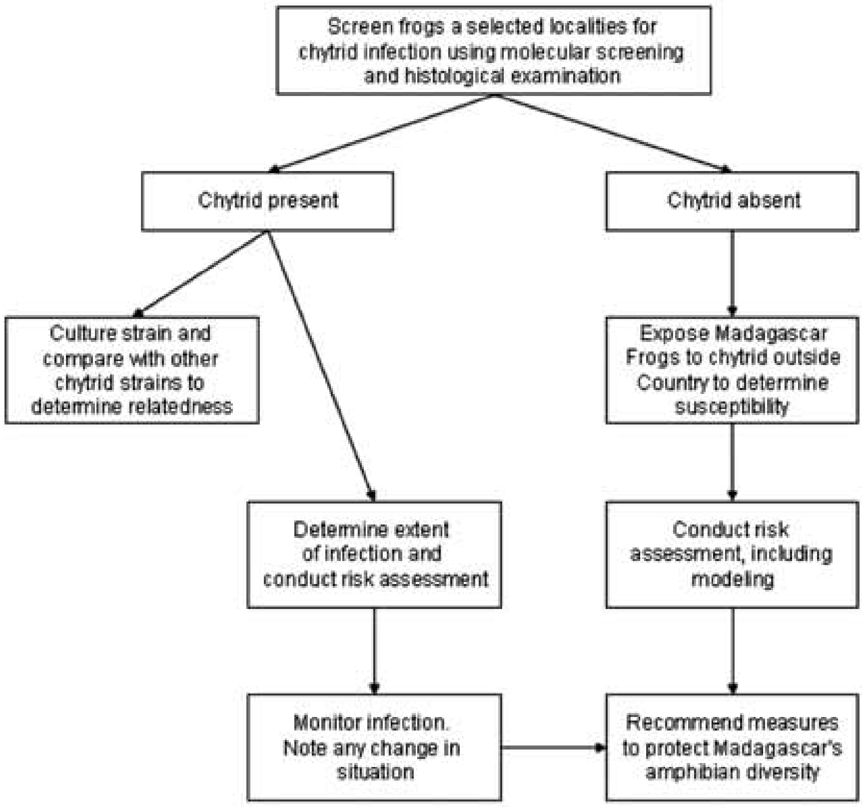

Fig. 2. Diagrammatic outline of proposed research activities aimed at curtailing chytridiomycosis in Madagascar.

Integration of the knowledge gained from the disease survey and risk assessment can aid in developing recommendations to protect Madagascar's amphibian diversity. The management plan must be made available to Madagascan conservation authorities, research facilities and other stakeholders to ensure concerted implementation. Effective functioning of a management plan would have to involve continued communication through the interactive exchange of information between risk assessors, research community, conservation authorities and all parties involved in the management process (stake holders, amphibian trade etc.).

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RÉSUMÉ

Lac de détection du chytride (Batrachochytrium dendrobatidis) *des amphibiens à Madagascar.*

La mycose du chytridiomycosis peut avoir des effets catastrophiques sur les populations des amphibiens en entraînant leurs déclins, voire leurs extinctions. Madagascar, de part sa grande diversité d'amphibiens hautement endémiques est particulièrement vulnérable à l'émergence de maladies infectieuses. Dans cette étude, nous enquêtons sur le recensement histologique du chytridiomycosis dans de multiples localités de l'est de Madagascar. Le champignon chytride n'a pas été détecté chez les 527 grenouilles que nous avons examinées. Un recensement plus global qui prend en compte toutes les zones bio géographiques de l'île constitue une nécessité urgente avant de pouvoir donner des conclusions sur la catégorisation de la chytridiomycosis de Madagascar. Des indications à propos d'une future recherche qui vise à contrôler la maladie sont également effectuées.

Mots clés: Amphibiens, Chytride, Histopathologie, Madagascar.

Ché WELDON
Louis DU PREEZ
North-West University
Potchefstroom Campus, Private Bag X6001
Potchefstroom 2520, South Africa
Email che.weldon@nwu.ac.za

Miguel VENCES
Zoological Institute, Technical University of Braunschweig
Spielmannstr. 8
38106 Braunschweig, Germany
Email m.vences@tu-bs.de

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 107-124

Julian GLOS [1], Anselme Toto VOLAHY [2], Robert BOUROU [2], Josef STRAKA [3], Richard YOUNG [2], Joanna DURBIN [2]

Amphibian conservation in central Menabe

ABSTRACT

The amphibian fauna of the Central Menabe region in Western Madagascar is important in respect to their extraordinary adaptations to the dry forest habitat. This habitat is highly threatened. Until 1990, the dry forest in the west of the island was thought to have been reduced to only 3% of its original extent. New analyses show that this deforestation was ongoing at an alarming rate also in the last decade. Based on an extensive inventory in 2004 we show that the distribution of Menabe amphibians depends on the quality of the habitat. Species diversity was highest in the two largest forest blocks, namely Kirindy and Ambadira, and was lowest in highly disturbed parts. We recommend that in particular two species are included into a long-term monitoring program that was started by DWCT in 2007, *Aglyptodactylus laticeps* and *Scaphiophryne menabensis*. Both species are distributed in Western Madagascar with *A. laticeps* being endemic to Central Menabe. Also, they appear sensitive to habitat degradation and are highly suitable as indicators of habitat integrity. Finally, we emphasize the need that future research must include detailed research on ecology and life history. This was so far not the priority in research on Madagascan amphibians.

Key words: Amphibians, Conservation, Dry forests, Madagascar, Menabe.

INTRODUCTION

Madagascar is one of the world's hot spots for biodiversity (Myers et al., 2000). After its separation from mainland Africa and India, Madagascar remained evolutionarily highly isolated for about the last 80 Mio years leading to extraordinary degrees of endemism in many taxa (Goodman & Benstead, 2003). Within this exceptional playground of evolution, the dry deciduous forests along the west coast are important centers of biodiversity. Moreover, the animals and plants inhabiting this ecosystem have developed remarkable adaptations to cope with the marked seasonality of their habitat.

[1] Technical University Braunschweig, Braunschweig.
[2] Durrell Wildlife Conservation Trust, Antananarivo.
[3] University of Würzburg, Würzburg.

Nonetheless, the dry deciduous forest ranks among the most endangered ecosystems, within Madagascar as well as worldwide (Janzen, 1988; Smith, 1997). Forest clearance by logging activities, slash-and-burn agriculture, and fragmentation has led to virtually completely isolated forest blocks throughout Madagascar (Smith, 1997). Alarmingly, the dry forest in the west of the island was thought to have been reduced to only 3% of its original extent (data from 1990; Smith 1997). One of the largest remaining blocks of this forest is situated in the Central Menabe region, which lies in the center of Western Madagascar and includes the area surrounding Morondava from the sea to the foothills of the central highlands. The region has been the focus of national and international development and research programs for the past few decades. Its biodiversity was recognized as being very important (Randrianandianina et al., 2003), and it is considered a priority area for protection (FANAMBY, 2003), leading to the affirmation of the area as "Site de Conservation" on 28th March 2006. Nevertheless, the survival of a multitude of endemic species is under threat as a result of the loss and the degradation of this habitat. Areas that are wholly intact or pristine no longer exist in the Central Menabe area.

During the last decade, extensive conservation research and its applications were established in the Menabe region. The main focus of these activities centered on vertebrate species with extremely restricted ranges within Central Menabe (e.g., giant jumping rat, *Hypogeomys antimena*; Sommer & Hommen, 2000; Sommer et al., 2002, flat-tailed tortoise, *Pyxis planicauda*; Gibson & Buley, 2004; Bloxam et al., 1996, pygmy mouse lemur, *Microcebus berthae*). Amphibians were so far not included into the conservational efforts as target species. This is unfortunate for a number of reasons. Amphibians are locally and globally highly threatened, they are seen as good bioindicators for ecological integrity (e.g., Welsh & Ollivier, 1998), and they are important for ecosystem functions (e.g., as prey and predators in the food chains). Since general habitat requirements of amphibians are very different to those of larger vertebrates the conservation of amphibians is not adequately accommodated for when their special needs are not taken into consideration by the design and management of protected areas. Especially limnic systems, which are essential habitats in amphibian life histories (e.g., as oviposition sites and habitats for larval stages), are regularly not adequately incorporated.

OBJECTIVES

Apart from providing data on the distribution of amphibian species in Central Menabe our study was especially designed also to be of extrinsic value by investigating the effects of forest disturbance and fragmentation on amphibian diversity as well as by furthering the understanding of the biogeography of key amphibian species. To improve the design of future monitoring programmes, data on the basic breeding biology and activity patterns of key species was collected opportunistically. Therefore, the field survey associated with this study is indispensable for the development of a promising monitoring programme that can be used to quantify the long term changes in abundance and/or distribution and thereby to help quantify the effects of conservation management on these taxa. The recent Global Amphibian Assessment (GAA; Andreone, 2005, Stuart et al., 2004) documented the global decline of amphibian populations around the globe and highlighted the need for time-series data on population trends in amphibian populations in order to better understand threats to their persistence. Accordingly, Durrell has prioritised amphibian conservation and field research as part of its conservation strategy.

In detail, the key research questions of this study were:
1. Which amphibian species occur in Central Menabe?
2. How are amphibian species distributed throughout Central Menabe?
3. What is the relationship between amphibian diversity and habitat type/quality?
4. What methods and sites should be used for successful future amphibian monitoring in Central Menabe?
5. Which species are suited for future monitoring programs?

METHODS

The deciduous dry forest of Central Menabe

Central Menabe is situated along the west coast of Madagascar between the town of Morondava and the Tsiribinha river (Fig. 1). It is a “Site de Conservation” since 28th March 2006, and covers an area of 125.000 ha whereof 100.000 ha are covered by forest, 4.000 ha by mangroves, and 1.000 ha are wetlands.

The climate of this area is highly seasonal (Fig. 2). The rainy season of 3 - 5 months from November-December to February-March is followed by a dry season of 7 - 9 months with no rain. Mean annual precipitation is about 800 mm (range 390 - 1511 mm; Sorg & Rohner, 1996, data from Kirindy CFPF). To our experience, annual rainfall decreases towards the coast, i.e. from east to west (pers. observation). Rainfall is highly unpredictable. We experienced within the last decade periods of both several days of constant rain (during cyclones) and dry periods of up to one week within the rainy season.

Most trees of the canopy in the forest are deciduous and an herbaceous layer is mostly missing. The forest grows largely on sandy soils, and therefore, the capacity of the soil to retain water is low. The vast majority of running and standing waters that can serve as breeding sites for amphibians dry up every year during the dry season. Therefore, breeding is possible only in the rainy season. For further information on Central Menabe see Ganzhorn & Sorg (1996) and Sorg et al. (2003).

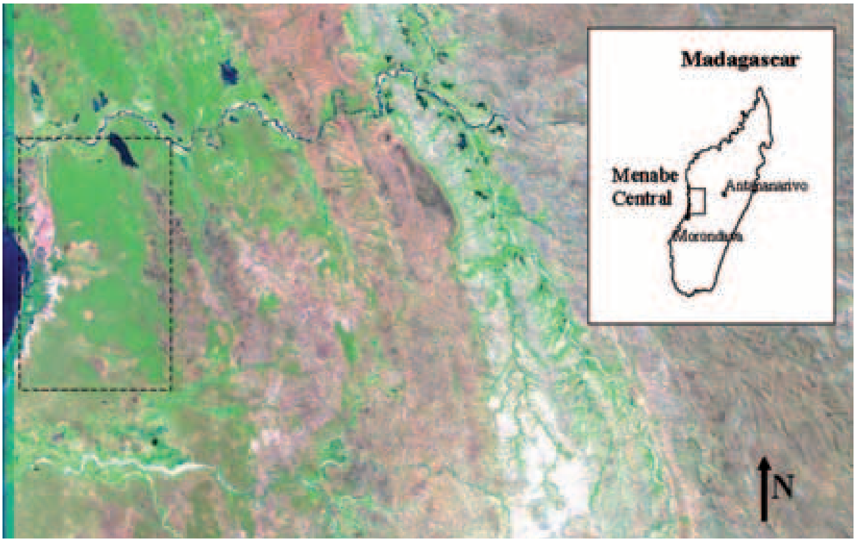

Fig. 1. Geographic position of Central Menabe within Madagascar (small figure), and forest cover (green) within Menabe (large figure). Grey and brownish areas represent nonforested areas. Larger rivers are the Tsiribinha river (north) and Morondava rivers (south). The approximate limitation of the new protected area is shown with the dashed quadrangle. Menabe Forest is among the largest tracts of continuous dry forest in Western Madagascar.

Research methods

During the rainy season of 2004, between January 12th and February 26th, we conducted five-day surveys in each of six different areas within Central Menabe. Each area covered about 1 km^2. The respecting sites were based on the criteria that they cover different areas and represent different levels of disturbance within the Menabe region: Two sites in the centre of the two main forest blocks with comparatively low disturbance by humans (Fig. 3): (a) Kirindy CFPF CS7 (coordinates of the central point within this site: S 20°04’28.6”, E 044°40’30.1”); (b) Ambadira Forest (S 19°48’24.0”, E 044°38’05.7”); (c) One site in the forest corridor connecting these two forest blocks (Corridor; S 19°58’41.4”, E 044°44’20.8”); Three sites with a high impact of human activities in recent times, i.e. large-scale slash and burn agriculture and ongoing logging of single trees (Figs. 4, 5) in (d) Kirindy Village Forest (S 20°03’30.8”, 044°33’57.8”), illegal commercial logging in (e) Kirindy CFPF South (S 20°06’03.6”, E 044°37’40.3”), and various anthropogenic influences in (f) Bedo Baobab Forest (S 19°55’42.9”, E 044°33’23.0”).

Fig. 2. Seasonality in Central Menabe. The same breeding pond of amphibians in Menabe is shown in the (a) wet and (b) dry season (Photos by J. Schmid).

Each survey was conducted by five investigators (JG, JS, ATV, RB, and one local assistant). We applied four different methods at each site:

a) Breeding pond surveys: Breeding ponds were localized acoustically, and frog species were subsequently determined by call and morphology.
b) Trapping of animals by pitfall traps and drift fences (18-22 pitfall traps, ~120m drift fences per site).
c) Transect walks in different parts of the respective study site, covering an area of about 1 x 1 km, performing investigative search (visual search, acoustic search, turning logs and bark, etc.).
d) Non-standardized opportunistic search.

We recorded data on presence and absence of all amphibian species.

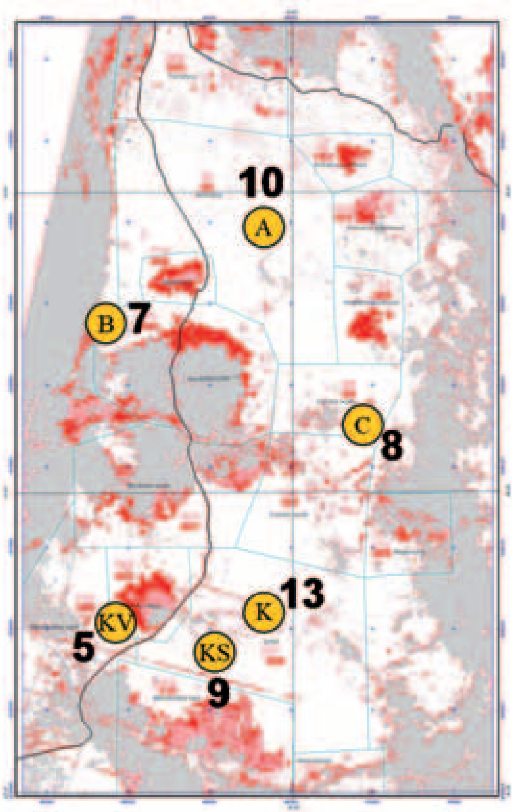

Fig. 3. Detailed map of Menabe with study sites and respective species numbers. A = Ambadira Forest, B = Bedo Baobab Forest, C = Corridor, K = Kirindy CFPF CS7, KS = Kirindy CFPF South, KV = Forest near Kirindy Village. White area = forested area in 2003, grey = nonforest area in 1992, pink = nonforest area in 2002, red = nonforest area in 2003. Pink and red numbers indicate forest loss in ha between 1992 and 2002 (pink) and between 2002 and 2003 (red).

Fig. 4. Deforested area near Kirindy Village. The forest is cleared on a large scale to cultivate cash crops (e.g., peanuts) and food plants (e.g., corn).

Fig. 5. Punctual logging within the forest area. Single trees are logged for constructing pirogues or collecting wild honey.

RESULTS AND DISCUSSION

Dry forest frogs – Species diversity and remarkable adaptations

Menabe's amphibian fauna consists of 15 species representing four families (Tab. I). For one species (*Aglyptodactylus laticeps;* for detailed information and photo see Glos et al., this volume) it is the only known area of occurrence, and it is one of a few known localities for other species (*Boophis xerophilus*, *Heterixalus carbonei*, *Scaphiophryne menabensis*) (Figs. 6-8).

The vast majority of waters that are used by amphibians for breeding in Central Menabe are temporary. Within Menabe, amphibians breed in three different habitat types, namely in ponds inside the forest with closed canopy, rock pools in the beds of seasonal rivers that are meandering through the forest (when the river is not running), and in secondary habitat such as savannah.

Species	Menabe Total	Kirindy CS7	Corridor	Ambadira Forest	Kirindy Village	Bedo	Kirindy South
Mantellidae							
Laliostominae							
Aglyptodactylus laticeps	+	+	+	+	-	-	+
Aglyptodactylus securifer	+	+	-	-	-	-	-
Laliostoma labrosum	+	+	+	+	+	+	+
Boophinae							
Boophis doulioti	+	+	+	+	+	+	+
Boophis xerophilus	+	+		+	+	+	+
Mantellinae							
Mantella betsileo	+	+	+	+	-	-	+
Blommersia cf. *wittei*	+	-	-	+	-	-	-
Ptychadenidae							
Ptychadena mascareniensis	+	-	+	-	+	+	-
Hyperoliidae							
Heterixalus luteostriatus	+	+	+	+	-	+	+
Heterixalus tricolor	+	+	-	+	-	+	-
Heterixalus carbonei	+	+	-	+	-	-	-
Microhylidae							
Dyscophinae							
Dyscophus insularis	+	+	+	+	-	-	+
Scaphiophryninae							
Scaphiophryne brevis	+	+	+	-	+	+	+
Scaphiophryne calcarata	+	+	-	-	-	-	+
Scaphiophryne menabensis	+	+	-	-	-	-	-
Species number	**15**	**13**	**8**	**10**	**5**	**7**	**9**

Tab. I. Species list of the six surveyed sites. The cross "+" indicates species presence at the respective site, "-" indicates absence; classification after Glaw & Vences (2006).

Fig. 6. *Boophis xerophilus*. This frog is a prolonged breeder that is known only from Menabe and from one site further in the South (Berenty).

Fig. 7. *Scaphiophryne menabensis* was just recently discovered. It is a habitat specialist that uses medium sized (< $200m^2$) temporal forest ponds as breeding sites. Within Central Menabe it is among the rarest frogs.

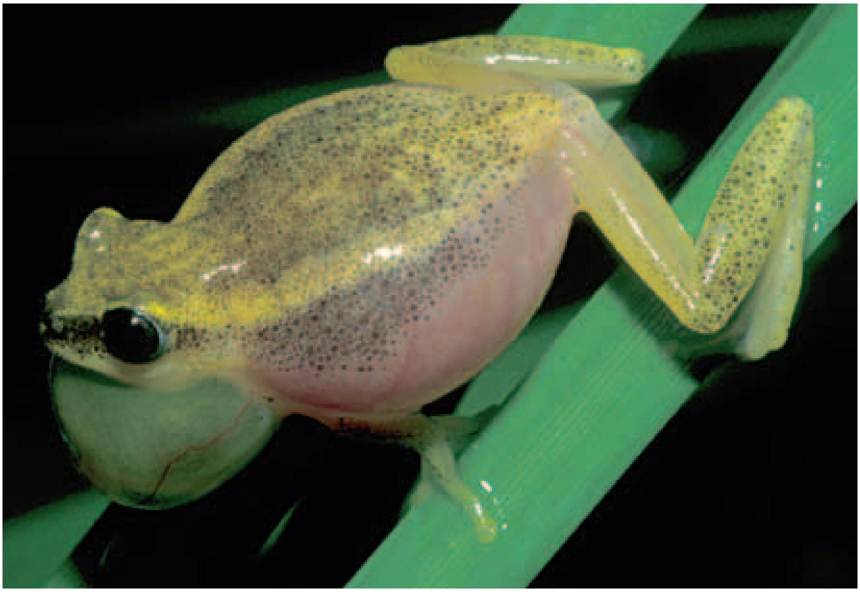

Fig. 8. *Heterixalus carbonei* prefers forested habitat, where it uses relatively large (> 500 m^2) ponds as breeding sites.

Most species are explosive breeders, reproducing only after heavy rainfalls, and only a few times during the breeding season. However, some prolonged breeders are found that reproduce over long periods of the rainy season. Apart from *Mantella betsileo*, which is calling both at day and night time, all species are primarily nocturnal. For more detailed information on the Menabe frogs see Glaw & Vences (2007), Glos (2003) and Glos & Volahy (2004).

The Menabe frogs show remarkable adaptations to the dry forest habitat. The embryonic and larval development is generally very fast, presumably as an adaptation to the unpredictability of rainfall and subsequent high ephemerality of the breeding ponds. Accordingly, in some species (*Aglyptodactylus laticeps*, *Scaphiophryne calcarata*, *S. brevis*), larval development can be as short as 10 days and is therefore among the fastest known for amphibians (compare Rödel, 1998 for *Bufo pentoni*).

For many species it remains enigmatic how they cope with the long dry period of up to 9 months per years with virtually no rainfall. Several individuals of *Scaphiophryne brevis* and *S. calcarata* were found by us (in the forest) and by local workers (on peanut fields) in the soil in depths of about 30 cm in the dry season. This indicates that the microhylid frogs are spending this period buried in the ground. Several mantellid frogs presumably hibernate in crevices and under rocks. The hibernation strategies of the treefrogs (*Boophis*, *Hyperolius*) remain unknown. In the transition period between rainy and dry season, adults of *Heterixalus* (*H. tricolor* and *H. carbonei*) were found sitting on leaves during the day. These frogs were fully sun-exposed, and had changed their colour from yellow to bright white or greyish. A similar behaviour is known from juvenile *Hyperolius nitidulus* (Rödel 2000) that reflect light due to their white skin colour during the dry season and therefore assure survival by reducing the desiccation risk. This strategy demands a wide variety of behavioural, morphological and physiological adaptations (Schmuck et al. 1988, 1994; Kobelt & Linsenmair, 1992, 1995; Linsenmair, 1998).

Distribution of amphibians within Menabe

Species number was between five and 13 species per site (Tab. I, Fig. 3). We conclude that two main factors, precipitation and anthropogenic disturbances, account for these differences.

It is obvious that the lower availability of open (running and standing) waters and/or lower precipitation in Kirindy Village Forest and Bedo Baobab Forest may account to a large extent for the lower species richness in these two most western sites. In the four eastern sites, a higher variety and a higher density of breeding ponds exists. In particular, Kirindy CFPF stands out as it offers both, many small temporary ponds (<50 m^2, <14 days durability) and larger (> 200 m^2), more permanent ponds (>2 months durability). For example, *Aglyptodactylus laticeps*, a species specialized to breed in small temporary ponds, and *Heterixalus carbonei*, a species specialized to breed in more permanent ponds, are found exclusively in eastern Menabe (Tab. I).

We argue that anthropogenic disturbances are a second important factor that is responsible for reducing species diversity. Species diversity was highest in sites with low anthropogenic disturbances (13 species in Kirindy CFPF CS7, 10 species in Ambadira Forest), and lowest in the most disturbed site Kirindy Village (ongoing logging and burning) (5 species). Kirindy CFPF South (with commercial logging impact) (9 species), the corridor between Kirindy and Ambadira (8 species) and the Bedo Baobab Forest (7 species) showed medium species richness. Taking humidity differences between east and west into account, there is still the pattern of reduced species diversity in disturbed sites when comparing species number of only the eastern sites. This is exemplified by comparing Kirindy CFPF CS7 and Kirindy CFPF South, as these sites are only 4 km apart (Fig. 3), but nevertheless differ profoundly in species richness.

According to our experience, one explanation for the reduction in species diversity in disturbed sites is that certain breeding waters become unsuitable for the respective frog species. Due to logging activities and the successive canopy loss, water evaporates quicker in the breeding ponds and they therefore dry up faster than in undisturbed sites. Additionally, several frog species (*Aglyptodactylus laticeps*, *Laliostoma labrosum*, *Scaphiophryne brevis*, *S. calcarata*, *Boophis doulioti*, *B. xerophilus*) use breeding waters that were unintentionally created by humans in dirsturbed sites, e.g. puddles on dirt roads.

These waters are generally shallow and vegetation-free, and very much exposed to sunlight. Although the frogs that breed in these waters are well adapted to temporal breeding waters, in periods of low rainfall that regularly interrupt periods of high precipitation during the rainy season in this region, a high proportion of these waters quickly dry up before even the fast metamorphosis of these frogs is completed. This then leads to a complete breeding failure (unpublished data).

Identification of key species for future monitoring

It is often not realistic to inventory all species and their requirements when monitoring amphibians. Therefore, it is often helpful for conservation purposes to appoint representative species for the specialised fauna of a certain habitat as target species (New, 1995). Such indicator species should have narrow ecological amplitudes with respect to one or more environmental factors and its presence can thus serve as an indicator for a particular environmental condition or set of conditions (Allaby, 1994). Due to specific characteristics of their group, e. g., low mobility and permeable skin, amphibians are generally seen as good indicators of environmental integrity (e.g., Welsh and Ollivier, 1998; Wilson and McCranie, 2003). In the Central Menabe region, we consider two species, *Aglyptodactylus laticeps* and *Scaphiophryne menabensis*, as especially suitable for this function for a number of reasons.

Aglyptodactylus laticeps is endemic to Menabe and is considered as endangered (EN; Andreone et al., 2005). However, it is abundant within the area. For detailed information of habitat requirements of *A. laticeps* and effects of disturbances on this species see Glos et al. (2008). *Scaphiophryne menabensis* was just recently discovered (Glos et al., 2005). Only a few sites of occurrences are known. Within the Menabe region, it is one of the rarest frogs. It is an explosive breeding species reproducing only 2 to 3 times per year after heavy rainfalls. Both species occur exclusively in relatively little disturbed forest parts. The presence of breeding adults around the pond or of their tadpoles in the pond is an indicator of temporary aquatic habitats within this forest that are characterized by a low water permanency, and high forest cover and other characteristics indicating undisturbed forests. Therefore, the presence or absence of these species within their natural range indicates the relative degree of environmental integrity of this habitat as a whole (Wilson and McCranie, 2003).

However, the appointment and use of indicator species in conservation remains controversial (Simberloff, 1998). They possess an undeniable appeal for practical conservationists, land managers, and governments as they provide a cost- and time-efficient mean to assess the impacts of environmental disturbances on an ecosystem. Their use is particularly advantageous when several species representing different taxa and life histories (and therefore different demands on the habitat) are included as indicator species in a monitoring program (Carignan & Villard, 2002). Ideally, the habitat requirements of the target species should also reflect the demands of other species in need of protection ("umbrella effect"; Simberloff, 1998; New, 1995). This is the case for *A. laticeps* and *Scaphiophryne menabensis*. The protection of suitable habitat for these species will also promote the survival of the syntopic *Boophis doulioti*, *Laliostoma labrosum*, *Mantella betsileo* (Mantellidae), *Dyscophus insularis*, and *Scaphiophryne calcarata* (Microhylidae) (Glos & Linsenmair, 2004) as well as aquatic species of other organism groups.

Recommendations of monitoring methods

Detecting changes in amphibian population sizes is problematic due to difficulties in estimating population size on the one side and often very high natural fluctuations of population size on the other side (Pechmann & Wilbur, 1994). The problem is even more evident when it concerns explosive breeding species. For example, the number of breeding individuals of *Aglyptodactylus laticeps*, *A. securifer*, *Dyscophus insularis* and three *Scaphiophryne* species changes dramatically between different nights depending on rainfall and other factors (Glos et al., this volume; Glos, 2003). In these species, non-breeding individuals are hard to detect and therefore are usually included into the census only to a minor part.

Monitoring of amphibians is more practicable when absence-presence data are recorded. To add more information on community structure we suggest to expand this design whenever possible by recording categorial abundance data that are easy and quick to obtain. Breeding sites of different types (e.g. permanent vs. ephemeral, lotic vs. lentic, fish vs. fish-free sites) should be selected as they offer habitats for different species. These sites should be monitored at specified time intervals (if possible after heavy rains) throughout each breeding season (usually December to March).

As methods, acoustic and visual monitoring at the breeding sites and tadpole sampling should be applied (Tab. II). Our data strongly suggest that transect and plot sampling inside the forest are inefficient for this system. The most effective sampling method is monitoring breeding ponds. Pitfall trap sampling yielded in some species accounts at some sites, however, it is recommended only as a possible addition to breeding pond search due to time-benefit considerations. Additionally, we highly recommend tadpole sampling as a very efficient monitoring method. The presence of tadpoles in a pond reveals the true choice of breeding habitat by the adults of a species. Moreover, tadpoles can be surveyed independently from any activity patterns of adult frogs. This is in particular advantageous when dealing with explosive breeding species, as in this system. Tadpoles of *S. menabensis* can be easily identified in the field (Glos et al., 2005, Grosjean et al., in press). Tadpoles of *A. laticeps*, however, are morphologically similar to those of *A. securifer* and *Laliostoma labrosum* (Glos & Linsenmair, 2004). Therefore, DNA-barcoding should be applied as a reliable and relatively inexpensive mean to identify *A. laticeps* as tadpole in a monitoring study.

	Aglyptodactylus laticeps	Scaphiophryne menabensis
Breeding pond survey	+	+
Transects in the forest	-	-
Opportunistic search	-	-
Pitfalls / Drift fences	0	-
Tadpole surveys	+ *	+ **

Tab. II. Recommendations for monitoring methods. + = recommended, 0 = limited recommendation, - = not recommended, * = recommended only when tadpoles are analyzed by DNA-barcoding, ** = tadpoles can be identified in the field.

Future prospects of amphibian conservation in Menabe

The amphibians of the Menabe region are special in respect of many characteristics, in particular their exceptional adaptations to the dry-forest habitat and their high degree of local endemism. This should make them a high priority target of amphibian conservation in Madagascar. The recent Global Amphibian Assessment (Andreone et al., 2005, Stuart et al., 2004) documented the global decline of amphibian populations around the globe and highlighted the need for time-series data on population trends in amphibian populations in order to better understand threats to their persistence. The already occurred high habitat loss in the past and the continuing threats to this forest to-date make the need to monitor amphibian populations certainly highly evident for Central Menabe. Therefore, Durrell has prioritised amphibian conservation in Menabe and associated field research as part of its conservation strategy in Madagascar. In January 2007, a long-term monitoring program on amphibians in Central Menabe was taken up. The main focus of this program will be monitoring those frog species that are typical for the dry forest habitat, i.e. have geographic distributions that are restricted to the dry forest and that show morphological, physiological and behavioural traits that are highly adapted to this habitat. As recommended in this paper, these will be mainly *A. laticeps* and *S. menabensis*. Additionally, information will be collected to assess the distribution, conservation status and habitat requirements of the complete community of amphibians in Menabe. Despite their uniqness, almost nothing is known about the biology of most of the species. Therefore, future research necessarily must include research on ecology and life history. In particular, habitat choice in different area scales (microhabitat to geographic scales) and habitat and resource requirements should be studied. To know what the needs of the different species are is essential when trying to protect their populations and to predict potential effects of habitat alteration on each species.

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RÉSUMÉ

Conservation des amphibiens du Menabe Central.

La faune d'amphibiens du Menabe Central, région de l'ouest de Madagascar, est importante du fait de leurs extraordinaires adaptations à un habitat en forêt sèche. Cet habitat est hautement menacé. Jusqu'en 1990, la forêt sèche de l'ouest de l'île était connue pour avoir été réduite à seulement 3% de son étendue originale. De nouvelles analyses montrent que cette déforestation avait également atteint un taux alarmant cette dernière décennie. Fondé sur un inventaire étendu de 2004 nous montrons que la distribution des amphibiens du Menabe dépend de la qualité de l'habitat. La diversité des espèces était plus élevée dans les deux plus grandes parcelles de la forêt, appelées Kirindi et Ambadira, et était plus basse dans de nombreuses parties disséminées. Nous indiquons ceci tout particulièrement pour deux espèces incluses dans un programme de monitorage sur le long terme commencé par Durell en 2007, l'*Aglyptodactylus laticeps* et la *Scaphiophryne menabensis*. Ces deux espèces sont distribuées à l'ouest de Madagascar dont l'*A. laticeps* étant endémique en Menabe Centrale. De plus, elles apparaissent sensibles à la dégradation de l'habitat et sont des indicateurs hautement pertinents de l'intégrité de l'habitat. Finalement, nous soulignons le besoin de futures recherches d'inclure plus de recherches détaillées sur l'écologie et l'histoire de la vie.

Mots clés: Amphibiens, Conservation, Forêts sèches, Madagascar, Menabe.

Julian Glos
Technical University Braunschweig
Zoological Institute
Spielmannstr. 8
38106 Braunschweig, Germany

Present address:
Ecology and Conservation
Biocenter Grindel and Zoological Museum
University of Hamburg

Martin-Luther-King Platz 3
20146 Hamburg, Germany
Email julian.glos@zoologie.uni-hamburg.de

Robert Bourou
Joanna Durbin
Anselme Toto Volahy
Richard Young
Durrell Wildlife Conservation Trust
Antananarivo, Madagascar

Josef Straka
University of Würzburg
Zoology II, Biozentrum
Am Hubland
97074 Würzburg, Germany

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 125-142

Julian GLOS[1], Kathrin H. DAUSMANN[2], K. Eduard LINSENMAIR[1]

Modeling the habitat use of *Aglyptodactylus laticeps*, an endangered dry-forest frog from Western Madagascar

ABSTRACT

A crucial factor for the successful reproduction and thus conservation of most amphibian species is the availability of suitable waters as breeding sites. We examined the use of breeding sites of an endangered, locally endemic frog of Western Madagascar, *Aglyptodactylus laticeps*, over a three-year period. Logistic regression was used to model the relationship between the species' breeding habitat use and environmental variables. This model was aimed to be predictive, rather than explanatory, and only environmental variables were included that are assessable in a time and cost effective manner, and that can therefore be used as an easy-to-use management tool in applied conservation. On the local scale of the Kirindy concession, *A. laticeps* is restricted to forest with a relatively low degree of disturbance and closed canopy cover. The model identified a few environmental variables that suffice to satisfactorily predict the use of respective breeding sites. Most breeding sites are characterized by high leaf litter coverage on the pond's ground, no emergent vegetation coverage, no surface water plants, and low water permanency. Based on these results, we present recommendations for the conservation management of this frog. Furthermore, the presence or absence of this species within its natural range indicates the relative degree of environmental integrity of its habitat, and we therefore consider this species as a suitable indicator species of temporary aquatic habitats within the dry forest that are characterized by a low water permanency and high leaf litter coverage. This study demonstrates that models constructed from basic ecological knowledge of relevant species may serve as valuable management tools in applied conservation.

Key words: *Aglyptodactylus laticeps,* Amphibians, Conservation, Madagascar.

[1] Department of Animal Ecology and Tropical Biology, Würzburg University.
[2] Department of Ecology and Conservation, University of Hamburg.

INTRODUCTION

The fauna and flora of the Central Menabe region in Western Madagascar are highly threatened. Even optimistic prognoses do not assume that all of the remaining forest with its extant biodiversity can be conserved in its present status. The rural population of Madagascar largely depends on the forest and its products for everyday life (Favre, 1996). Thus, human pressure from the surrounding villages will lead to further degradation of at least some parts of the forest. In a pragmatic view, research and conservation efforts must therefore focus on selected sites of extraordinary conservation interest. These sites might be chosen either according to high general levels of biodiversity, or based on the distribution and ecology of species of particular interest ("flagship species"). Conservation research and its application on flagship species was established in Central Menabe during the last decade. These activities centered mainly on vertebrate species with extremely restricted ranges within Menabe. Amphibians were so far not included as target species into the conservational efforts.

Therefore, we strongly recommend to include amphibians into conservation activities in Central Menabe. To realize this aim, it is necessary to increase the knowledge on ecological requirements of amphibians in this area. A crucial factor for the successful reproduction and thus conservation of an amphibian species is the availability of suitable waters as breeding sites. Therefore, this study examines the use of breeding sites of an endangered, local endemic Madagascan frog, *Aglyptodactylus laticeps*, over a three year period. Logistic regression was used to model the relationship between the species' breeding habitat use and environmental variables at a local scale in Kirindy Forest, one major forest block in Central Menabe. In our model, we included environmental variables that are assessable in a time and cost effective manner, and that can therefore be used as an easy-to-use management tool in applied conservation. Our model was aimed to be predictive, rather than explanatory.

MATERIAL AND METHODS

Study site

The area of the Kirindy Forest (120 km^2) lies within the Central Menabe region which has the dubious reputation of containing one of the largest remaining dry, deciduous forests of Western Madagascar (Nelson & Horning, 1993). It is located about 50 km northeast of Morondava and 20 km inland (44°39'E, 20°03'S; 18 – 40 m above sea level; Sorg and Rohner, 1996). The forest is managed by the "Centre de Formation Professionelle Forestière" (CFPF), and is a "Site de Conservation" since 28th March 2006. Until about 1994, Kirindy/CFPF was the focus of silvicultural research projects and agroforestry experiments including sustainable timber exploitation with subsequent reforestation (Sorg et al., 2003). In surrounding areas with cleared forest, the vegetation consists of secondary-forest formations, scrub, and savanna. Human density is low and concentrated in small villages spread out over the area (Sorg et al., 2003).

The rainy season of 3 – 5 months from November-December to February-March is followed by a dry season of 7 – 9 months with virtually no rain. Mean annual precipitation is about 800 mm (range 390 – 1511 mm; Sorg and Rohner, 1996). The potential breeding sites for amphibians in this area can be found in three different habitat types, namely the forest (forest ponds), the bed of a river that is meandering through the forest (before the river is running; riverbed ponds), and the surrounding savanna (savanna ponds). All stretches of running and standing waters dry up every year except for very few pools in the riverbed. For further information on amphibian breeding sites in Kirindy see Glos (2003).

Study species

Agylptodactylus laticeps (Anura: Mantellidae: Laliostominae) (Fig. 1, 2) was described first from the study site (Glaw et al., 1998). From current knowledge it is endemic to the Central Menabe region, from Kirindy Forest in the South to the Tsiribinha river in the north (Glos et al., 2008). It is classified as an endangered species (EN) on the basis of its restricted extent of occurrence and the observed shrinking of its habitat area (criteria for EN B1a and B1b (iii); IUCN, 2001) (Andreone et al., 2005). However, within its habitat it is locally abundant (Glos, 2003).

Fig. 1. Breeding couple of *Aglyptodactylus laticeps*. These frogs are medium sized, cryptically coloured leaf litter frogs. Snout-vent length of adult males is 3.2–4.9 cm, of adult females 5.4–7.2 cm (Glos, 2003).

Fig. 2. Female of *Aglyptodactylus laticeps*. This frog is an explosive breeding species that breeds only one to a few times per year. In one breeding event, they lay one large clutch (as surface layer) of relatively small eggs (clutch size: 3636 ± 470 eggs; mean ± SD; range 2686-4231; N = 7; ovum diameter: 1.76 ± 0.20 mm; N = 722; Glos & Linsenmair, 2004).

This frog shows distinct adaptations to the dry forest habitat. It is active only during the rainy season, while spending the cool dry season presumably hibernating under ground. Breeding starts about two to four weeks after the beginning of the rainy season and extends over its whole duration. *A. laticeps* is an explosive breeding species that usually reproduces within two days after heavy rainfalls that exceed 30 mm of precipitation (Glos, 2003) (Fig. 3). Larval development is very short, with a minimum of ten days (Glos and Linsenmair, 2004). The tadpoles have been shown to exhibit adaptive plasticity in metamorphic traits (Glos, unpubl. data).

LOGISTIC REGRESSION MODEL

Statistics

In order to extract the key habitat factors that predict the choice of breeding waters by *A. laticeps* we designed a habitat model using multiple logistic regressions (Hosmer and Lemeshow, 1989). Logistic response functions are appropriate when there is a sigmoid relationship between a species' probability of occurrence and the independent variables (e.g., in contrast to hump-shaped response curves; McCune, 2004). In *A. laticeps*, we expected the response variable (probability of occurrence) to fit this assumption over the range of the relevant independent variables.

Using a backward stepwise logistic regression (LR – method; SPSS© 12.0) and likelihood ratio statistics, we included binary presence / absence data of *A. laticeps* tadpoles as the dependent variable, and environmental characteristics of the breeding ponds as independent variables. Each breeding pond represents one replicate. We used a significance level of 0.10 for exclusion of variables as this is considered to provide better discrimination performance than less conservative levels (Adler and Wilson, 1985). For model calibration and evaluation of the goodness-of-fit of the model, we used Nagelkerke's R^2 (Nagelkerke, 1991). In order to express the classification accuracy of the models irrespective of their threshold criteria, 'Receiver Operating Characteristics' (ROC) – plots were constructed, and 'Area Under Curve' (AUC) – values were calculated providing a single quantitative index of the diagnostic accuracy of the model (Zweig and Campbell, 1993). This method measures the probability that the model will assign a higher probability of occurrence to cases with observed presence in any data pair, randomly chosen from the presence / absence data. AUC values vary from 0.5 (no apparent accuracy) to 1.0 (perfect accuracy). For model discrimination, we calculated from the classification matrix: prevalence (proportion of presences in the total sample), sensitivity (proportion of the correct predictions for presence), and specificity (proportion of correct predictions for absence). Sensitivity and specificity were calculated for different classification thresholds: $P_{optimal}$ (maximizes the proportion of correct

Fig. 3. Natural breeding pond of *A. laticeps* in Kirindy Forest. Breeding waters are generally small (0.5-200 m^2) temporary forest ponds with a high risk of desiccation.

classifications), $P_{balanced}$ (when sensitivity $\approx$ specificity), and $P_{0.5}$ (classification threshold = 0.5). We tested for spatial autocorrelation of the variables using standardised deviation residuals to calculate Moran's I as an index of covariance between different pond locations (CrimeStat® 2.0 software).

Data acquisition of dependent variable

Amphibian breeding habitat choice was analyzed over three consecutive rainy seasons (1999-2000, 2000-2001, 2001-2002), in a total of 157 different potential breeding waters (n = 60 for forest ponds, n = 84 for riverbed ponds, n = 13 for savanna ponds). The sampled forest and riverbed ponds represent all breeding sites within an area of 3 km^2 that are locally known as CS5, CS6, and CS7. Additionally, three forest ponds outside this area were included. The ponds analyzed in the savanna represent all ponds available in this habitat. This savanna is surrounded by the Kirindy Forest, and is situated in the area locally known as CS 9-12 within the Kirindy concession. Whether a pond was used as a breeding site or not was evaluated by repeatedly (see below) recording the presence or absence of *A. laticeps* tadpoles. This procedure has the advantage of directly measuring the actual reproduction, in contrast to the analysis of e.g., calling activity of adult frogs. Moreover, this method is independent of any activity patterns of the adults and considers that not all breeding waters with calling male frogs are actually used for reproduction (J. Glos, unpubl. data).

Presence of *A. laticeps* larvae was recorded by standardized dip-netting (Heyer et al., 1994). In each pond, 30 dip net strokes were performed, randomly distributed over the pond. The dip net was triangular shaped with a base of 400 cm^2 (30 x 30 x 30 cm). Each dip net stroke was 1 m long, and was touching the ground substrate. This is the preferential microhabitat of *A. laticeps* tadpoles (Glos and Linsenmair, 2004). All captured tadpoles were determined in the field or in the field camp to species level, using a stereo microscope, existing literature (Blommers-Schlösser & Blanc, 1991; Glaw & Vences, 2007; Glos & Linsenmair, 2004; 2005; Glos et al., 2005), and a reference collection. The distinction between *A. laticeps* and *A. securifer* tadpoles (and to a lesser degree also to *Laliostoma labrosum*) that is based on morphological characters is difficult and requires intensive experience. Therefore, we do not recommend this method when it is applied by untrained observers, e.g. when monitoring this species. In this case, DNA barcoding is much more reliable and efficient (see Glos et al., 2008). Specimens were released subsequently to determination.

Depending on pond properties (e.g., ground substrate, exposition, water depth) and the length of periods with low precipitation, some study ponds dried out during the rainy season. When they were refilled after rainfalls, they were repeatedly used for breeding by amphibians, leading each time to a new set of tadpoles. To get a complete picture of pond use by *A. laticeps* throughout the rainy season, therefore, our analysis was performed several times per season and breeding site. We repeated our analysis within ten days after each rainfall > 30 mm, and after each refilling of a pond when it had been dried out before. Our method thus was adjusted to the breeding ecology of *A. laticeps* (Glos, 2003), and therefore reliably detected its presence in the respective ponds. Presence of *A. laticeps* tadpoles in a pond during at least one control check, irrespective of year and date, was coded as 1, and absence in all control checks at that particular pond was coded as 0.

We pooled the data for all years for numerous reasons. First, the fundamental idea of our study is to analyze overall breeding habitat use, i.e. in as many ponds as possible over a time span as long as possible. Pooling the data meets this claim, and furthermore avoids pseudo-replications. Additionally, the differences in the environmental characteristics of individual ponds between seasons are negligible (J. Glos, unpubl. data), thus providing the legitimate basis for their pooling over different years. Moreover, there is an implicit assumption in most presence / absence designs that breeding habitats are saturated (Capen et al., 1986). In *A. laticeps*, however, particular characteristics of its breeding ecology (e.g., forming of breeding aggregations, colonizing preferably freshly filled ponds) make it likely that not all suitable habitats are occupied when tadpole presence is measured only at one point of time. Therefore, this assumption might then not be met.

Data acquisition of environmental variables

Thirteen variables that are characterizing abiotic and biotic properties were measured at each study pond. Detailed nomenclature and definitions of these variables are given in Table 1. Habitat variables were recorded parallel to the control checks for species presence. The variables were chosen with regard to their applicability in practical conservation management. First, these variables are known to constitute important resources or habitat requirements to anurans

Variable name	*Variable definition*	*Unit*	*Methods*
Macrohabitat	Forest, Riverbed, or Savanna pond	3 categories	
Pond origin	Pond is of natural or anthropogenic origin	2 categories	
Pond size	Absolute surface area of pond when completely water-filled	m^2	Calculated from pond length, width, and shape
Pond depth	Maximum pond depth when pond is completely water-filled	cm	Measured at the deepest point in the pond
Shallowness	Relative area of the pond < 3 cm water depth	0 – 100 %	Estimated
Water permanency	Time until pond dries up after complete water-filling	5 categories, from I (high permanency) to V (low permanency); categories were defined as days until desiccation of the pond I: > 150 days, II: 55 – 150 days, III: 20 – 54 days, IV: 5 – 19 days, V: < 5 days	Measured after heavy rain that left all study ponds completely water-filled and a consecutive dry phase without rain
Rock substrate	Relative area of the pond bottom composed of rocky substrate	0 – 100 %	Estimated
Shading	Relative area of pond shaded by foliage of shrubs and trees	0 – 100 %	Estimated as relative area shaded at 12:00 a.m.
Leaf litter	Relative area of pond bottom covered with dead leaves	6 categories I: 0 %, II: 1 – 20 %, III: 21 – 40 %, IV: 41 – 60 %, V: 61 – 80 %, VI: 81 – 100 %	Measured at plots of 0.25 m^2 within the pond and averaged
Surface water plants	Relative area of pond surface covered with water plants (mainly *Nymphea lotus*, *Salvinia* sp.)	6 categories I: 0 %, II: 1 – 20 %, III: 21 – 40 %, IV: 41 – 60 %, V: 61 – 80 %, VI: 81 – 100 %	Estimated
Submerged plants	Relative volume of pond filled with submersed water plants (mainly *Lagarosiphon madagascariensis*, *Najas* sp.)	6 categories I: 0 %, II: 1 – 20 %, III: 21 – 40 %, IV: 41 – 60 %, V: 61 – 80 %, VI: 81 – 100 %	Measured at plots of 0.25 m^2 within the pond and averaged
Emergent vegetation	Relative area of pond surface covered with emergent water plants	6 categories I: 0 %, II: 1 – 20 %, III: 21 – 40 %, IV: 41 – 60 %, V: 61 – 80 %, VI: 81 – 100 %	Estimated
Fish	Presence of fish (mainly *Oreochromis* sp.)	2 categories (presence / absence)	Observation, dip-netting

Tab. I. Environmental variables in the logistic regression model.

in other systems. Second, they are measurable with passable effort and in relatively short time, independent of extensive preparatory training and any academic ecological knowledge.

In a first step of prae hoc analysis we eliminated two variables (*Macrohabitat*, *Fish*) out of statistical reasons from the logistic regression analysis. *Macrohabitat* was excluded because *A. laticeps* was mainly restricted to forest ponds, and was found only in two riverbed ponds and never in savanna ponds (see Results section). Hence, the subsequent analysis was run only for forest ponds (n = 60). *Fish* was excluded as only two riverbed ponds contained fish at all, and all ponds occupied by *A. laticeps* were fish free.

In a second step, we constructed a correlation matrix with the remaining independent variables, and subsequently eliminated high collinearity within the environmental variables (exclusion of variables in cases of Spearman rho > 0.7, see suggestions by Fielding and Haworth, 1997). In these cases, one of two or more correlated variables were eliminated according to their practical applicability, i.e. those variables were kept that required less effort to measure or proved to be more reliable to measure, being thus more useful in applied conservation management. As a result, we eliminated the variables *Pond origin* (rho = 0.87 with *Rock substrate*), *Water permanency* (rho = -0.72 with *Pond size*), and *Shallowness* (rho = 0.80 with *Water permanency* and rho = -0.79 with *Pond depth*). Finally, we included eight environmental variables in the initial regression model (Tab. II).

Variables	Coefficient	SE	P	Exp(B)
Initial logistic regression model				
Pond size	0.00	0.00	0.70	1.00
Pond depth	- 0.02	0.02	0.32	0.98
Rock substrate	3.15	981.67	1.00	23.29
Shading	0.08	0.01	0.48	1.01
Leaf cover	0.32	0.25	0.21	1.37
Surface water plants	- 0.05	0.05	0.28	0.95
Submerse plants	0.05	0.33	0.88	1.05
Vegetation cover	- 0.02	0.01	0.17	0.98
Final logistic regression model				
Leaf cover	0.32	0.10	< 0.01	0.97
Surface water plants	- 0.09	0.04	0.04	0.92
Vegetation cover	- 0.03	0.01	0.17	0.36

Tab. II. Logistic regression analysis of the breeding habitat use of *Aglyptodactylus laticeps* (presence = 1, absence = 0), using a model that incorporates eight independent variables (stepwise backwards, LR – method). Initial logistic regression model: n = 60, $\chi^2 = 22.58$, Nagelkerke $R^2 = 0.42$, AUC = 0.80, p = 0.004. Final logistic regression model using variables from the initial regression (stepwise backwards analysis): n = 60, $\chi^2 = 18.54$, Nagelkerke $R^2 = 0.35$, AUC = 0.78, p < 0.001. Coefficient = regression coefficient B; SE = standard error; P = probability level. In a prae hoc analysis five variables were eliminated: Macrohabitat, Pond origin, Shallowness, Water permanency, Fish. Settings of analysis were: P (exclusion of variable) = 0.10, number of iterations = 20. For definition of the environmental variables see Tab. I.

RESULTS

Of all habitats, 153 of 157 ponds (98.1 %) were used by at least one amphibian species. *A. laticeps* tadpoles were found predominantly in forest ponds (Fig. 3), only in two riverbed ponds and never in savanna ponds. Correspondingly we never noticed any calling choruses as are typical of *A. laticeps* (Glos, 2003) from other riverbed ponds or from savanna ponds during extensive acoustic monitoring of amphibian breeding activity (unpubl. data). In the forest ponds, the breeding sites of *A. laticeps* were not restricted to primary forest, but in general to forest areas with closed canopy cover. Accordingly, *A. laticeps* was found both in primary forest and in parts of the forest that had been used for low impact sustainable logging during the last decades (Sorg et al., 2003). In addition, puddles that had been unintentionally created by humans on abandoned dirt roads were frequently used for breeding (Fig. 4). *A. laticeps* was never found in ponds that were inhabited by fish. However, only two rock pools of the river bed contained fish at all. Within the closed forest, the potential breeding waters cover a wide range of all environmental variables (Tab. III).

The parameters of the initial and of the final multiple logistic regression model for the occurrence of *A. laticeps* tadpoles are listed in Tab. II. Their importance for the model predictions is reflected by the correlation coefficient (r). Five variables were stepwise eliminated from the model: *Submerged plants*

Fig. 4. Anthropgenically created breeding site of *A. laticeps*. These sites (e.g., small puddles on dirt roads, drainages for roads) are sometimes used for spawning. However, they often do not result in any reproductive success as they dry out before metamorphosis is completed.

Variable	*N*	*Mean*	*SD*	*Minimum*	*Median*	*Maximum*
Pond size (m^2)	67	840.3	3099.3	0.1	26.67	20000.0
Pond depth (cm)	67	34.3	30.7	5.0	26.0	165.0
Shallowness (%)	67	60.2	36.9	3.0	75.0	100.0
Water permanency (cat.)	67	3.8	1.2	1.0	4.2	5.0
Rock substrate (%)	67	1.8	8.9	0.0	0.0	60.0
Shading (cat.)	67	4.1	0.9	2.0	4.3	5.0
Leaf litter (cat.)	67	3.3	1.3	1.0	3.1	5.0
Surface water plants (%)	67	5.3	15.5	0.0	0.0	90.0
Submerged plants (cat.)	67	1.1	1.2	0.0	1.0	4.2
Emergent vegetation (%)	67	10.3	22.3	0.0	0.14	100.0

Tab. III. Descriptive analysis of the environmental variables. Data are from all study ponds, i.e. *Aglyptodactylus laticeps* tadpoles being absent and present. For variable definition see Tab. I.

(step 2), *Pond size* (step 3), *Shading* (step 4), *Pond depth* (step 5), and *Rock substrate* (step 6). In the final model, the observed and predicted presence of *A. laticeps* tadpoles rises with increasing cover of leaf litter at the bottom of the pond (variable *Leaf litter*), decreases with the proportion of the pond area covered by surface water plants (*Surface water plants*), as well as decreases with the relative area of the pond surface covered with emergent water plants (*Emergent vegetation*) (Fig. 5).

Prevalence of *A. laticeps* at the ponds was 56.7 %, meaning that this proportion of the ponds was used by *A. laticeps* for breeding at least once during our study. The overall percentage of correctly predicted presences and absences was 73.3 % (for threshold value $P_{optimal}$ = 0.40), and 68.3 % (for threshold value $P_{balanced}$ = 0.65 and P = 0.50; Tab. IV). The AUC – value of 0.78 (95% confidence interval 0.66 – 0.90) confirms a good ability of the final model to give correct predictions for all possible classification thresholds. There was no evidence for spatial autocorrelation in our data (Moran's I coefficient = -0.022).

DISCUSSION

The Madagascan dry forest is an extremely threatened ecosystem

The knowledge of a species' ecological requirements is often a prerequisite for its successful conservation (Araújo et al., 2002). Especially in the tropics, where anthropogenic landscape modifications rapidly reduce many natural habitats, the lack of detailed biological knowledge handicaps effective conservation of many rare species. Therefore, this study examines one important ecological requirement, the choice of breeding habitat, by an endemic and endangered frog species in Madagascar, *Aglyptodactylus laticeps*.

This frog exclusively occurs in the Central Menabe region (Glaw et al., 1998). Since the arrival of humans some 2000 years ago, this eco-system has seen severe pressure from slash and burn agriculture, illicit and licit harvesting,

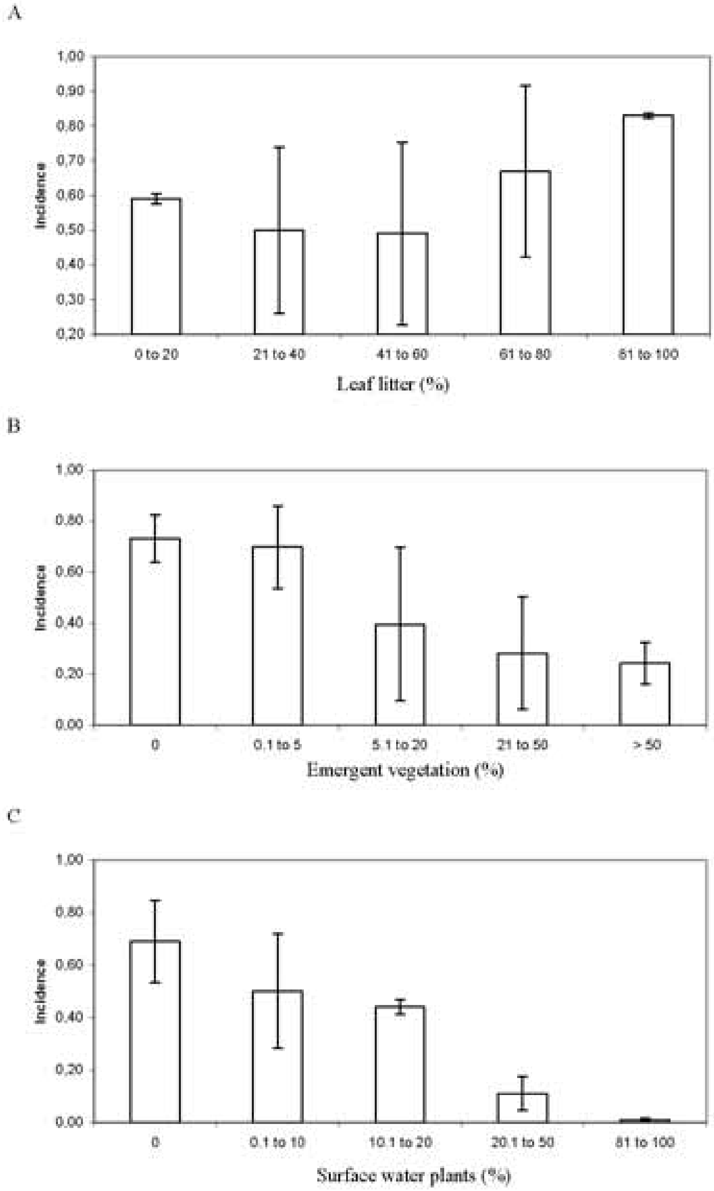

Fig. 5. Incidence, given as the probability of occurrence (mean ± SD), of *Aglyptodactylus laticeps* depending on the variables included in the final logistic regression model; (A) Leaf litter, (B) Emergent vegetation, (C) Surface water plants. For definition of these variables see Table 1.

	Correct predictions (%)	Sensitivity (%)	Specificity (%)
$P_{opt} = 0.40$	73,3	97,1	42,3
$P = 0.50$	68,3	88,2	42,3
$P_{balanced} = 0.65$	68,3	70,6	65,4

Tab. IV. Classification accuracy for the logistic regression model; for model settings see Tab. II. P_{opt} = classification threshold for highest overall classification accuracy; $P_{balanced}$ = classification for sensitivity ≈ specificity.

and expanding human populations surrounding the forest corridor (FANAMBY, 2003; Sorg et al., 2003). It has been reduced to about 3 % of its initial surface area and has become extremely fragmented (Smith, 1997). Consequently, conservation of the remaining dry deciduous forests of Western Madagascar and its fauna and flora have become a matter of great concern (Hannah et al., 1998; Ganzhorn et al., 1997). Even though dry deciduous forests generally rank among the most endangered major ecosystems of the world (Lerdau et al., 1991; Janzen, 1988) very little is known about the ecological processes and requirements of most of the species inhabiting these forest ecosystems.

Several factors render *A. laticeps* a suitable focus of conservation priorities: The high level of local endemism, the restriction to relatively little disturbed forests, the high local abundance that is indicating an important functional role in the ecosystem, and its remarkable ecological and life history traits (Glos & Linsenmair, 2004).

Occurrence of A. laticeps can be predicted by environmental variables

On the local scale of the Kirindy concession, *A. laticeps* is restricted to forest with a relatively low degree of disturbance and closed canopy cover. The species was absent from waters in secondary vegetation formations that are surrounding the Kirindy Forest, such as scrub and savanna. Furthermore, *A. laticeps* did not regularly use the rock pools in the bed of the Kirindy River that are usually formed at the beginning of the rainy season as breeding sites. Corresponding with these results, on a regional scale, *A. laticeps* was found only in the two largest and least disturbed forest blocks (Ambadira Forest, Kirindy Forest) and its connecting corridor forest during a survey within the Central Menabe region in 2004 (Glos et al., 2008). By no means can these sites be classified as pristine primary forest, as they have a long history of timber harvesting, honey collecting, and hunting (Sorg et al., 2003). At the moment, however, these forest blocks are certainly among the largest and best preserved remnants of the dry forest of western Madagascar (Nelson & Horning, 1993), and the only known sites of occurrence for *A. laticeps*.

Our model highlights the relationship between environmental conditions and species occurrences. The model identified three environmental variables that suffice to satisfactorily predict the use of respective breeding sites by *A. laticeps*, namely leaf litter, vegetation coverage and surface water plants (Fig. 5). The probability of *A. laticeps* occurrence increases with the proportional area of the pond bottom that is covered by leaf litter, decreases with the proportional surface area that is covered by standing vegetation such as grasses, and also decreases with the area covered by water plants such as water lilies (*Nymphea* sp.), water fern (*Salvinia* sp.) and duckweed (*Lemna* sp.). In particular, a vegetation cover of below 5 % of the pond's surface area, the complete absence of surface water plants, and the coverage of leaf litter on the pond's bottom of over 60 % of the bottom area best meet the requirements of *A. laticeps*.

Our model was designed to be predictive rather than explanatory. Consequently, we do not imply that the avoidance of *A. laticeps* to breed in highly vegetated waters is necessarily based on a negative causal relationship, although there is a negative statistical correlation. However, the growth of this type of vegetation requires a combination of sufficient exposure to direct sunlight and an ample duration of water permanency of at least over a month. Accordingly, these plants can be considered as an indicator of low forest canopy cover, and high water permanency. Two of the variables with the highest explanatory power in our main model, vegetation cover and surface water plants, can therefore be merged into one key factor that might be causally (negatively) related to breeding habitat choice of *A. laticeps*, namely water permanency. This variable, however, is known for not being proximately assessable by naïve frogs, although it is critically important for reproductive success. In contrast to the vegetation parameters, breeding habitat choice might be causally determined directly by the quantity of leaf litter in a pond. Dead and decaying leaves and / or its microfauna represent an important food resource for many tadpole species (McDiarmid & Altig, 1999), including *A. laticeps* (Glos & Linsenmair, 2004). Furthermore, leaf litter constitutes an important structural component for tadpoles, offering retreat sites and camouflage against predators.

Management implications and recommendations

The three variables with the highest explanatory power in the model, two concerning vegetation cover and the 3rd quantity of leaf litter, are easy and quick to assess even by inexperienced persons. Other variables either proved to be not very predictive, although easy to measure (e.g., pond size, pond depth, water chemistry), or might be predictive but not measurable with reasonable effort (e.g., water permanency). Therefore, the use of these three variables for the prediction of *A. laticeps* occurrence represents an effective management tool that can be easily applied to identify potentially suitable habitat within and outside the Menabe region. By sampling the relevant waters within its range of distribution, the species' presence in formerly not inspected habitats can be predicted, and the suitability of the habitat for this species can thus be judged. Accordingly, the distribution of *A. laticeps* could be narrowed down. Furthermore, the effects of habitat alteration on the presence of this species could be predicted, and forest use options could subsequently be ranked according to the estimated effect on the species' distribution.

When sampling potentially suitable habitat, the date of sampling within the season is a crucial factor for sampling success. Breeding of *A. laticeps* starts two to four weeks after the beginning of the first heavy rainfall, and extends over the entire rainy season (Glos, 2003). Therefore, sampling will be most effective during the main part of the rainy season, which usually is January and February. *A. laticeps* is an explosive breeding species, reproducing only after heavy rainfalls (> 30 mm) in freshly filled ponds (Glos, 2003). As larval developmental time can be very short (minimum 10 days; Glos & Linsenmair, 2004), *A. laticeps* tadpoles might be missed in actual breeding ponds when the timing of sampling is inadequate. Therefore, sampling should preferably be done in the time span between one and two weeks after a heavy rainfall (except the first rains in a season), when *A. laticeps* tadpoles are easily distinguishable from other species, but have not yet completed metamorphosis.

Within its range of distribution, *A. laticeps* also uses breeding waters that were unintentionally created by humans, mainly puddles on dirt roads. These waters are generally shallow and free of any aquatic vegetation, and very much exposed to sunlight (Fig. 4). *A. laticeps* obviously assesses this habitat as suitable for breeding, as does our model (no vegetation cover and low water permanency). However, in periods of low rainfall that regularly interrupt periods of high precipitation during the rainy season in this region, a high proportion of these waters quickly dries up before even the fast metamorphosis of *A. laticeps* is completed, leading to a complete breeding failure in those waters (unpubl. data). Therefore, this anthropogenically created habitat may act as a population sink rather than increasing the number of suitable breeding sites for *A. laticeps*.

The availability of suitable breeding habitat is not the only ecological requirement for the successful establishment and persistence of a species at a given site. Suitable habitat for juveniles and adults (e.g., retreat sites during the day, overwintering or aestivating sites), qualitative and quantitative food availability, microclimatic conditions (e.g., temperature, moisture level), the identity and density of predators (e.g., lizards; Glos, 2004) and of competitors, or a combination of any of these factors might influence the presence and density of *A. laticeps* at a site. When transferring our model to other habitat types, therefore, these factors must be considered. For example, environmental characteristics of the breeding sites in the secondary (e.g., savanna) habitat that is surrounding Kirindy Forest do not in all cases satisfactorily explain the absence of *A. laticeps* from these waters (unpubl. data). In this case, the absence of *A. laticeps* tadpoles is more likely caused by the lack of suitable habitat for adults surrounding these ponds. This is certainly not the case for riverbed ponds as the river meanders through the closed forest without pronounced river banks, and therefore suitable adult frog habitat is nearby. However, there is a temporal incongruity between the formation of the riverbed ponds and the breeding phenology of *A. laticeps*. *A. laticeps* preferably spawns first in newly filled ponds, usually within the first two nights. However, when riverbed ponds are filled, *A. laticeps* is not yet active in breeding (Glos, 2003). Later on, the riverbed ponds are already populated by other tadpole species and therefore no longer the preferred breeding habitat for *A. laticeps*.

Aglyptodactylus laticeps – a suitable indicator species

Conservation activities often focus on species that represent the specialised fauna of a certain habitat. Such indicator species should have narrow ecological amplitudes with respect to one or more environmental factors and its presence can thus serve as an indicator for a particular environmental condition or set of conditions (Allaby, 1994). Our study shows that *A. laticeps* is qualified for this function in the Western Madagascan dry forest. Adults of *A. laticeps* occur exclusively in relatively little disturbed forest parts, and the presence of its tadpoles is an indicator of temporary aquatic habitats within this forest that are characterized by a low water permanency and high leaf litter coverage. Although the integrity of the terrestrial components of the dry forest might be equally well indicated by e.g., botanical variables, these are of only limited significance in respect its aquatic components. Therefore, the presence or absence of this species within its natural range indicates the relative degree of environmental integrity of this habitat as a whole (Wilson & McCranie, 2003).

CONCLUSIONS

The model presented in this study opens up the possibility to assess suitable habitat of *A. laticeps* as an indicator species and thus predict presence and absence of this species, by using only few, easy-to-obtain and easy-to measure variables. It demonstrates that models constructed from basic ecological knowledge of relevant species may serve as valuable management tools in applied conservation. With their aid, not only can recommendations be made as to which areas of an ecosystem conservation should focus on, but also inferences be made as to which direction a habitat should be improved, or advice may be derived on how to effectively restore an already impoverished habitat.

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RÉSUMÉ

*Modelage des habitudes d'habitat de l'*Aglyptodactylus laticeps *une grenouille des forêts sèches de l'ouest de Madagascar mise en danger.*

Un facteur crucial pour le succès de la reproduction et donc de la conservation de la majorité d'espèces d'amphibiens est la disponibilité d'eaux convenables comme site d'élevage. Nous avons examiné l'usage de sites d'élevage d'une grenouille locale endémique non menacée de l'ouest de Madagascar, *Aglyptodactylus laticeps*, pendant plus de trois ans. Une régression logistique est utilisée pour modeler la relation entre les types d'habitats d'élevage des espèces et des variables environnementales. Ce modèle a pour objectif d'être préventif, plutôt qu'explicatif, et seulement des variables environnementales y sont intégrées et évaluées en temps et en coût de manière effective, et peut donc être utilisé comme un instrument de gestion de conservation appliquée simple à utiliser. A l'échelle locale de la concession Kirindy, *A. laticeps* est limitée à la forêt avec un relativement bas degré de nuisance et un environnement couvert et fermé. Le modèle identifie trois variables environnementales qui suffisent à prédire de manière satisfaisante, l'utilisation de sites d'élevage respectifs. La plupart des sites d'élevage sont caractérisés par une litière de feuilles importante sur la surface des mares, pas de végétation de couverture, pas de plantes d'eau en surface, et peu d'eau stagnante. Fondées sur ces résultats, nous présentons des recommandations pour la conservation et la gestion de cette grenouille. De plus, la présence ou l'absence de cette espèce dans son milieu naturel indique le degré d'intégrité environnementale de son habitat, et nous considérons donc cette espèce comme un indicateur pertinent d'espèces aux habitats temporairement aquatiques dans la forêt sèche caractérisée par une faible permanence de l'eau et une litière de feuilles de couverture élevée. Cette étude démontre que les modèles qui ont été construits à partir de la connaissance de l'écologie élémentaire d'espèces pertinentes peuvent servir d'instrument de gestion précieux en conservation appliquée.

Mots clés : *Aglyptodactylus laticeps,* Amphibiens, Conservation, Madagascar.

Julian Glos*
K. Eduard Linsenmair
Department of Animal Ecology and Tropical Biology
Biocenter, Würzburg University
Am Hubland, 97074 Würzburg, Germany
* Present address:
Ecology and Conservation
Biocenter Grindel and Zoological Museum
University of Hamburg
Martin-Luther-King Platz 3
20146 Hamburg, Germany
Email julian.glos@zoologie.uni-hamburg.de

Kathrin H. Dausmann
Department of Ecology and Conservation
Biocenter Grindel and Zoological Museum
University of Hamburg
Martin Luther King-Platz 3
20146 Hamburg, Germany

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 143-196

Vincenzo MERCURIO[1], Gennaro APREA[2], Angelica CROTTINI[3 4 5],
Fabio MATTIOLI[6], Jasmin E. RANDRIANIRINA[7],
Tokihery J. RAZAFINDRABE[8], Franco ANDREONE[4 *]

The amphibians of Isalo Massif, southern-central Madagascar: high frog diversity in an apparently hostile dry habitat

ABSTRACT

We provide a list of the amphibians from the Isalo Massif, southern-central Madagascar, with data on their ecology and acoustics. Although this area is constituted by a xeric sandstone massif crossed by canyons and extended savannah-like grasslands, the number of discovered frog species turned out to be high (21). This is the highest number of amphibian species ever found at a western locality of Madagascar. The number of species known to be endemic from this area is at least five (*Mantella expectata*, *Gephyromantis azzurrae*, *G. corvus*, *Mantidactylus noralottae*, and *Scaphiophryne gottlebei*), with some other taxa (*Boophis occidentalis*, *B.* cf. *periegetes*, *Mantidactylus* sp. aff. *ulcerosus*), that are possibly Isalo-endemic too. This high endemicity level indicates the refuge effect played by the massif during repeated climatic changes, and the specialisation of these species to the peculiar canyon-habitat. Two sympatric species of *Gephyromantis* (*G. azzurrae* and *G. corvus*) evolved independently, likely for adaptation to two different aspects of the canyons (narrow or open). Part of the massif is currently managed as a national park, which is the most visited protected area of Madagascar. The remaining part of the massif is still unprotected and is threatened by the repeated fires and by the ongoing exploitation for sapphire mining. Two species, *Mantella expectata* and *Scaphiophryne gottlebei*, are captured for pet-trade, and considerations are provided regarding their conservation status.

Key words: Amphibians, Canyons, Conservation, Isalo, Madagascar.

1 Forschungsinstitut und Naturmuseum Senckenberg, Frankfurt a.M.
2 Università degli Studi, Napoli.
3 Dipartimento di Biologia, Università di Milano.
4 Museo Regionale di Scienze Naturali, Torino.
5 Technical University of Braunschweig.
6 Acquario di Genova, Genova.
7 Parc Botanique et Zoologique de Tsimbazaza, Antananarivo.
8 Département de Biologie Animale, Université d'Antananarivo.
* Corresponding author.

INTRODUCTION

The species distribution pattern in the amphibian fauna of Madagascar is influenced by the climatic diversity of the island and by the distribution of the major biomes. The discovery of centres of endemism and indications on species vicariance are crucial subjects to identify conservation priorities (Andreone, 2004). During the last years a series of field-surveys have been conducted in Madagascar aimed not only to unveil the distribution of most of the over 235 frog species, but also to identify new hotspots (Andreone et al., 2000, 2003). This is the case for the dry and xeric areas of Madagascar that, so far, have been not enough considered for protection actions. However, some dry areas resulted to host numerous endemic species even revealing surprises such as the discovery of the new subgenus, *Tsingymantis*, in the karst Ankarana region (Glaw & Vences, 2006).

One important biodiversity area is the Isalo Massif. Located in southern-central Madagascar and roughly north-south oriented, is one of the most visited protected areas. Here the landscape aspects are predominant but life history and biodiversity are attractions too. The massif frequentation increase in popularity after the description of two frog species: *Mantella expectata* and *Scaphiophryne gottlebei* (Busse & Böhme, 1994). Due to their attractive colours these frogs were immediately included in the international pet-trade becoming soon the "most wanted" species (Andreone et al., 2005). The importance of the massif grew with the description of a new mantelline species: *Gephyromantis corvus* (Glaw & Vences, 1994). Finally, after the discovery of two other new species during our conservation project (e.g., *Arovy ny sahona gasy*, see Andreone et al., 2005b): *Gephyromantis azzurrae* and *Mantidactylus noralottae* (Mercurio & Andreone, 2007) the number of endemic species from the Isalo rapidly increased.

This paper provides a list of the amphibians found in the Isalo Massif on the occasion of two surveys carried out in 2004. The species are presented in detail, with information on their life history and distribution. Colour photographs and data on their acoustic emissions are also included. In the frame of the workshop *"A Conservation Strategy for the Amphibians of Madagascar"* (ACSAM), the present contribution is hopefully useful in terms of conservation assessment representing an important tool for the protection of one of the most renowned areas of Madagascar.

MATERIALS & METHODS

Study area and habitat types

The Isalo Massif covers an area of about 81,540 ha and is one of the largest protected areas in Madagascar. It is situated between 22°10'–22°40'S and 45°11'–45°23'E in the southwestern corner of the Province of Fianarantsoa (Fianarantsoa Faritany) (Fig. 1). It is a sandstone massif characterised by the alternation of canyons, savannahs, and plateaux. The elevation varies between 510–1268 m with narrow canyons of up to 200 m of depth in particular in the eastern and northwestern sectors. The climate in the area is dry tropical, but some canyons are on the limit of the humid eastern and dry western biomes (White, 1986). Around 850–1200 mm of rain falls every year, with 90% precipitations between November and March; rainfall is higher in the sandstone massif than outside, due to the greater elevation. Many of the streams present in the massif running through the canyons are permanent, whereas there are several seasonal ponds and many seasonal rivers. Temperatures vary greatly between monthly means: 17° in June and 25° in February. The lowest temperature is 3° C and the highest 35° C (http://www.parcs-madagascar.com/isalo/climat.htm of 4th August 2007).

Landscapes and vegetation typologies are shown in (Figs. 2-3). Extensive areas of the massif are covered by bare rock or grass savannah, the latter being maintained by human actions through the centuries. Annual grassfires are set by the Bara ethny, to manage the savannah as grazing for zebu cattle. Grass savannah is interspersed with a mosaic of tree savannah, mostly composed of fire-resistant species. In open rocky areas, in particular on steep slopes or exposed ridges, vegetation is dwarf and xerophytic. Secondary forest formations grow in valley and along permanent watercourses. Along seasonal streams, mostly in the lower parts of the valleys, small relict patches of degraded western Malagasy deciduous forest occur. Part of the Massif is managed as a National Park, established in 1962.

Survey methods

Our field activity was carried out in two periods of 2004: (1) 15 January – 3 February (members of the team were FA, GA, JER, VM), (2) 10 November – 21 December 2004 (FA, FM, VM, TJR). Further visits were made by GA on 8–10 February 2003 and 20–23 January 2004. A few more observations and voucher specimens refer to a rapid visit by FA carried out in 1994.

Opportunistic search and refuge examination were conducted in all available habitats, mainly by night, with the aid of head-lamps and flashlights. Amphibians were active mostly overnight, when the temperature and humidity conditions were more suitable. Diurnal and secretive species were also sought in refuges during the day (e.g., under rocks and within canyons), or searching the tadpoles by hand-netting. Due to substrate hardness, pit-fall trapping usually used for rainforest survey (Raxworthy et al., 1998; Andreone et al., 2000), was not applied during the present study.

The following data were recorded at the time of capture or observation of each individual: (i) date, (ii) time, (iii) longitude and latitude (obtained by a GPS device), (iv) altitude, (v) microhabitat type, and (vi) capture circumstances. Individuals were photographed to document their colouration. A few specimens were captured and fixed in 10% buffered formalin or 90% ethanol, and later transferred into 70% ethanol. Collected material was deposited in the Museo Regionale di Scienze Naturali di Torino, Italy (MRSN),

	TOPONYM	COORDINATES		ELEVATION m a.s.l.	NUMBER OF VISITED SITES
		SOUTH	EAST		
1	Ambatovaky	23°24.18’	45°06.16’	240	1
2	Ambovo	22°30.48’	45°21.15’	1000	1
3	Amparambatomavo	22°18.11’	45°21.36’	880	1
4	Ampasibe	23°02.35’	45°16.57’	480	1
5	Andohaosy	22°31.00’	45°20.00’	930	1
6	Andohasahenina	22°50.00’	45°11.28’	620–700	5
7	Andozoky	22°29.00’	45°18.00’	920	1
8	Andranombilahy	22°48.51’	45°14.16’	710	1
9	Andranomena	22°44.41’	45°16.50’	780–820	2
10	Andriamanero	22°22.03’	45°23.52’	640	1
11	Antambonoa	22°22.31’	45°17.46’	710	3
12	Antoha	22°03.47’	45°23.51’	380	1
13	Bemenara	22°48.07’	45°15.00’	830–880	2
14	Bereketa	22°36.50’	45°09.47’	870	1
15	Bevato	22°30.36’	45°21.35’	970	1
16	Grotte des Portugais	22°18.06’	45°18.37’	560	1
17	Iambahatsy	22°24.35’	45°16.13’	690	2
18	Karofoty	22°07.42’	45°24.53’	510	1
19	Lola	22°55.54’	45°19.48’	630	2
20	Malaso	22°35.31’	45°21.32’	870–880	2
21	Marojana River	22°27.43’	45°22.40’	860	1
22	Morahariva	22°46.12’	45°18.42’	740	1
23	Namazaha Valley	22°32.20’	45°22.49’	765	1
24	Piscine Naturelle	22°33.58’	45°22.31’	920	1
25	Reine de l’Isalo	22°37.41’	45°20.38’	840–860	2
26	Sahanafa	22°18.35’	45°17.48’	500–570	2
27	Sakamalio	22°26.09’	45°15.31’	680–690	2
28	Sakavato	23°29.01’	44°56.09’	200–220	2
29	Tsianerena	22°52.38’	45°18.26’	710–740	2
30	Tsimanolabero	22°34.59’	45°23.00’	620	1
31	Tsiombivositra	22°18.15’	45°21.50’	830–900	3
32	Tsitorina	22°03.49’	45°21.37’	520	1
33	Vallée Petit Nazareth	22°33’25’	45°21’23’	880–890	2
34	Vohitanana	22°38.12’	45°20.46’	890	1
35	Zahavola	22°37.38’	45°21.52’	820–860	6
TOTAL					60

Tab. I. Toponyms, coordinates and altitude of the visited sites in the Isalo Massif. The names are given according to local people and must be considered as unofficial. In each major site further sites have been visited.

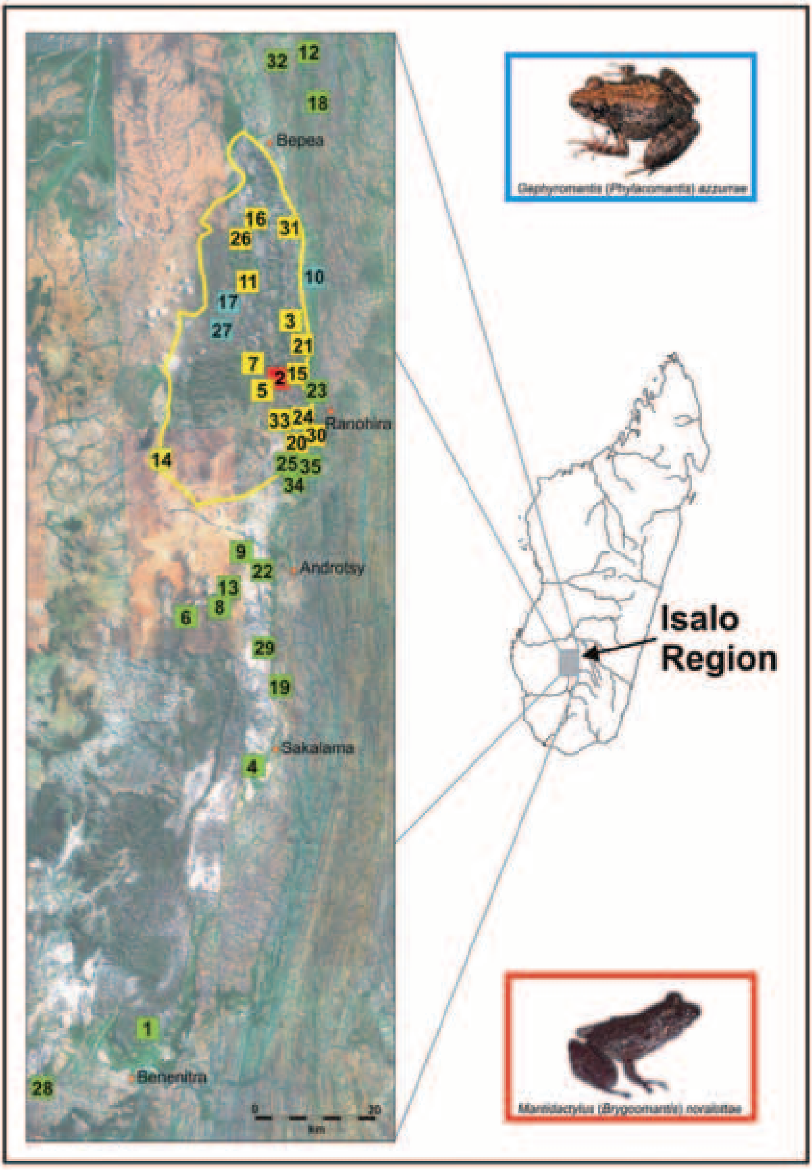

Fig. 1. The visited sites within the Isalo Massif, with reference to the national park borders. The numeration correspondence is given Tab. I. The localities placed within the National Park boundaries are in yellow, while those outside are marked in green. The two new frog species described after our activity are here reported, together with their known distribution. *Gephyromantis azzurrae* is illustrated in the upper right corner, and the localities where the species was found are given in light blue. *Mantidactylus noralottae* was found at only one site, here given in red.

Forschungsinstitut und Naturmuseum Senckenberg, Germany (SFM), and Parc Botanique et Zoologique de Tsimbazaza, Madagascar (PBZT-FAZC). Further material referring to Isalo from published data is housed in the University of Michigan, Museum of Zoology (UMMZ).

Museum numbers of voucher specimens are given at the beginning of each species paragraph, followed by the localities where they were captured. Basing upon the data collected by all the observations and trapping methods we drew the species accumulation curves (Andreone & Randriamahazo, 1997; Andreone & Randrianirina, 2000). Other acronyms have been reported as follows: (h), holotype; (pt), paratype; (e), eggs; (t), tadpoles; (nm), neometamorphosed; and (j), juveniles.

Taxonomy, bioacoustics, and DNA analysis

We used Glaw & Vences (1994) as the main literature source. The taxonomy follows Glaw & Vences (1994, 2006) and Frost et al. (2006). For taxonomic determination, the morphological approach alone was not always sufficient. For this reason we applied a combination of morphological, life history, bioacoustics, and genetical data.

With this approach it was possible, for most of the species, to reach a sufficiently clear taxonomic determination. In some cases several evidences suggest that the species may represent new taxa. Some of these taxa will be described in future. In these cases the acronym composition "sp. aff." is interposed between the genus and the species (e.g., *Mantidactylus* sp. aff. *ulcerosus*). In other cases, some uncertainty about the correct taxonomic attribution still exists. This is evident for species belonging to groups still under revisionary process, such as the *Mantidactylus*, subgenera *Ochthomantis* and *Hylobatrachus.* In such cases, we reported a preliminary determination, with the acronym "cf." between genus and species (e.g., *Mantidactylus* cf. *femoralis,* and *M.* cf. *lugubris*).

The advertisement calls of some species were recorded using a digital Sony TCD-D100 recorder accessorised with a semi-directional microphone. The sound analysis was carried out with the software Adobe AUDITION 1.5. All the vocalisations were edited with a sampling rate of 44.100 Hz and 16 bits per sample in the mono pattern and in "Waveform" (*.wav) extension. The software was set with the "Hamming" Windowing Function, 1024 bands Fast Fourier Transform (FFT), and a Plot Style of 80–90 dB.

Finally, a fingertip (or the tail tip in case of tadpoles) was cut from some individuals and stored in 90% ethanol. Total genomic DNA was extracted from the tissue samples using proteinase K digestion (10 mg/ml concentration) followed by a standard salt extraction protocol (Bruford et al., 1992). Following the protocol of Vences et al. (2000), we sequenced a fragment of ca. 540 bp of the 16S rDNA gene. PCR products were loaded on 1% agarose gels, stained with ethidium bromide, and visualised on a ''Gel Doc'' system (PeqLab). When results were satisfying, products were purified using QIAquick spin columns (Qiagen). The heavy mtDNA strands were

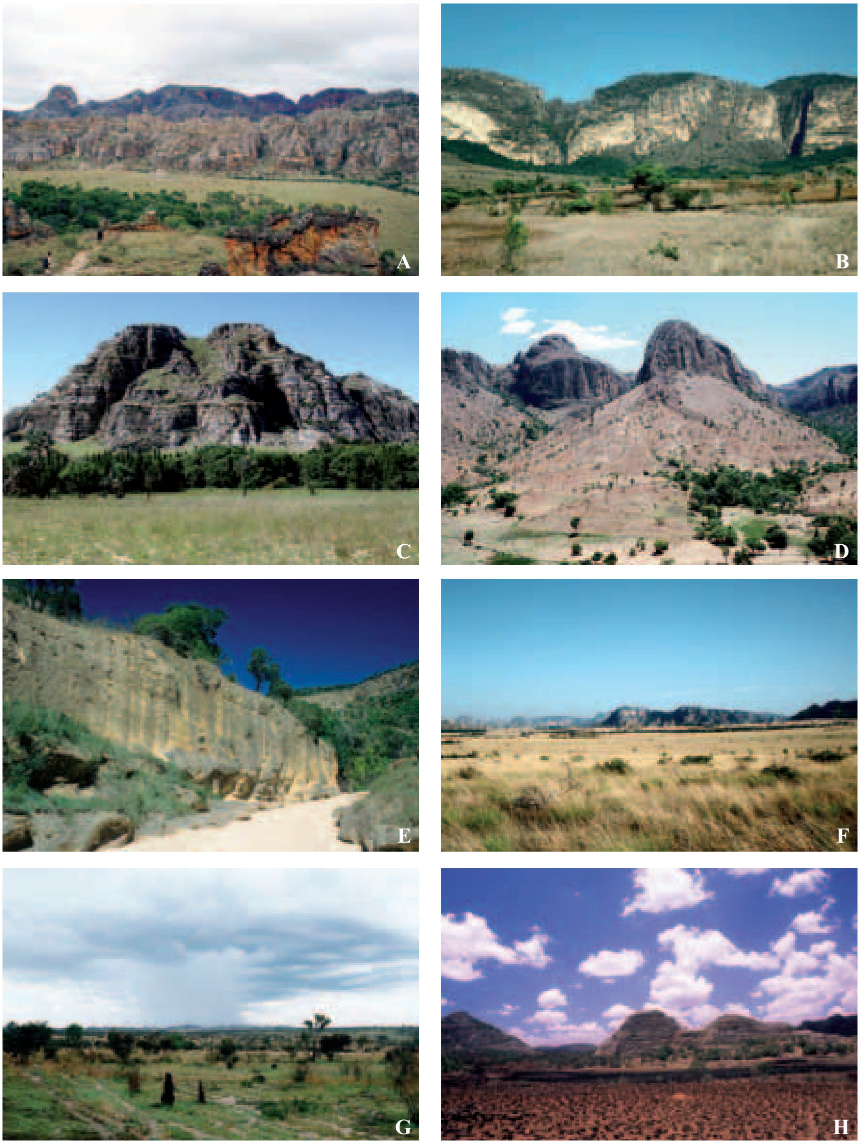

Fig. 2. Isalo landscapes: (A) the peculiar morphology of the Isalo Massif seen from the external surrounding savannah (Vallée du Petit Nazareth); (B) two most famous canyons of the Isalo Massif, the Canyon des makis (or C. des singes) and the Canyon des rats; (C) *Pandanus* forest along a permanent river at Andohasahenina; (D) the open valley and degraded slopes at Andriamanero; (E) temporary river at Bemenara; (F) the savannah landscape near Zahavola; (G) landscape around Ilakaka, with a localised storm; (H) post-fire savannah habitat near Sevalava.

Fig. 3. Isalo habitats and vegetations: (A) small stream crossing the Canyon des rats; (B) Namazaha Forest; (C) *Pandanus* swamp at Andohasahenina; (D) Sakamalio Forest along the Sakamalio River; (E) dry forest near Antoha; (F) the large permanent river "Menamaty" (Andriamanero); (G) spiny shrub forest at the southern part of the massif near Benenitra; (H) temporary pond at Lola, typical habitat of many explosive breeders, such as *Dyscophus insularis* and *Scaphiophryne brevis*.

sequenced using an ABI 3730XL automated sequencer at Macrogen Inc. Sequences were manually edited and unanbiguously aligned using the BioEdit sequence alignment editor (version 7.0.5, Hall, 1999). The alignment required inclusion of gaps to account for indels in some hypervariable regions. Data analysis was carried out with PAUP, version 4b10 (Swofford, 2002). Most of the sequences are not yet deposited in Genbank and will be object of a further publication.

Biogeographic analysis

The Isalo batrachofauna was compared with other sites: two southern rainforests: Andringitra and Andohahela (data from Andreone, 1994; Glaw & Vences, 1994; Andreone & Randriamahazo, 1997; Raxworthy & Nussbaum, 1996a; Nussbaum et al., 1999); two dry forests: Kirindy and Ampijoroa (data from Glos, 2003; Mori et al., 2006), and a dry transitional Sambirano forest: Berara (data from Andreone et al., 2001). The species inventories were checked for current nomenclature consistence and completeness with further data coming from additional publications. No claim of completeness and taxonomic certainty is intended.

The comparison of the beta diversity has been done by means of the "coefficient of biogeographic resemblance" (CBR) (Herrmann et al., 2005) as follows: CBR = 2C / (N_1 + N_2). In this formula, C is the number of the shared species of the two compared areas, and N_1 and N_2 represent respectively the number of species of the single studied area. In two sites without shared species CBR = 0, while two sites with exactly the same species inventory have CBR = 1. The use of this index allows, through the direct comparison of the shared species, a simple evaluation of the uniqueness of the species composition.

RESULTS

A detailed list of all visited sites is provided in Tab. I, while the species list is given in Tab. II. Families are sorted according to Glaw & Vences (2006), while lower taxa (subfamilies, genera, species, and subspecies) are reported alphabetically. The species discovery accumulation curve is given in Fig. 4.

During our surveys we found 20 amphibian species, while one species (*Scaphiophryne menabensis*) was known upon bibliography and voucher specimens. Five of these species turned out to be Isalo endemics: *Scaphiophryne gottlebei*, *Mantella expectata*, *Gephyromantis corvus*, *G. azzurrae*, and *Mantidactylus noralottae* (Mercurio & Andreone, 2007), while three are new records (*Mantella betsileo, Dyscophus insularis* and *Scaphiophryne calcarata*). The taxonomic status of other species inhabiting the Isalo Massif needs to be clarified (*Boophis occidentalis*, *Boophis* cf. *periegetes*, and *M.* sp. aff. *ulcerosus*), and may reserve important novelties in terms of endemicity.

Three main habitat types have been recognised for the Isalo Massif: (1)

	Species	HABITATS			RAINFORESTS		DRY AND TRANSITIONAL FORESTS		
		Temporary water bodies	Permanent water bodies	Canyon	Andringitra	Andohahela	Kirindy	Ampijoroa	Berara
1	*Heterixalus luteostriatus*	+			-	-	+	-	+
2	*Ptychadena mascareniensis*	+	+		+	+	+	+	+
3	*Laliostoma labrosum*	+			-	-	+	+	+
4	*Boophis luteus*		+		+	+	-	-	-
5	*Boophis occidentalis**		+		-	-	-	-	+
6	*Boophis* cf. *periegetes**			+	+	-	-	-	-
7	*Boophis doulioti*	+		+	-	-	+	+	+
8	*Blommersia* sp. aff. *wittei*		+		-	-	+	+	-
9	*Mantella betsileo*	+	+		+	-	+	-	+
10	*Mantella expectata**	+		+	-	-	-	-	-
11	*Mantidactylus* sp. aff. *ulcerosus**		+		-	-	-	-	-
12	*Mantidactylus* cf. *femoralis*			+	+	+	-	-	-
13	*Mantidactylus* cf. *lugubris*			+	+	+	-	-	-
14	*Mantidactylus noralottae**			+	-	-	-	-	-
15	*Gephyromantis azzurrae**			+	-	-	-	-	-
16	*Gephyromantis corvus**			+	-	-	-	-	-
17	*Dyscophus insularis*	+			-	-	+	+	-
18	*Scaphiophryne brevis*	+			-	-	+	-	-
19	*Scaphiophryne calcarata*	+			-	-	+	+	-
20	*Scaphiophryne gottlebei**			+	-	-	-	-	-
21	*Scaphiophryne menabensis*	+			-	-	+	-	-
	Total number of species				79	53	15	7	14
	Number of shared species				6	4	10	6	5
	CBR				0.12	0.11	0.55	0.43	0.29

Table II. Amphibians of Isalo Massif quoted in literature and confirmed by this survey listed with the amphibian fauna of five areas of Madagascar and their relationships based on the Coefficient of Biogeographic Resemblance (CBR). Taxa marked with an asterisk (*) are considered as Isalo endemics.

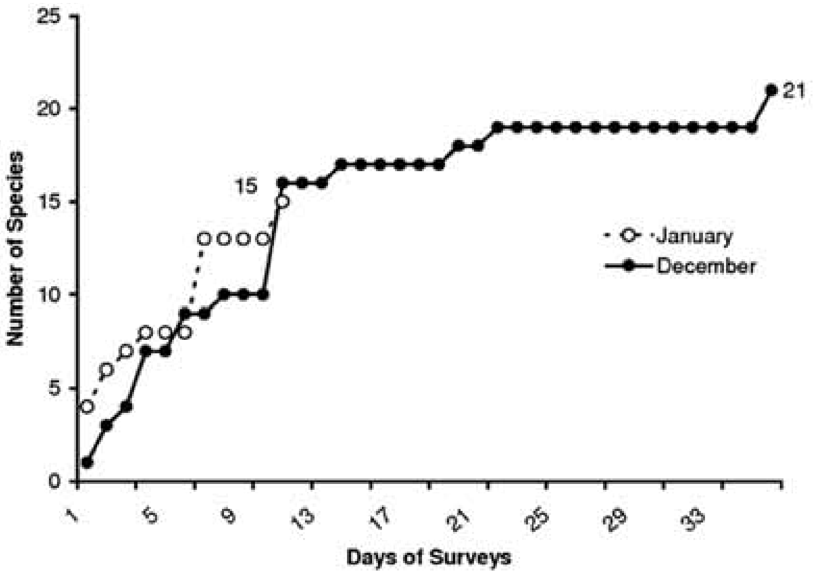

Fig. 4. Amphibian species accumulation curves at the Isalo Massif during the survey work conducted in January and November-December 2004.

savannahs, (2) open valleys, and (3) narrow canyons (Mercurio & Andreone, 2006).

(1) The savannahs are subject to repeated fires and are covered by extensive meadows, with scattered trees and isolated forest parcels. The night-day temperature range is high, and the humidity is usually very low. Aquatic habitats are represented by temporary pools, often used for cattle. The temporary rivers are filled by seasonal rains, and are dry for most of the year. A few permanent or semi-permanent rivers are present and may be accompanied by gallery forests. In this habitat we found species which breed in temporary waters (e.g., *Boophis occidentalis*, *Laliostoma labrosum*, *Ptychadena mascareniensis*, *Scaphiophryne brevis*, and *Dyscophus insularis*).

(2) The open valleys are usually crossed by permanent or semi-permanent torrents with quite wide water beds, cascades and pools, and gallery forests of various sizes. We found frog species that usually need permanent water to breed, such as *Gephyromantis azzurrae*, *Mantidactylus* cf. *femoralis*, *M*. sp. aff. *ulcerosus*, *Boophis* cf. *periegetes*, and *B. occidentalis*.

(3) The rocky and montane part is crossed by canyons of various lenght, width and depth and with variable water presence. Some canyons are very narrow with a sandy bed delimited by vertical rocky walls. The habitat is dark and sometimes similar to a cave, with a low and constant temperature

(19–22°C) and high humidity (about 100%). Within these narrow canyons, vegetation is absent (due to scarcity of light) or limited to a few isolated trees. Typical species of this habitat are *Scaphiophryne gottlebei*, *Mantidactylus corvus*, and *M. noralottae*.

COMMENTED LIST
Family Hyperoliidae

Heterixalus luteostriatus (Andersson, 1910)

Voucher specimens: MRSN A5017, A5018. **Locality records**: Canyon des Makis, Vohimaro, Ranohira (Glaw & Vences, 1994).

This frog is typical of the western slope inhabiting moist vegetation areas, swamps, as well as anthropogenetic habitats in dry environments. Curiously, *H. luteostriatus* (Fig. 5), abundant in other regions (Glos, 2003), seems to be very rare within the Isalo Massif. Of the overall 60 surveyed sites, we had the occasion to find two specimens in two sites, one in secondary savannah and the other one outside the Canyon des Makis, in a sun-exposed spot. This apparent rarity could be explained by: a) the scarceness throughout the massif of semi-permanent standing waters; b) the unpredictable rainfall regime that characterizes the massif causing strong population oscillations during dry periods.

Family Ptychadenidae

Ptychadena mascareniensis (Duméril & Bibron, 1841)

Voucher specimens: MRSN A2719, A2720, A2721, A3127, A3128, A5402, A5403, A5404, A5405, A5406, A5407 (j), A5408, A5409, A5410, A5411, A5412, A5413, A5850 (t), A5853 (nm), A5883 (t), A763. **Locality records**: Iambahatsy, Ambovobe, Andohasahenina, Andranomena, Andriamanero, Ilakaka, Moraharivа, Oasis, Ranohira (Glaw & Vences, 1994), Reine de l'Isalo, Sahanafa, Sevalava, Vallée du petit Nazareth, Zahavola.

This species is widely distributed in Madagascar, where it mainly inhabits open habitats and only penetrates within narrow forests. It is able to adapt to unpredictable environments, such as ricefields and small ponds. So far, it was thought to be a non-endemic, but studies by Vences et al. (2004) suggest a possible differentiation of Malagasy populations. Within the Isalo Massif *P. mascarensis* appears to be more abundant in open sunny space with permanent water and becomes sporadic in closed habitats (Fig. 6). This observation is in agreement with what is known for this species (Glaw & Vences, 1994; Glos, 2003).

Fig. 5. *Heterixalus luteostriatus.* Adult from Vohimaro.

Fig. 6. *Ptychadena mascareniensis*. Mating pair from Zahavola.

Fig. 7. *Boophis doulioti.* Adult from Zahavola.

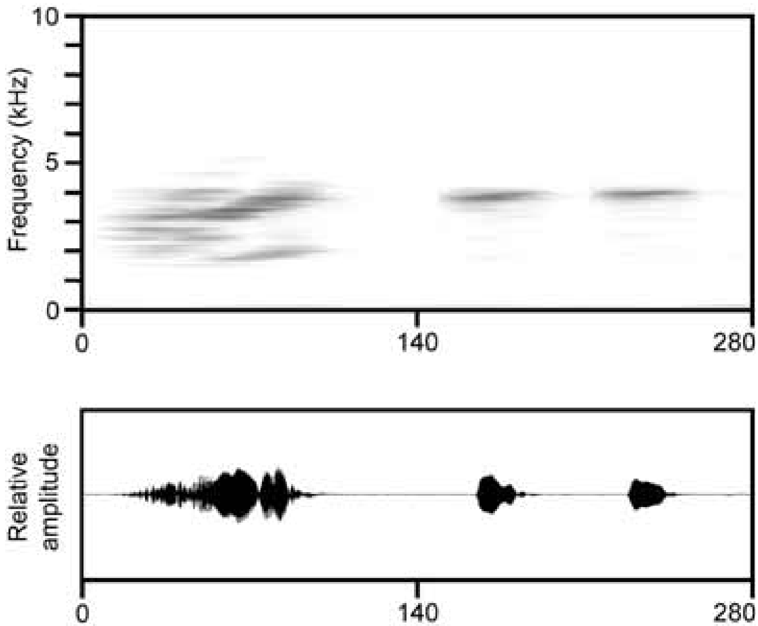

Fig. 8. *Boophis doulioti.* Sonogram (above) and oscillogram (below) of the advertisement call. Recorded at Zahavola, 18th November 2004 (19:15, 20° C). The call consists in the repetition of harmonic notes (note A, left) with the interposition of trilled notes (note B, right). Time scale: milliseconds.

Family Mantellidae
Subfamily Boophinae

Boophis (*Sahona*) *doulioti* (Angel, 1934)

Voucher specimens: MRSN A767, A2981, A2982, A4999, A5003, A6033, A6035-A6038. **Locality records**: Iambahatsy, Andohasahenina, Andranomena, Canyon des Makis, Mandarano, Marojana River, Namazaha Valley, Ranohira (Glaw & Vences, 1994), Vohimaro, Zahavola.

This fairly common frog from the dry areas of western Madagascar was considered until recently as *Boophis tephraeomystax* (Glaw & Vences, 1994). According to biomolecular and chromosome data, the western populations, Isalo included, were newly ascribed to the resurrected species *B. doulioti* (Vences & Glaw, 2002). This represents a good case of east-west vicariant species for the distribution pattern of Malagasy amphibians. At Isalo, this species is present in many available habitats, from *Pandanus* swamps inside savannah to river beds with permanent water in gallery forest disclosing itself as a truly generalist (Fig. 7). The advertisement call recorded at Zahavola on 18 November (19:15, temperature 20° C) consists of two different notes continuously repeated with a rather distinct pattern (Fig. 8). The call consists in the repetition of one harmonic note (note A) with the interposition of trilled notes (note B). Apparently, as the motivation of the male increases, the number of B notes increases. As described by Glaw and Vences (1994) the A note resembles the yelping of a young dog. In the populations living on the Isalo Massif these notes are arranged in groups of two or three in decreasing amplitude, often followed by two-six B notes (3.5 ± 1.5, N = 6). Duration of note A is comprised between 45-74 ms (60.8 ± 8.2, N = 16). Intervals between notes are between 116-365 ms (202 ± 66.5, N = 15) while between groups of A notes there are 620-1800 ms (1130 ± 378, N = 8). B notes are trills of a duration of 11-29 ms (22.2 ± 5.4, N = 15) repeated an intervals of 39-86 ms (47.7 ± 11.9, N = 15). The frequency range of A notes is between 1500 and 4500 Hz with two recognisable frequency bands. The first is 1700-2000 Hz and corresponds to the fundamental frequency; while the second is between 3200-4500 with a dominant frequency of 1800 Hz. The frequency range of B notes is between 3500-4000 Hz with a dominant frequency of 3800 Hz.

Boophis (*Boophis*) *luteus* (Boulenger, 1882)

Voucher specimens: MRSN A2827, A2828, A2829. **Locality records**: Namazaha Valley.

This typical rainforest species was firstly reported for the Isalo Massif by Raxworthy & Nussbaum (1996). Despite our extensive survey work, we found *B. luteus* only in one locality (Namazaha) where it was detected by means of male's vocalisations (Fig. 9). Most likely, the presence of this species has been

Fig. 9. *Boophis luteus*. Adult from Namazaha.

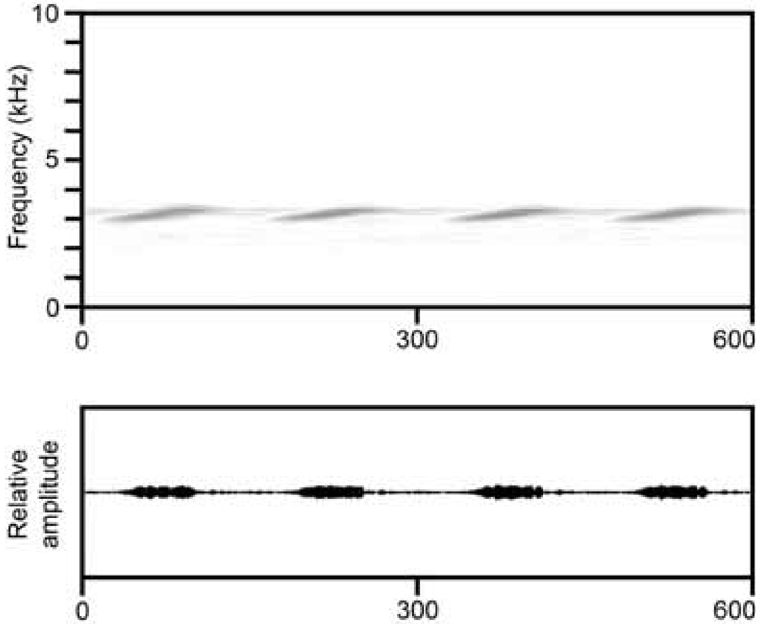

Fig. 10. *Boophis luteus*. Sonogram (above) and oscillogram (below) of the advertisement call. Recorded at Namazaha, 9th December (20:00, about 24° C). Time scale: milliseconds.

overlooked in other possible suitable habitats (e.g. Andriamanero, Canyon des rats, Sakamalio). Its presence is known for the open canyons with dense evergreen gallery vegetation along permanent streams, where male specimens are calling from the canopy. The advertisement call recorded at Namazaha on 19 December (20:00, about 24°C) consists in the regular repetition of one single whistling note (Fig. 10). The call lasts about 30 sec (N = 2) with about 170 notes per call. Note duration is between 79-95 ms (88.4 ± 4.0, N = 15). Interval between notes is 62-78 ms (69.7 ± 5.8, N = 15). Note repetition rate is about 6.8/s. Frequency range is between 2800-3500 with a dominant frequency of 3100-3300 Hz. This call is in accordance with those reported by Glaw & Vences (1994) from Andasibe and Tolagnaro.

Boophis (*Boophis*) cf. *periegetes* Cadle, 1995

Voucher specimens: MRSN A2779-A2782, A2853-A2858, A4104, A5387-A5391. **Locality records**: Iambahatsy, Andran'ombilahy, Andriamanero, Ankademoky, Canyon des Makis, Canyon des Rats, Andohasahenina, Marojana River, Namazaha Valley, Vallée du petit Nazareth.

A brownish ground-dwelling frog found in several sites. Seen its overall morphology, and the absence of evident elbow and heel flaps, it was preliminarily attributed to *B. goudoti* (Glaw & Vences, 1994, 2007; Mercurio & Andreone, 2007). On the basis of biomolecular data obtained by one of us (A. Crottini, unpubl.), it seems that this species is closely related to *B. periegetes*, thus representing a new taxonomic entity, likely endemic of the massif. All the individuals we found lacked the spiny dorsal skin features typical of *B. periegetes* (Fig. 11). We ignore if this is due to a real difference between the populations, or to the fact that the individuals, we collected were not in the breeding period, when the horny spiculae are known to develop (Cadle, 1995). We usually found specimens within canyons, in areas characterised by high humidity rate, comparatively low temperature and absence of direct sunlight.

Boophis (*Boophis*) *occidentalis* Glaw & Vences, 1994

Voucher specimens: MRSN A754, A2706-A2712, A2884, A4998 (t), A5000 (j), A5002 (j), A5004 (j), A5006 (j), A5320, A5321 (nm), A5847 (t), A5869 (t). **Locality records**: Iambahatsy, Andriamanero, Canyon des Makis, Namazaha Valley.

Formerly considered as a subspecies of *Boophis albilabris* (Glaw & Vences, 1994) it was raised to full species rank upon morphological and bioacoustics characters of a population from the Sahamalaza Peninsula (Andreone et al., 2001). Although some populations of the western coast (e.g., Berara, Tsingy de Bemaraha) were ascribed to *B. occidentalis* some of them are possibly

Fig. 11. *Boophis* cf. *periegetes.* Adult from Canyon des Makis.

Fig. 12. *Boophis occidentalis*. Adult from Canyon des Makis (A), and tadpole from Andriamanero (B).

belonging to different species on the basis of differences observed in call structure and biomolecular information (M. Vences, pers. comm.). Taking into consideration that the Isalo Massif is the *terra typica* of this species (Namazaha Valley; Andreone, 1993; Glaw & Vences, 1994), if this preliminary consideration will be confirmed by further research, *B. occidentalis* will become another Isalo endemic, and the other populations should be ascribed to a different species. At Isalo *Boophis occidentalis* appears to be largely arboreal and associated with the gallery forest along streams where permanent water is usually available. Curiously, one individual collected in May 1994 in the Canyon des Makis (MRSN A754) was found during a heavy storm after jumping from a tree (Fig. 12A). Tadpoles were observed inside slow moving permanent rivers (Fig. 12B). An interesting life history trait is the remarkable size at metamorphosis representing 47-60% of the adult SVL, most likely an adaptation to the arid environments of the Isalo Massif (Andreone et al. 2007).

Subfamily Laliostominae

Laliostoma labrosum (Cope, 1868)

Voucher specimens: MRSN A2760, A2761, A5336-A5343, A5344 (nm), A5345 (nm), A5346, A5856 (t), A5858 (t), A5870 (e), A5879 (t), A5880 (t), A5884 (t). **Locality records**: Iambahatsy, Andohasahenina, Andranomena, Bemenara, Lola, Namazaha, Oasis, Ranohira (Glaw & Vences, 1994), Sakavato, Sevalava, Zahavola.

Laliostoma labrosum is widely distributed in the western regions of Madagascar (Glaw & Vences, 1994), and it is found throughout the Isalo Massif in a variety of habitats (Fig. 13A). Single specimens were found in open spaces prevalently during the night, even far away from water bodies. Two populations were found in ephemeral ponds in a sunlight-exposed area in the savannah, with several males calling in chorus, once together with *Scaphiophryne brevis*. The males were calling from the edges of the pool, while some other specimens were floating in the water. Tadpoles were found at Lola in a relatively large depression (around 20 m in diameter) in full sun-exposed savannah. Tadpoles move at mid water level, cohabiting with *Dyscophus insularis* tadpoles (Fig. 13B). The call from the Isalo populations (21:00, 23 November, Reine de l'Isalo, about 23°C) consists in the regular repetition of a series of unharmonius notes (Fig. 14). The call duration is variable from 747 to 5300 ms (1980 ± 1200, N = 11). Notes per call are 11-64 (25.7 ± 14, N = 11) lasting 40-46 ms (41 ± 1.6, N = 15). Intervals between notes are 32-50 ms (38.5 ± 4.6, N = 15). Note repetition rate was 12/sec. The frequency ranges from 700-4500 Hz, with a dominant frequency of 2100 Hz. Calls from the Isalo populations are similar to what reported by Glaw & Vences (1994) for other populations.

Fig. 13. *Laliostoma labrosum.* Mating pair (A), and tadpole (B) from Reine de l'Isalo.

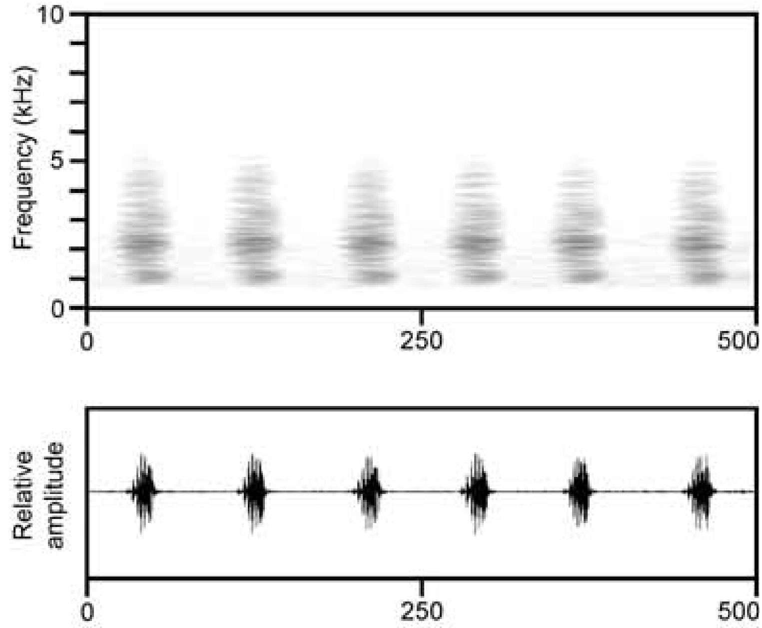

Fig. 14. *Laliostoma labrosum.* Sonogram (above) and oscillogram (below) of the advertisement call. Recorded at Reine de l'Isalo on 22th November (20:45, 23° C). Time scale: milliseconds.

Subfamily Mantellinae

Blommersia sp. aff. *wittei* (Guibé, 1974)

Voucher specimens: A2957-A2958, A5252-A5273, A5348-A5351, A5353-A5360, A5855 (e), A5864 (e), A5867 (e). **Locality records**: Andohasahenina, Andriamanero, Ranohira (Glaw & Vences, 1994), Sakamalio, Zahavola.

The taxonomic status of this small-sized and complex group is rather confusing, with the possible existence of several different sibling species. On the basis of biomolecular data, the populations living in the Isalo Massif appear to be genetically differentiated from those of the eastern slope and may be a different entity sharing similarities with the populations of Bemaraha (M. Vences & A. Crottini, unpubl. data). Their phylogenetic and biogeographic relationships will be clarified in the near future. We found individuals in temporary rivers and *Pandanus* swamps in the open savannah (e.g., Ilakaka, Zahavola) and inside well-developed gallery forests (e.g., Andriamanero,

Fig. 15. *Blommersia* sp. aff. *wittei.* Adult (A) in egg-guarding behaviour, and eggs (B) from Sakamalio.

Sakamalio) (Fig. 15A). Observations on the reproduction and egg-guarding behaviour (Fig. 15B) for these populations are in agreement with what is reported by Glaw & Vences, (1994).

The Isalo populations differ from the other "*wittei*" on some bioacoustics characters. Even though some differences between populations are noticeable, the calls of the northern populations generally consist of up to 25 unharmonious notes of a duration of about 28-46 ms. The notes are repeated at intervals of about 30-80 ms with a dominant frequency comprised between 4.5-6.0 kHz (Glaw & Vences, 1994). Calls from Isalo differ in having 2-4 metallic opening notes "*tsk-tsk*" followed by the usual above described call (Fig. 16). The opening notes lasted 77-182 ms (130.5 ± 42.4, N = 12) repeated at intervals of 630-1100 ms (832 ± 160.3, N = 11). These are followed by 14-22 notes (19.3 ± 3.6, N = 4) of 55-100 ms (65.5 ± 14.1, N = 12) repeated after quite regular intervals of 43-64 ms (54.2 ± 6.7, N = 12). Note repetition rate was 9/sec. The frequency of opening notes range from 2000 to 6000 Hz with a dominant frequency of 2500-2900 Hz. In the other notes two distinct frequency bands are recognisable: one between 2400-2800 and the other one between 5000-5700 Hz with a dominant frequency of about 2700 Hz. On the basis of the available information calls from northern and southern populations differ by: a) the presence of metallic opening notes; b) a longer note duration (65.5 ms vs 46.2 and 28, respectively Nosy Be and Sambava; Glaw & Vences, 1994). In addition, the dominant frequency seems to be lower than that of the northern populations (2.7-2.9 vs 6.0-6-5 KHz) and than that reported by Glaw and Vences (1994) from Ranohira (6.5 kHz). However, in our recordings dominant frequencies were difficult to detect in the spectrogram because of the equal repartition of energy in the note.

Mantella betsileo (Grandidier, 1872)

Voucher specimens: MRSN A5225-A5239. **Locality records**: Andriamanero, Antoha, Bereketa, Karofoty, Sahanafa, Sakavato, Tsianerena, Tsitorina.

This mantella was recorded for the first time inside the Isalo Massif by Andreone et al. (2005b). Of the about 60 visited sites, its presence was confirmed in seven sites (Fig. 17). In three sites (Sahanafa, Tsianerena, and Sakavato) *M. betsileo* was living in syntopy with *M. expectata*. Notably at Sahanafa and Tsianerena the individuals ascribed to *M. betsileo* on the basis of biomolecular data (MRSN 5211, PBZT-FAZC 12880, and PBZT-FAZC 12879) do not show any relevant colouration difference from the other syntopic individuals ascribed to *M. expectata*, thus resulting indistinguishable on the basis of the external morphology (Crottini et al., in press). On the contrary, at Sakavato, on the extreme South of the massif, near the Benenitra village, we found *M. expectata* (MRSN A5204) and *M. betsileo* (PBZT-FAZC 12825) together with the presence of possible hybrids (MRSN A5222, A5230). These

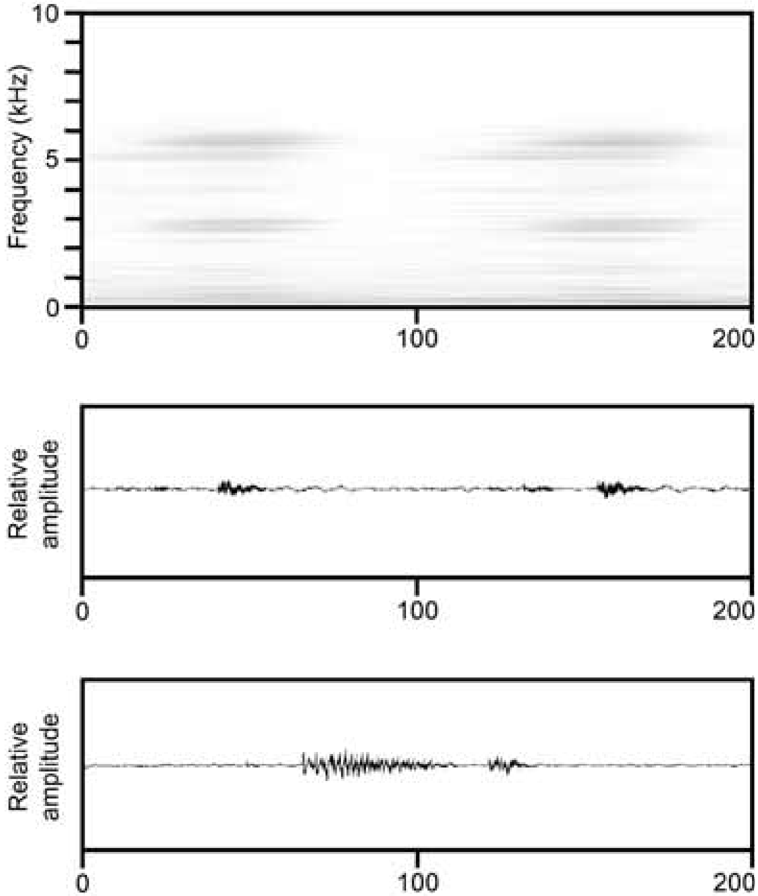

Fig. 16. *Blommersia* sp. aff. *wittei.* Sonogram (top) and oscillograms (centre, bottom) of the advertisement call. Recorded at Sakamalio on 16 December (21:15, 20°C). Time scale: milliseconds.

putative hybrids were characterised by a lighter brown-yellowish dorsal colouration, bluish legs and by the presence of faintly diamond-shaped markings on the dorsum. However, for the individuals looking intermediate, determination by means of colouration alone is difficult. *Mantella betsileo* with typical colouration has been found only at Andriamanero and Tsitorina, although they always lacked the continuous frenal stripe typical of the species, elsewhere given as diagnostic (Jovanovic et al., 2007). In the Isalo Massif preferred habitats are represented by small temporary streams, often in sun-exposed open savannah, and canyons with widespread vegetation and permanent large streams, slightly

Fig. 17. *Mantella betsileo.* Adult from Andriamanero in dorsal (A) and ventral view (B).

differing from those of *M. expectata*, which prefers much more ephemeral and temporary habitats (Fig. 18). Tadpoles ascribable to *M. betsileo* were found at Antoha, in a full sun-exposed small hole in a rocky streambed. The small pond measured 450 mm diameter and around 30 mm deep.

Mantella expectata Busse & Böhme, 1992

Voucher specimens: A3080-3086, A3089-3091, A3228 (j), A3432-3435 (t), A4695 (j), A5053, A5142-5144, A5204, A5222 (*M. betsileo* x *M. expectata* hybrid), A5230 (*M. betsileo* x *M. expectata* hybrid). **Locality records**: Iambahatsy, Ambatovaky, Ambovo, Amparambatomavo, Ampasibe, Andohasahenina, Andozoky, Antambonoa, Bemenara, Bereketa, Grotte des Portugais, Lola, Moraharivа, Malaso, Petit Nazareth, Reine de l'Isalo, Sahanafa, Sakamalio, Sakavato, Tsimanolabero, Tsianerena, Tsiombivositra, Vohitanana, Zahavola.

Mantella expectata was formerly known only from four sites (Vences et al., 1999): 1) 20 km SE of Toliara; 2) the area around Morondava (based on a picture made by a German development aid worker and published by Meier, 1986); 3) the Isalo Massif; and 4) Mandena in south-eastern Madagascar, as given by Glaw & Vences (1994). This attractive frog was together with *Scaphiophryne gottlebei*, actively searched for the international pet-trade (Andreone & Luiselli, 2003). As stressed by Vences et al. (1999) the findings at

Fig. 18. *Mantella betsileo*. Breeding pool at Antoha.

Fig. 19. *Mantella expectata* and *M. expectata* X *M. betsileo* hybrid. (A-B) *Mantella expectata,* “normal morph” from Zahavola; (C) *Mantella expectata,* “red morph” from Tsiombivositra; (D) *Mantella expectata,* “red morph” from Antambonoa; (E-F) *M. expectata* X *M. betsileo,* putative hybrid from Sakavato.

1, 2, and 4 are probably erroneous. In fact, type individuals shown by Busse & Bohme (1992), and said to come from ”20 km SE of Toliara” show the characteristic yellow and blue pattern that turned out to be found only in the populations living on the central-western part of the Isalo Massif. The Morondava record was based on an individual with brown-orange dorsum and light limbs (Meier, 1986, fig. 8). As discussed by Rabemananjara et al. (2007a), the systematics of the *betsileo* group is quite complex, with the presence of at least one undescribed species from western and south-western Madagascar, and named by them *Mantella* aff. *expectata* (and *Mantella* ”desert” by Staniszewski, 2001). The findings from Morondava, Toliara and even Mandena, could be referred to this species.

The individuals of *M. expectata* found during our survey showed different chromatic aspects. In particular, the typical yellow-blue colouration appeared to be mainly restricted to individuals coming from the central-western part of the massif (e.g., Andohasahenina, Zahavola), whereas individuals from the northern part of the massif (e.g. Tsiombivositra) presented a bicoloured dorsal yellow-red colouration, sometimes very clearly cut by a straight horizontal line behind the eyes (Fig. 19 C). Tadpoles of *M. expectata* are morphologically similar to those of other mantellas of the *M. betsileo* group, with a total length at Gosner 37 of 29 mm. After a development period of about 1-2 months the froglets measure about 10 mm respectively, showing the adult colouration pattern (Mercurio & Andreone, 2006) (Fig. 19). *Mantella expectata* is well adapted to the temporary sites, colonising savannah and sub-desertic as well as humid areas (Figs. 20 C-D). The preferred habitats are represented by small pools inside the rocky canyons and temporary streams in sun-exposed savannah.

We were not able to find the species inside the open valleys, such as “Canyon des Makis” and “Canyon des Rats”. It seems likely that canyons with widespread vegetation and large streams, are not a suitable habitat for *M. expectata*. The call consists of an almost endless series of notes (Fig. 21). As for other *Mantella* species the well identifiable carrier is composed by two very short clicks (Glaw & Vences, 1994). Each note consists of the regular repetition of the carrier. Based on our recordings in each single note the carrier is repeated once or twice with up to six clicks per note (5.0 ± 1.0, N = 21). The number of clicks per note seems to be related with the different motivation of the males with more excited males producing more clicks. The note duration is 100-180 ms (140 ± 31.4, N = 21). Duration of the carriers are 40-55 ms (44.9 ± 4.7, N = 12) with intervals between them of 10-35 ms (18.3 ± 7.8, N = 13). Duration of the first click is 8-14 ms (11.3 ± 1.7, N = 12), while duration of the second one is 18-25 (22.4 ± 2.4, N = 12). Intervals between clicks are 4-20 ms (7.8 ± 4.6, N = 12). The note repetition rate was between 1.0 and 1.5/sec. The frequency ranges between 3500-5000 Hz. The dominant frequency is 3800-3900 Hz. On one occasion (21:30, 24 November, Reine de l’Isalo, about 23°C) we noticed a small group of individuals calling during the night. This is in agreement with other nocturnal vocalisations witnessed for another species, *Mantella nigricans* (Andreone, 2002). Call parameters were similar to those above mentioned.

Fig. 20. *Mantella expectata.* (A) egg clutch at Malaso; (B) tadpole; (C) habitats near Ilakaka Be and (D) Andranomena.

Mantella expectata is classified as "critically endangered", based upon its small distribution and affecting threats, such as pet-trade and habitat alteration (IUCN, 2008). On the other hand, our observations indicate that this species is widely distributed within the massif, from north to south: of the about 60 visited sites, 40 were confirmed by the presence of *M. expectata*. Some of the visited populations appeared rich in terms of individuals. For all these reasons we believe that this species, although interested by collecting for pet-trade (Rabemananjara et al. 2007a, b), is less threatened than other *Mantella* species (especially those from rainforests). Other threats impending on the arid and rocky habitats are the periodical fires that interest the savannah managed for grazing. However, on two fire occasions we noticed that the expected mantellas are able to hide in underground refuges and immediately recover when the fire has extinguished. Therefore, this species seems to be well adapted to the habitat degradation and to recurrent fires. Despite its restricted distribution, once clarified if the populations with a different phenotype have to be considered as different management units, it does not seem that *M. expectata* is in imminent danger.

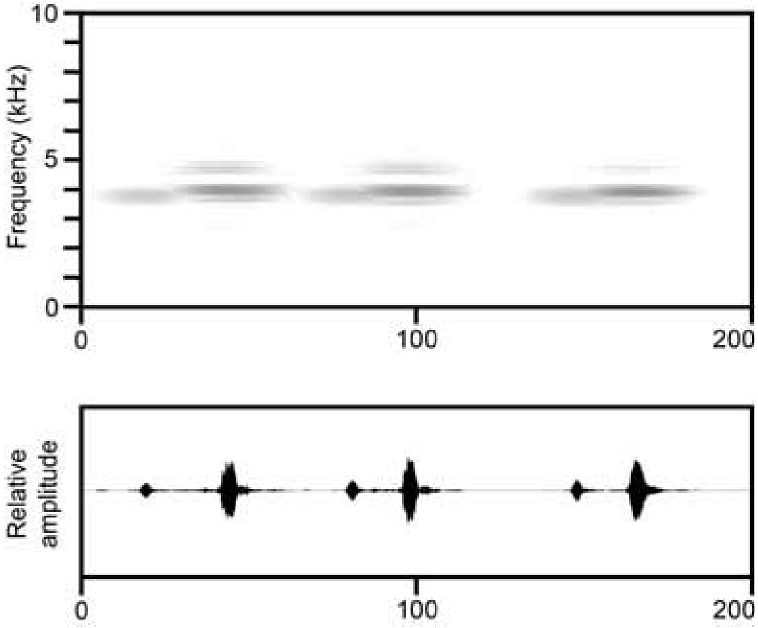

Fig. 21. *Mantella expectata.* Sonogram (above) and oscillogram (below) of the advertisement call with three notes. Recorded at Zahavola, on 11th November (10:00, about 26°C). Time scale: milliseconds.

Mantidactylus (Brigoomantis) sp. aff. *ulcerosus* (Boettger, 1880)

Voucher specimens: A2965-2973, A5021-A5024, A5392-A5398, A5400, A5849 (t), A5868-A5872 (t), A5875 (t), A5877 (t), A5878 (t), A5881 (t), A6027-A6032, A6034. **Locality records**: Iambahatsy, Ampasibe, Andohasahenina, Andriamanero, Ankademoky, Antoha, Canyon des Makis, Karofoty, Lola, Namazaha, Ranohira (Glaw & Vences, 1994), Sakamalio, Tsimanolabero, Tsitorina, Zahavola.

Since its first discovery, the populations of the Isalo Massif have been considered somehow different from the typical *M. ulcerosus* (Glaw & Vences, 1994), and for this reason this species is actually under description (F. Glaw, pers. comm.) (Fig. 22). The current distribution outside the massif is unknown and this species could represent another possible local endemic. *Mantidactylus* sp. aff. *ulcerosus* is commonly found in swamps and slow moving streams with gallery forest representing its preferred habitats. On several occasion, tadpoles have been seen swimming in slow moving rivers. The call (Fig. 23) of specimens from

Fig. 22. *Mantidactylus* sp. aff. *ulcerosus.* Adult from Iambahatsy.

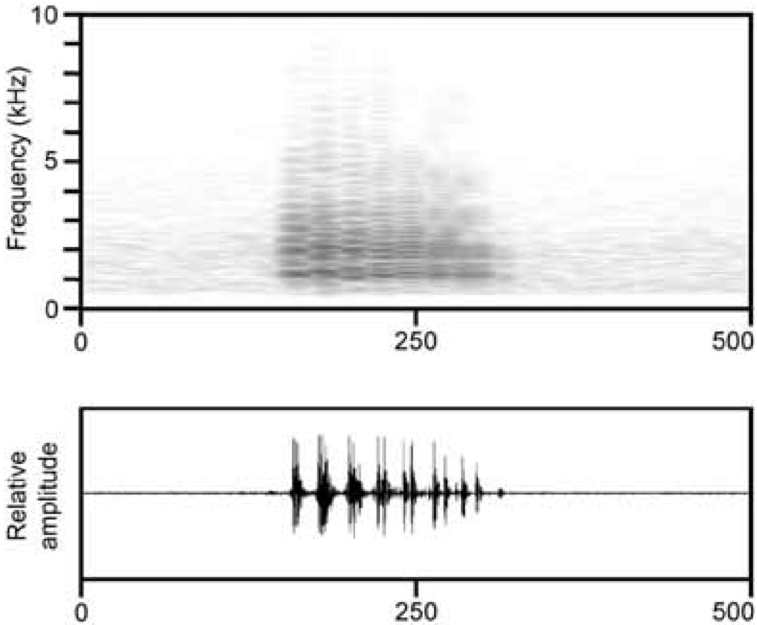

Fig. 23. *Mantidactylus* sp. aff. *ulcerosus.* Sonogram (above) and oscillogram (below) of the advertisement call. Recorded at Namazaha 9th December (20:30, about 24° C). Time scale: milliseconds.

Ranohira (Glaw & Vences, 2006) differs from that of the populations from Nosy Be (*Terra typica*) in showing more notes per call with a lower number of pulses, and shorter notes with shorter intervals (Glaw & Vences, 1994; Mercurio & Andreone, 2007).

Mantidactylus (Brygoomantis) noralottae Mercurio & Andreone, 2007

Voucher specimens: MRSN A5254, A5035, A5036, A A5317 (ht), A5318-A5319, A5252 (pt); PBZT-FAZC 12996, PBZT-FAZC 12998, SMF 85861, SMF 85862-85864 (pt). **Locality records**: Ambovo.

This recently described species is a remarkable discovery enriching the list of the Isalo batrachofauna (Mercurio & Andreone, 2007). *M. noralottae* is a localized species known only from a single locality on the northern part of the Isalo Massif. *M. noralottae* appears to be specialised to the canyon habitat, with unusually enlarged fingertips, enabling it to facilitate a scansorial life style (Fig. 24). We found individuals within a narrow canyon in the initial and gully tracts (Mercurio & Andreone, 2006). Males were calling hanging from the canyon wall or from the water surface. The call consisted of a single long note composed of a train of about 100 short pulses. Considering its limited distribution, *M. noralottae* was preliminarily categorised as "critically endangered" in its description paper, but recently it has been listed as "endangered" (IUCN, 2008).

Mantidactylus (Hylobatrachus) cf. *lugubris* (Duméril, 1853)

Voucher specimens: MRSN A5419-A5420, A5421 (j), A5422-29, A5432-A5441. **Locality records**: Ankademoky, Isalo (Raxworthy & Nussbaum, 1997), Sakamalio.

This brook-dwelling forest species has been recorded for the first time at Isalo by Raxworthy & Nussbaum (1997). Here the individuals have a small body-size, and share phylogenetic similarities with the populations of Ranomafana and Antoetra, slightly differing in colouration (Fig. 25). The revision of the subgenus *Hylobatrachus* is much needed, considering that several cryptic species may be described or revalidated. We cannot currently attribute these populations unequivocally, suggesting that they may belong to *M. lugubris* s.str. Frogs have been found in the northern part of the massif only where large canyons with permanent fast running streams and abundant gallery vegetation occur. The presence of *M.* cf. *lugubris*, species typical of humid forests, highlights the former relationships of the massif with the eastern forest belt.

Fig. 24. *Mantidactylus noralottae*. Adult from Ambovo (paratype MRSN A5254).

Fig. 25. *Mantidactylus* cf. *lugubris*. Adult from Iambahatsy.

Mantidactylus (Ochthomantis) cf. *femoralis* (Boulenger, 1882)

Voucher specimens: MRSN A2790-2791, A2680-2681, A2682-2686, A2690, A5027, A5275-5283. **Locality records**: Iambahatsy, Andriamanero, Canyon des Rats, Canyon des Makis, Namazaha Valley, Sakamalio, Tsimanolabero, Zahavola.

This species was already reported for Isalo by Glaw & Vences (1994). Anyhow, the taxonomy of this group is still quite confusing, thus it was uncertain to which of the already known or yet-to-be described species, the Isalo populations belong (Fig. 26). Our preliminary molecular and karyological data suggest that the Isalo population belongs to a different, genetically well-differentiated species closer to or conspecific with those of the Andringitra massif than to the eastern populations (Glaw & Vences, 2004).

Gephyromantis (Phylacomantis) corvus (Glaw & Vences, 1994)

Voucher specimens: MRSN A2783-2787, A2799-2800, 2963, 2992, 3181 (t), 4776, A5322-5326, A5372-5374, 5872. **Locality records**: Iambahatsy, Ambovo, Andohaosy, Andohasahenina, Andriamanero, Bemenara, Malaso, Namazaha valley (Glaw & Vences, 1994), Sakamalio, Tsiombivositra, Tsitorina, Zahavola.

Gephyromantis corvus is rather widespread and common, especially in the northern part of the Isalo Massif, becoming rare in the southern portion (Fig. 27). Outside the Isalo massif the species has been recorded from Analavelona, Bemaraha, and the Kelifely (Glaw & Raxworthy, 2004). Unpublished analyses showed that these populations do not belong to *G. corvus*, but to still undescribed species. Therefore, *G. corvus* appears to be restricted to the Isalo area. Despite the type locality (Namazaha valley), which consists of a permanent river with gallery forest, our observations show *G. corvus* to be common within small canyons with temporary pools. Occasionally, we found specimens in the savannah tract. Tadpoles show a unique aggressive and territorial behaviour associated with the emission of vocalisations (Glaw & Vences, 1994). It has been suggested that hetero-specific attacks are mainly addressed on predation, while co-specific attacks are directed to territorial issues. To confirm this observation we never found inside small ponds tadpoles of *G. corvus* together with some of other species (except for some *M. expectata* tadpoles at Malaso). The call consists of a series of up to 14 unharmonious notes resembling the call of a raven (Glaw & Vences, 1994; Mercurio & Andreone, 2007).

Gephyromantis (Phylacomantis) azzurrae Mercurio & Andreone, 2007

Voucher specimens: MRSN A5309 (pt), A5310 (ht); A5311-5313 (pt); SMF 8585-85860 (pt). **Locality records**: Iambahatsy, Andriamanero, Sakamalio.

Fig. 26. *Mantidactylus* cf. *femoralis.* Adults from Ambovo: striped (A) and unstriped (B) individuals.

Fig. 27. *Gephyromantis corvus.* Adult from Zahavola.

This newly described species is a further important discovery (Mercurio & Andreone, 2007) (Fig. 28). *Gephyromantis azzurrae* is phylogenetically close related to *G. corvus* with a remarkable syntopic occurrence. These two species show an ecological segregation with *G. corvus,* apparently linked to close and gully canyons, while *G. azzurrae* with open well forested valleys. Calling males were observed at night on leaves in the forest at about 50-150 cm above the ground. The advertisement call of *G. azzurrae* consists in a consecutive series of complex and harmonic notes (Mercurio & Andreone, 2007).

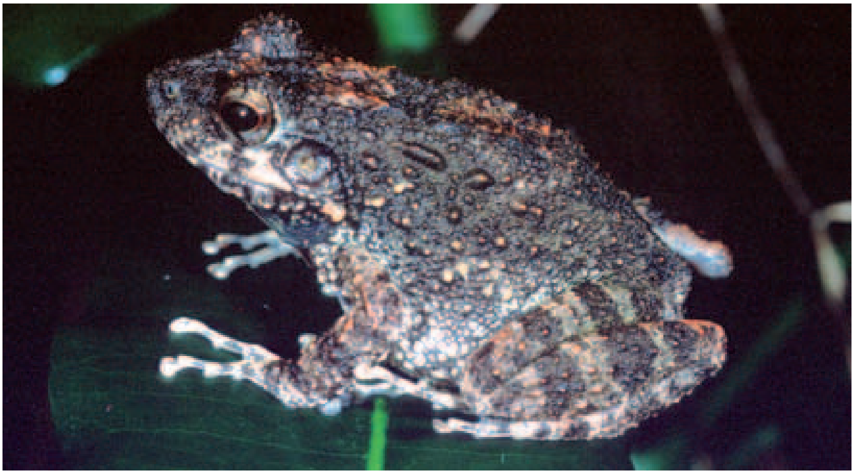

Fig. 28. *Gephyromantis azzurrae*. Adult from Sakamalio (paratype MRSN A5313).

Family Microhylidae

Dyscophus insularis Grandidier, 1872

Voucher specimens: MRSN uncatalogued (t). **Locality records**: Lola.

This fossorial species has been recorded for the first time for the Isalo Massif. In spite of our extensive research *Dyscophus insularis* has been found only at one site by means of presence of tadpoles (Fig. 29). As for several other explosive breeder species inhabiting the Isalo, the adults are likely very difficult to detect. Tadpoles have been collected inside a temporary sun exposed pool in the savannah.

Scaphiophryne brevis (Boulenger, 1896)

Voucher specimens: MRSN A2687, A5308, A5040-5041. **Locality records**: Ilakaka, Reine de l'Isalo, Ranohira (Glaw & Vences, 1994).

This burrowing frog was known from the southwestern arid areas of Madagascar (Glaw & Vences, 1994). At Isalo we found it in two sites with adults detected through opportunistic search. In particular, in a night of November after a heavy rainfall we observed several calling males and some egg clutches laid in a small temporary pool located in a sun-exposed spot in the savannah (Fig. 30). Similar observations were recorded for the population of Kirindy Forest (Glos, 2003). Eggs are laid in a film floating on the water surface. Tadpole developmental time has been reported to be very short corresponding to 10-11 days (Glos, 2003) (Fig. 31). The advertisement call recorded at Reine de l'Isalo on 22 November (20:45, about 23°C) consists in the regular repetition of one single clearly pulsed harmonic note (Fig. 32). Note duration is between 449-492 ms (475 ± 15.4, N = 10). The interval between notes is 604-742 ms (666 ± 51, N = 9). Pulses per note are 48-49 (48.4 ± 0.51, N = 10) with intervals between them of 2-5 ms (4.45 ± 1.0, N = 11). Pulse duration is 4-6 ms (4.45 ± 0.82, N = 11). The note repetition rate is about 1/s. The frequency range is between 2000-3000 with a dominant frequency of 2500-2600 Hz.

Scaphiophryne calcarata (Mocquard, 1895)

Voucher specimens: MRSN A2822. **Locality records**: Andranomena.

This is a new amphibian record for the Isalo. We found two individuals respectively within a small canyon between the ground vegetation, and under a dead branch wood in the savannah near a temporary stream. Since its secretive habits and the dependence of its surface activity from heavy rain, as already highlighted for other Isalo species, its presence in many of the visited sites has been probably overlooked.

Fig. 29. *Dyscophus insularis.* Tadpole from Lola.

Fig. 30. *Scaphiophryne brevis.* Adult from Reine de l'Isalo.

Fig. 31. *Scaphiophryne brevis.* Tadpole from Reine de l'Isalo.

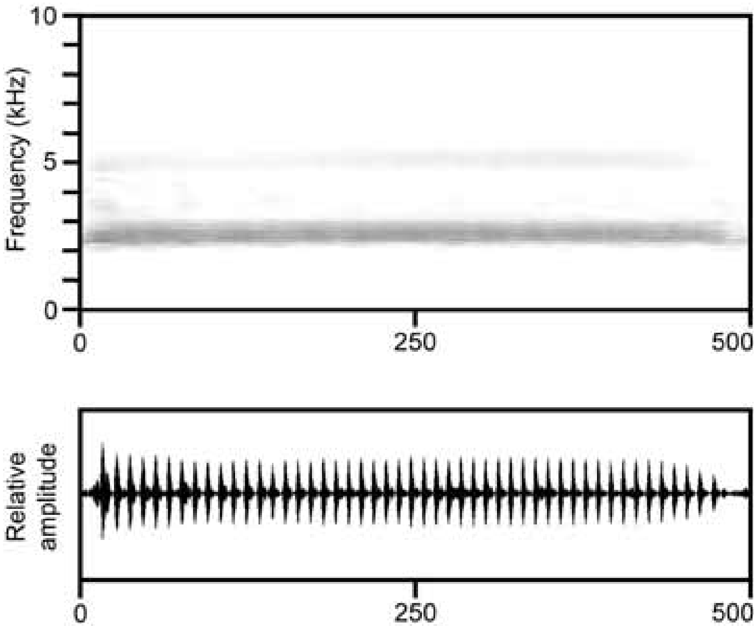

Fig. 32. *Scaphiophryne brevis.* Sonogram (above) and oscillogram (below) of the advertisement call. Recorded at Reine de l'Isalo on 22 November (20:45, about 23°C). Time scale: milliseconds.

Fig. 33. *Scaphiophryne calcarata*. Adult female from “near Ilakaka” (photograph by O. Pronk).

Scaphiophryne gottlebei Busse & Böhme, 1992

Voucher specimens: MRSN A2802, A2803-2804 (j), 2805-2806, A5837-5843 (t), A2854, A2857, A2866, A2873, A2876, A2882 (t), A2618-2619 (t), A2801, A2807-2808, A2809-2811 (j), A3089-3095, A3096 (j), 3097-3105, 4961-4962 (t). **Locality records**: Ambovo, Andohasahenina, Bevato, Amparambatomavo, Antambonoa, Bemenara, Lola, Malaso, Marojana River, Morahariva, Tsiombivositra, Vallée des Makis (Busse & Böhme, 1992), Vohitanana, Zahavola.

Scaphiophryne gottlebei is one of the Isalo amphibian endemics (Fig. 34). Together with *M. expectata* it has been object of intensive collecting for pet trade (Andreone et al., 2005a, b). Formerly known for only a few (and vague) localities, it has been found in many sites, and appears less rare than formerly believed. In 28 out of the total visited sites we confirmed its presence, with great part of them confirmed on the basis of tadpoles only. Probably, this is due to the fact that *S. gottlebei* is mainly nocturnal, fossorial and usually voiceless, with an unpredictable surface activity extremely dependent on the atmospheric conditions. On the basis of our data, it appears that *S. gottlebei* is more restricted than *M. expectata* in the northern portion of the massif, with the southernmost population found at Lola. Many aspects of the species’ life history still remain unknown. *Scaphiophryne gottlebei* shows some singular ecological aspects exhibiting both fossorial and rupicolous habits. In fact, our observations confirmed its ability to climb up almost vertical canyon walls. On these walls some small holes, caused by the fall of small cobbles, are often used as refuges (Fig. 35). On other occasions individuals were found buried in the sand present on the bottom of the canyons.

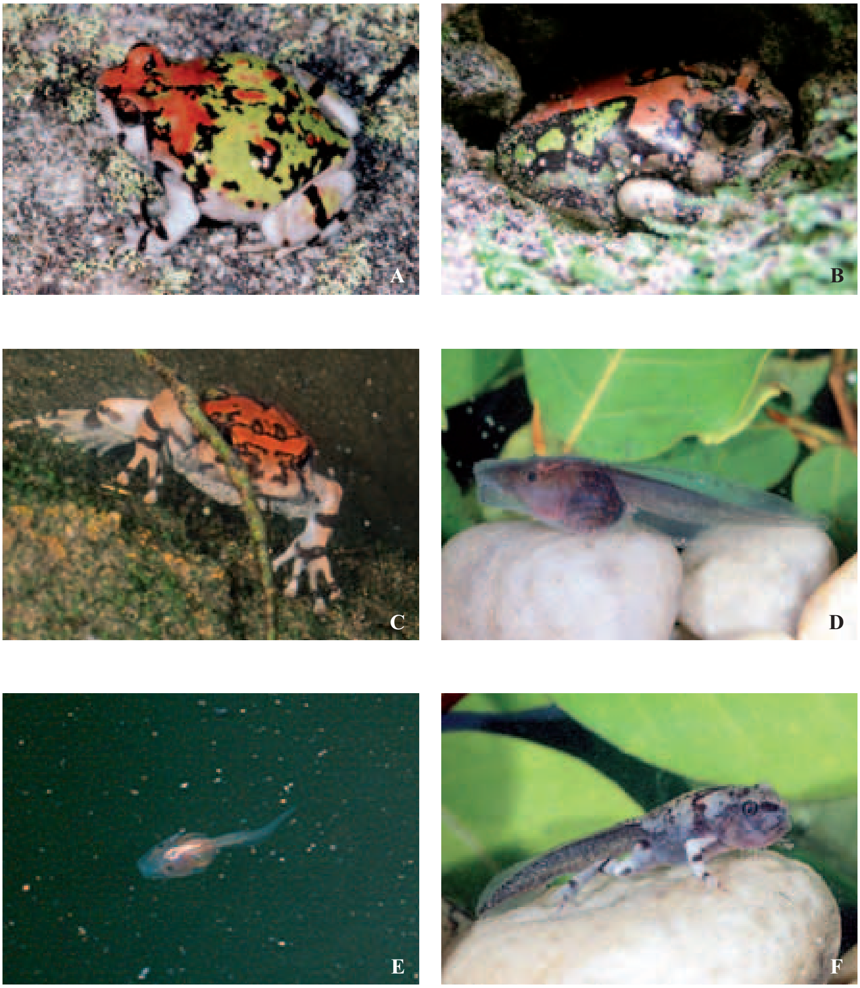

Fig. 34. *Scaphiophryne gottlebei.* (A) Adult female; (B) hidden female; (C) underwater male; (D) tadpole; (E) swimming tadpole photographed overnight; (F) almost metamorphosed tadpole. All individuals from Zahavola.

Unexpectedly, although this species is largely fossorial and specialized to live within narrow canyons, it shows a high dispersal capability leading to a high panmixis of the populations, as shown by a recent DNA analysis (Crottini et al., in press). This statement is reinforced by the observations of adults moving in open spaces far away from any water point during some stormy days. In fact, the low nucleotide substitution rate of the whole genus *Scaphiophryne* has been explained relating to their pond-breeding and putative vagile biology that makes difficult the local haplotype fixation (Vences et al. 2002). This species prefers small rocky pools within deep canyons. A breeding site was represented by a pool (about 4 X 3 m wide and 2 m deep), within a narrow cave-like canyon (Fig. 35). The pool had a sandy bottom and was surrounded by rocky walls, without aquatic vegetation, and fed by percolating water. Inside the canyon no direct sunlight was present, with humidity and temperature nearly constant (90-100% and around 19-21°C). The reproduction appears limited to a very short period, coincident with the first heavy storms. According to observations on larval development (obtained at Zahavola in November 2004) we found tadpoles in advanced development stages (Gosner's stage 38) likely hatched at the beginning of October. During the day, tadpoles usually stay close to the bottom and burrow within the substrate, propelled by intermittent movements of tail and body, with half the body dug into the sand and the tail obliquely upwards. In this posture they likely ingest particles from the substratum. During night-time the tadpoles leave the bottom and swim throughout the water column while filtering suspended particles. Metamorphosis likely takes place in 2-3 months according to climatic conditions with newly metamorphosed toadlets reaching 10-15 mm SVL with a colouration similar to that of the adults.

The advertisement call was described by Andreone et al. (2005c). The data here provided have been obtained from the same recordings but through the analysis with a different software (Adobe Audition ™). In particular, the analysis revealed that the note duration is much shorter than the one reported of about 77 ms. Maybe due to the recording conditions, the distinction of each single note was not possible with the software VOXYS used by Andreone et al. (2005c). The advertisement call consisted of a train of very short inharmonious notes (Fig. 36). Based on our registration the call can be an almost endless series, interrupted only in case of disturb or lasting about 2.5-3.5 sec (2900 ± 378 ms, N = 4) likely corresponding to the inflation and deflation (and/or vibration) of the vocal sac. In the latter case, two males were observed calling nearby antiphonally. Note duration is between 10-54 ms (22.4 ± 10.3, N = 30). Intervals between notes are about 1ms (vs. about 35 ms as formerly reported). The note repetition rate was 32-36/s. The frequency ranged from 500-1400 Hz with a dominant frequency of about 1000 Hz. As showed in the oscillogram, the waves have different cycle lengths, with longer and shorter notes of different amplitude modulation, apparently without the presence of a well identifiable carrier. Since the call has been recorded from specimens floating in the water inside a cave with a

Fig. 35. *Scaphiophryne gottlebei*. Canyon habitats. Narrow canyon at Andohasahenina (A), and cave-like canyon at Zahavola (B), from where tadpoles and underwater male of Fig. 34 were photographed.

strong eco, we ignore if this pattern represents an artefact due to these recording conditions.

The call structure broadly resembles that of *S. spinosa* (Vences et al., 2003). Since its discovery *S. gottlebei* has been exploited by the international pet trade (Andreone et al., 2005a, b). Similarly to *M. expectata*, and considering its narrow distribution *S. gottlebei* was classified as "critically endangered" (Andreone et al. 2005a, b) and included in CITES Appendix II. Most recently (IUCN, 2008), it has been downgraded to "endangered". Surprisingly, despite the high interest, *S. gottlebei* has not been yet successfully bred in captivity: mating and egg laying occurred at the London Zoo, but the tadpoles eventually hatched died after a few days (R. Gibson, pers. com.). Concerning the exploitation for pet trade and the consequent fixation of exportation quotas as stressed by Andreone et al. (2006), so far no numerical estimations of population size are available. Therefore, the current export quota of 1.000 individuals per year should be regarded as preliminary, and further investigations on the reproductive biology of this species are urgently needed. An appropriate management programme, with a long term monitoring of *S. gottlebei* is to be considered a requirement that cannot be disregarded in the frame of a regular exploitation.

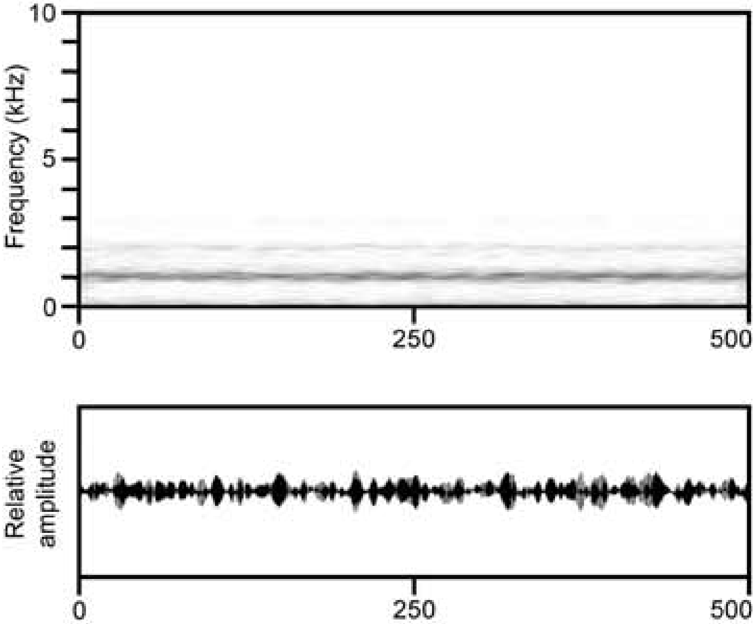

Fig. 36. *Scaphiophryne gottlebe*i. Sonogram (above) and oscillogram (below) of part of the advertisement call. Recorded at Zahavola on 23th November 2004 (19.30, 21° C). Time scale: milliseconds.

Scaphiophryne menabensis Glos, Glaw & Vences, 2005

Voucher specimens: UMMZ 227489. **Locality records**: Isalo region (Vences et al. 2003; Glos et al. 2005).

This recently described species inhabits the dry deciduous forest of the Menabe area (Kirindy Forest) of western Madagascar (Glos et al., 2005). So far, the only Isalo specimen known is UMMZ 227489. Vences et al. (2003) in their revision of the *S. marmorata* complex, ascribed this specimen to *S. marmorata*, noting its unusual distribution and the presence of two different eastern (greenish) and western (brownish) colour patterns. Later, individuals coming from western localities (e.g., Kirindy, Tsingy de Bemaraha, Namoroka, and Isalo) were recognised (based on larger body size and mitochondrial differentiation) as a new species, *S. menabensis*. However, as already stressed by Glos et al. (2005), the Isalo and Namoroka records, both represented by single specimens, need further confirmation. In fact, considering the presence at

Isalo of several other typical rain forest species, even if almost unlikely, this record may also belong to *S. marmorata*.

DISCUSSION

The species accumulation curves indicate that the total number of detected amphibians is near to the highest value. The discovery of two new species, *Gephyromantis azzurrae* and *Mantidactylus noralottae*, during the last days of survey, highlights the possibility that further species could be discovered at Isalo. This could happen if other areas will be actively searched in the future. Seen the difficulty in detecting adult individuals (whose activity is mostly dependent on rainfalls) we recommend to conduct a standardised tadpole survey.

The amphibian diversity of the Isalo Massif is high, with a fauna of at least 21 species. This diversity, when looking at the apparently unsuitable habitat, is surprising. Other western areas have a certain number of species, but they are all lower than the one observed at Isalo. At Kirindy the number is 15, at Berara (that moreover is a transitional dry-Sambirano forest) 14, and at Ampijoroa 7. The analysis of the Isalo frog fauna permits to identify the reasons of this richness. In particular, the amphibians belong to three different biogeographic and ecological components.

The first component includes frogs of the arid western slopes of Madagascar. With the exception of *S. menabensis*, these savannah species are typical pond-breeders and in general quite adaptable to habitat modifications: *Dyscophus insularis*, *Scaphiophryne brevis*, *S. calcarata*, *Heterixalus luteostriatus*, *Boophis doulioti*, *Laliostoma labrosum*, and *Ptychadena mascareniensis.* Little is known about their genetic differentiation, but they appear to be quite homogeneous. These species are widely distributed, and are present in most of the western areas. This situation is also mirrored by the similarity index: the highest similarity (CBR = 0.55) is with Kirindy with ten shared species, whereas a similar situation has been found for the two other western sites: Ampijoroa (CBR = 0.43) and at lesser extent at Berara (CBR = 0.29).

A second component of the Isalo frogs is represented by rainforest species. They are, for example, *Boophis luteus*, *B.* cf. *periegetes*, *Mantidactylus* cf. *femoralis*, *M.* cf. *lugubris.* The genetic analysis of these species shows that they are faintly differentiated from the populations from the south-eastern rainforests. In particular, *B. luteus* from Isalo clusters with individuals from Andohahela, *B.* cf. *periegetes* with individuals from Ranomafana and Andringitra, *M. lugubris* with individuals from Antoetra and Itremo, and *M.* cf. *femoralis* with individuals from Andringitra. The presence of these species and their low differentiation clearly indicate that until recently, the Isalo Massif has remained in contact with the eastern rainforest block (Raxworthy & Nussbaum, 1996).

Third, the batrachofauna of Isalo exhibits a high number of endemic species. They are *Scaphiophryne gottlebei*, *Mantella expectata*, *Gephyromantis corvus*, *G. azzurrae*, and *Mantidactylus noralottae*. Three other species

(*Mantidactylus* sp. aff. *ulcerosus*, *Boophis occidetalis* and *B.* cf. *periegetes*) might be recognised as endemics as well. If this turns out to be true the total number of eight endemic species would sum up to more than one third of the whole batrachofauna. These species appear to be derived from more widely distributed forest species, of which they present special offshoots. *Mantella expectata* is an Isalo-derived of the group "aff. *expectata*" (Rabemananjara et al., 2007), *Gephyromantis corvus* and *G. azzurrae* of the *G. pseudoasper* group (present with still undescribed species in other dry forest fragments), *M.* sp. aff. *ulcerosus* of the *M. ulcerosus* group, and *B. occidentalis* of the *B. occidentalis* group. *Mantidactylus noralottae* is another endemic showing genetic relationships with *M. betsileanus* from Andohahela. *Scaphiophryne gottlebei* is very peculiar, since it is a tetraploid species, likely derived by hybridisation of two *Scaphiophryne* species (Vences et al., 2002). The situation regarding *B.* sp. aff. *wittei* from Isalo is more complicated, since it clusters with individuals from Kirindy, and is far differentiated from populations of the northern part of Madagascar.

Comparing the Isalo amphibian fauna with other localities a remarkable absence concerns *Aglyptodactylus* species. We suspect that *A. madagascariensis* (typical of the eastern rainforests) or *A. securifer* (typical of the west) could be found at Isalo after more intense research. The same could be applied for *Heterixalus betsileo* and for some other *Boophis* species.

The rich amphibian community of the Isalo is referable to the overlaying of these three-components. The savannah species with their ecological plasticity can be designate as opportunistic amphibians, able to colonise ephemeral breeding habitats. Their presence all over western Madagascar is an indication of this ecological value. The rainforest species are typical "stream species", that are likely able to adapt to riverine habitats, even in case of their persistence within the mosaic of savannah and harsh habitats. These species are able to survive for a long time (and sometimes even thrive) where the original rainforest coverage has gone and secondary forests or bushes have replaced it (Andreone et al., 1994; Andreone & Luiselli, 2001). Their presence at Isalo witnesses the survival of original riverine habitats. Finally, the endemic species are all canyon-species that have differentiated from their closest relatives after having "discovered" a new habitat, the cave-like narrow canyons distinctive of the massif. The erosion of the massif created a novel habitat which assured stability in terms of temperature, water availability, and humidity, and, likely trophic resources. Nowhere else in Madagascar a similar habitat is present, except perhaps the karst Tsingy areas. Interestingly, at Tsingy de Bemaraha there is an endemic green treefrog sister of *Boophis luteus* (Köhler et al., in press), and *Gephyromantis* sp. aff. *corvus* (Glaw & Vences, 2006; Andreone, unpublished), while at Tsingy de Ankarana there is a further endemic belonging to an old radiation, *Tsingymantis antitra* (Glaw & Vences, 2006).

The high species diversity and high degree of endemicity in the Isalo amphibian fauna can be explained by paleogeographic events. In fact, the occurrence of both species typical from the eastern humid slope and dry adapted species inhabiting the western regions highlight the role played by the massif as a refuge for humidity during drastic climatic fluctuations (Raxworthy & Nussbaum, 1997). It is also likely that during the known Pleistocene African climatic shift (Livingstone, 1982) the Malagasy eastern rain forest belt once connected with that of the western slope has been fragmented leading to disjoint populations.

Most of the conservation considerations about Madagascar refer to the eastern rainforests where deforestation and fragmentation are more noticeable while little is usually said about the dry areas. The condition of high diversity of amphibians summed to that of reptiles (Andreone & Mercurio, unpublished) stresses the importance to be paid to the conservation of Isalo habitats (Fig. 37).

Immediate and evident threats affecting the Isalo area include the extensive prairie burning. The Isalo savannahs are currently maintained through periodic fires, with the monocultural grass presence due to anthropogenic activities. In general, this action does not seem to affect seriously the remnant refuges of amphibians. Occasional observations show that savannah-adapted species are somehow resistant to fire as stressed by the case of *M. expectata*. However, for the remaining species the conservation of the canyon habitats and gallery forests is mainly correlated with the control of these periodic fires. Another potential threat is represented by the excavation of mines for searching sapphires, an activity that has a great potential of long-term persistence and is thus seriously threatening the Isalo biodiversity (Duffy, 2006). We are unaware of the effect of mine excavation in areas currently out of the national park boundaries, but we suspect that it may be underestimated. Furthermore, the remaining forested areas outside the park are threatened by daily wood exploitation.

A different, although complementary, threat regards the effect of pet-trade. This concerns mainly two species, *Mantella expectata* and *Scaphiophryne gottlebei*. Both species were (and likely are) collected almost all around the Ilakaka surroundings. This area outside the park boundaries is interested by an intensive sapphire searching activity liable to the presence of a growing and extremely crowded, urban centre (named "Ilakaka sapphire") where hygienic conditions and landscape impacts are scarcely considered. Data on the effect of pet-trade collecting for the Malagasy amphibians and reptiles are largely missing (Andreone et al., 2005a, 2006). Our observations on the abundance of *M. expectata* along the massif indicate that this species is abundant and almost widespread. It is more difficult to understand the situation regarding *S. gottlebei*. This species is much more elusive, although likely abundant in the northern part of the massif. Still unpublished age structure data indicate that both species have a short life-span, not beyond three years of life. This suggests that there is a conspicuous turnover in natural populations. For this, the collecting of individuals – currently established in 1000 per year – appear sustainable, and far from representing a threat for the species survivorship.

The Isalo Massif is an area with high biodiversity and spectacular landscapes. According to our studies several populations of the "endangered"

Fig. 37. Threats and human disturbance affecting the Isalo area: (A) burning prairie (near Andriamanero); (B) burning vegetation within an open canyon (Ampasika); (C) an excavation site for sapphire extraction (near Bemenara); (D) increase in human density shown by the growing urban centre Ilakaka.

species (*Scaphiophryne gottlebei, Mantella expectata, Mantidactylus noralottae*, *Gephyromantis azzurrae*, and *G. corvus*) lie outside the protected area. Furthermore, as showed by the case of *M. expectata* and *S. gottlebei* many peculiar haplotypes are found outside the boundaries (Crottini et al., in press).

In the frame of President Ravalomanana's "Durban Vision" we suggest the inclusion of the whole massif inside the protected area, assuring the protection of its unique amphibian fauna. This would be a success for the ACSAM programme presented in this book.

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RÉSUMÉ

Les amphibiens du Massif de l'Isalo, Madagascar centre-méridional: haute diversité de grenouille dans un habitat apparemment hostile.

Nous présentons une liste commentée des amphibiens présents dans le Massif de l'Isalo, Madagascar centro-méridionel. Bien que cette aire est composée d'un massif arénacé aride traversé par canyons profonds le nombre d'espèces de grenouilles découvert est apparu étonnamment haut (21). Le nombre d'espèces considérées endémiques dans cette aire est au moins cinq (*Mantella expectata*, *Gephyromantis azzurrae*, *G. corvus*, *Mantidactylus noralottae* et *Scaphiophryne gottlebei*), avec d'autres taxa qui sont probablement des endémismes d'Isalo. Ce niveau d'endémismes indique l'effet réfuge joué dans le passée par le massif pendant les changements climatiques répétés. Deux espèces sympatriques de *Gephyromantis* (*G. azzurrae* et *G. corvus*) se sont évoluées indépendamment, vraisemblablement pour l'adaptation à deux différents aspects des canyons qui caractérisent le massif. D'autres espèces survivantes dans des poches de forêt autour des fleuves hautement saisonnières sont co-spécifiques avec des espèces qui vivent dans les forêts pluviales orientales, donc en renforçant la connection qui devait exister avec la bande de forêts pluviales orientales jusqu'à des temps comparativement récents. Une partie du massif est actuellement gérée comme parc national, qui représente l'aire protégée la plus visitée du Madagascar. Malheureusement, le reste du massif est encore non protégé et est menacé par les feux répétés et par la continuelle exploitation minière de saphirs. Deux espèces, *Mantella expectata* et *Scaphiophryne gottlebei*, sont capturées aussi pour le commerce d'animaux, et des considérations sont faites sur leur status de conservation.

Mots clés: Amphibiens, Canyons, Conservation, Isalo, Madagascar.

Vincenzo Mercurio
Forschungsinstitut und Naturmuseum Senckenberg,
Senckenberganlage 25, D-60325
Frankfurt a.M., Germany
Email vmercurio@senckenberg.de

Gennaro Aprea
Università degli Studi di Napoli Federico II
Dipartimento di Biologia Strutturale e Funzionale
Via Cintia, I-80126 Napoli, Italy
Email oranabe@ libero.it

Angelica Crottini
Universitá degli Studi di Milano,
Dipartimento di Biologia, Sezione di Zoologia e Citologia
Via Caloria, 26, 20133 Milano, Italy
Email tiliquait@yahoo.it

Fabio Mattioli
Acquario di Genova
Pontespinola, Area Porto Antico
I-16128 Genova, Italy
Email fmattioli@ acquariodigenova.it

Jasmin E. Randrianirina
Parc Botanique et Zoologique de Tsimbazaza
PB 4096, Antananarivo 101, Madagascar
Email randrianirina_herpeto@yahoo.fr

Tokihery J. Razafindrabe
Università d'Antananarivo
Département de Biologie Animale
BP 946, Antananarivo 101, Madagascar
Email tokyraz@yahoo.fr

Franco Andreone
Museo Regionale di Scienze Naturali
Via G. Giolitti, 36, I-10123 Torino, Italy
Email franco.andreone@ regione.piemonte.it

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 197-214

Nirhy RABIBISOA[1], Olga RAMILIJAONA RAVOAHANGIMALALA[1] ,
Christopher J. RAXWORTHY[2]

Diversité spécifique et endémisme inattendus dans le Nord de Madagascar: résultats biogéographiques préliminaires de *Mantidactylus* sous-genre *Ochthomantis*

ABSTRACT

Surveys of Northern Madagascar completed by the University of Antananarivo, Department of Animal Biology, and the American Museum of Natural History (AMNH) reveal the biogeographic and conservation importance of this region for the *Mantidactylus* subgenus *Ochthomantis*. Despite a relatively modest surface area, nine of 13 species from this group are distributed in Northern Madagascar: three species currently described (*M. femoralis, M. anbreensis*, and *M. mocquardi*) and six species that are currently being described. Both localized and regional endemism is found for the species endemic to northern Madagascar, with species endemic to Montagne d'Ambre, Analabe (Sambirano), and the Tsaratanana Massif complex. Utilizing the distributions of all *Ochthomantis* species for all of Madagascar, we find that five of the six identified major endemic clades identified by the Parsimony Analysis of Endemism (PAE) include sites in Northern Madagascar. Fortunately, for Northern Madagascar, all known species of *Ochthomantis* have distributions that are included within the existing protected area network. However, we also suggest expanding these protected areas to include (1) unprotected additional forests in the Manongarivo region, (2) the forest corridor between Tsaratanana and Marojejy, and (3) unprotected forests in the Vohemar region.

Key words: Biogeography, Conservation, *Ochthomantis*, *Mantidactylus*, Tsaratanana, Madagascar.

[1] Département de Biologie Animale, Antananarivo.
[2] American Museum of Natural History, New York.

INTRODUCTION

D'après la résolution du Vision Durban, le système d'aires protégées de Madagascar devra être augmenté de trois fois de leur surface actuelle; en effet, il est important de connaître autant que possible la diversité spécifique des amphibiens, à l'intérieur des nouvelles réserves. Les détails des modèles de diversité des amphibiens malagasy ne sont pas encore bien décrits, mais il est déjà clair que le Nord de Madagascar représente en général une région différente, avec des richesses spécifiques élevées, et de hauts degrés d'endémisme (voir Andreone et al., 2005). Parmi les groupes d'amphibiens d'une richesse exceptionnelle dans la région septentrionale de l'Ile figure *Mantidactylus*, sous-genre *Ochthomantis* (Glaw & Vences, 1994) dans lequel cinq espèces sont reconnues comme valides, avec des soupçons élevés (en se basant sur des données préliminaires non publiées) de diversités cryptiques additionnelles (voir Glaw & Vences, 2004). Les *Ochthomantis* couramment reconnus sont respectivement *Mantidactylus ambreensis, M. femoralis, M. majori, M. mocquardi* et *M. zolitschika* (Glaw & Vences, 2006). En outre, Glaw et Vences (2004) avait suggéré aussi que *M. catalai* du Sud-est de Madagascar mérite d'être ressuscité.

A partir de notre travail d'inventaire dans la région septentrionale de Madagascar, une collection importante d'*Ochthomantis* a été faite dont quelques-unes sont de nouvelles espèces. Ces données vont améliorer notre connaissance sur la biogéographie de la distribution et l'endémisme des espèces. La description morphologique, détaillée et formelle, de ces nouveaux taxons, sera publiée ailleurs. Cependant, on présentera un sommaire biogéographique de ces résultats, que nous espérons susceptible d'aider et de renseigner sur le programme de conservation des amphibiens dans le Nord de Madagascar. Dans ce manuscrit, nous présentons les données à deux niveaux spatiaux: (1) la région septentrionale de Madagascar où nous allons nous concentrer sur les sites et les réserves, et (2) et de Madagascar en général, où nous allons traiter le modèle d'endémisme régional en comparant le Nord avec les autres domaines régions biogéographiques (écorégions, voir Faramalala et Rajeriason, 1999).

Ainsi dans cette recherche, nous essayerons de démontrer l'importance de la région septentrionale de l'Ile en ce qui concerne le sous-genre *Ochthomantis* car d'une part, elle est déjà reconnue par son importance des points de vue endémicité et diversité pour certaines espèces herpétofauniques (cf. Raxworthy & Nussbaum, 1995; Mahaviasy, 2004; Raselimanana & Rakotomalala, 2000; Raselimanana et al., 2000) et, d'autre part, elle possède plusieurs espèces non encore décrites (Andreone et al., 2003). Le but final de cette étude est alors de proposer des zones ou sites de conservation nouveaux, non encore protégées pour la pérennisation du groupe *Ochthomantis* et les systèmes hydrographiques qui lui sont indispensables.

MATERIELS ET MÉTHODES

L'étude a duré trois années, du mois de décembre 2000 au mois d'Avril 2003 dans 7 sites majeurs et 26 campements. Elle englobe le complexe montagneux de Tsaratanana (de l'est à l'ouest). L'échantillonnage, d'une durée de 1 à 15 jours se fait en période chaude et pluvieuse de l'année (entre les mois d'octobre et d'avril). La technique choisie est celle de Raxworthy et al. (1998). Il s'agit de la recherche visuelle et acoustique. Les visites diurnes et nocturnes se font le long des différents points d'eau (fleuve, rivière, cours d'eau, lacs, marres et flaques d'eau) aux différentes altitudes et d'habitats qui peuvent exister. Des lampes frontales sont utilisées la nuit. A chaque collecte, les paramètres suivantes sont relevés: date, heure, longitude, latitude, altitude, microhabitat, vitesse de l'eau, hauteur de l'animal par rapport au sol et d'autres circonstances pendant la capture. Les animaux qui ne sont pas utilisés comme spécimens de références sont relâchés dans leur lieu d'origine. Les autres sont fixés à l'aide de formol dilué à 10% et puis transférés dans de l'alcool plus tard. Des photos de quelques individus permettront de montrer leur coloration naturelle sont prises. Des chants sont enregitrés si possibles. Les matériels biologiques collectés sont partagés également entre le Département de Biologie Animale, Université d'Antananarivo (UADBA) et l'American Museum of Natural History (AMNH). Les individus mâles et femelles adultes sont analysés séparément suivant de nouveaux caractères diagnostiques morphologiques. Les spécimens étudiés, la description des nouvelles espèces et les analyses morphométriques, seront publiés ailleur.

L'analyse biogéographique utilise le PAE (Parsimony Analysis of Endemism) (Rosen & Smith, 1988). La technique est la même que pour l'analyse phylogénétique mais les sites prennent la place des taxons et les taxons jouent le

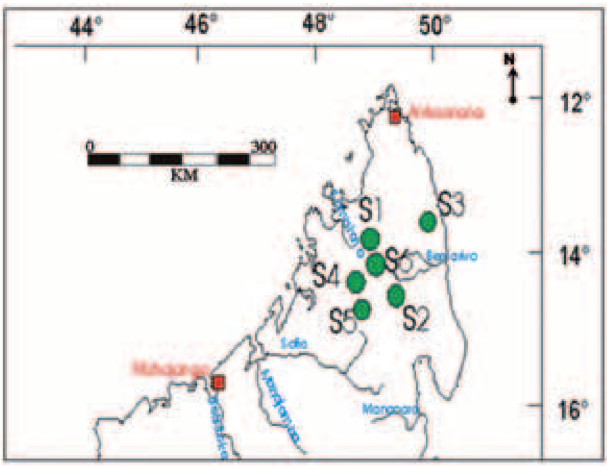

Fig. 1. Station d'étude dans le Nord de Madagascar.

Sites	Campements	Jours/Mois/Année	Positions géographiques	Altitudes (m)
Site 1. RNI de Tsaratanana: 1) le versant Ouest (Analabe), forêt humide particulière de type Sambirano, de basse à moyenne altitude, 2) le versant Est: Forêt pluviale de haute montagne et de savane.	Mandrizavona	7/12/00, 14/12/00, 30-31/01, 4/04/01	13°48,043'S/48°44,785'E	450
	Betaidambo	8-13/12/00	13°51,932'S/48°49,189'E	500
	Est Betaindambo	11/12/00, 23/01/01, 29-30/01/01	13°51,799'S/48°51,062'E	550
	Maroamalona	5/04/01	13°51,023'S/48°47,907'E	700
	Antsahamamonjy	24/01/01	13°52,262'S/48°52,799'E	900
	Antsahatelo	6/04/01	13°51,588'S/48°51,979E	800
	Besahona	25-29/01/01, 7/04/01	13°54,372'S/48°52,475'E	680
	Ramena	8-14/04/01	13°55,071'S/48°53,179'E	730
	Antsaravy	14-25/04/01	13°55,560'S/48°54,353'E	1150
	Matsabory Maiky	02-12/02/ 03	14°09,175'S/48°57,431'E	2000
	Ambodinitsaratanana	14-22/02/ 03	14°04'48,4''S/48°59'07,4''E	2500
	Befosa river-Antetikalambaraha	01/02/01, 22-28/02/03	14°10,455'S/48°56,708'E	1600
	Ambinanitelo	01/03/03	14°13,533'S/48°57,778'E	1200
Site 2. Limite Sud de la F. C. de Betaolana (Forêt pluviale humide de basse et moyenne altitudes).	Ambolokopatrika	27/11/01, 5/12/01, 12-13/12/ 01	14°32'18,1''S/49°26'14,6''E	850
	Bekamahery	6-10/12/01	14°31'52,6''S/49°25'37,4''E	1200
	Ambodivoara	14/12/01	14°31'21,6''S/49°25'05,2''E	550
	Andranomavohely	15-16/12/01	14°34'09,9''S/49°16'34,1''E	800
Site 3. Forêt aux environs de Vohemar (Forêt pluviale humide de basse et moyenne altitude)	Beravona	08-16/02/ 02	13°31,962'S/49°51,954'E	530
	Salafiana	22/02-01/03/02	13°26'15,4''S/49°43'0,6''E	400
	Ankitsika	19-25/03/02	13°52'20,6"S/49°47'02,7"E	830
	Sorata 1	11-19/04/02	13°41,147'S/49°26,511'E	1300
	Sorata 2	19-23/04/02	13°41,986'S/26,687'E	970
Site 4. Forêt aux environs de Bealanana, ou Les Trois Lacs (Forêt pluviale de type transitionelle)	Matsaborimena	9-16/03/ 03	14°19,859'S/48°35,240'E	1600
	Analapakila	16-23/03/03	14°26,233'S/48°36,696'E	1450
Site 5. Irony (Forêt ripicole de type caducifoliée)	Irony	01-02/04/03	14°44,9'S/48°29,449'E	900
Site 6. Lohanandroranga (Limite ouest de la F. C. d'Ambo-himirahavavy): Forêt pluviale de haute Montagne et ripicole	Lohanandroranga	6-13/04/03	14°24,990'S/49°08,855'E	1750
	Ambatomainty	13-19 04/ 03	14°24,076'S/49°10,253'E	1430

Tab. I. Site d'étude dans le Nord de Madagascar.

rôle des états de caractères. Le PAE est traité en PAUP 4.0, beta version (Swofford, 2002). L'arbre est enraciné par un site hypothétique où tous les taxons sont absents (Rosen & Smith, 1988; Raselimanana, 2000). L'arbre le plus court est obtenu par la recherche par parcimonie suivant la technique de la recherche heuristique à partir des fichiers des données à format Nexus. Elle utilise le "tree-bisection-reconnection", avec une addition au hasard à 100 replication. Un total de 33 sites et 13 taxons du sous-genre ont été utilisés. Le choix des sites est fonction de: (1) la disponibilité des résultats collectés par notre équipe et d'autres chercheurs depuis une dizaine d'années, (2) la représentativité des zones biogéographiques et d'endémie des amphibiens malgaches, (cf. Raxworthy & Nussbaum, 1996), et (3) les distributions altitudinale et latitudinale. Les sites à l'intérieur d'un même corridor et d'un même massif sont rassemblés en un seul site. Les termes suivants désignent un site, 1: de basse altitude (< 800m), 2: de moyenne altitude (801-1500m) et 3: de haute altitude (> 1500m). Les 33 localités sont obtenues à partir de la compilation de la distribution des espèces dans le nord, et les autres spécimens examinés à l'UADBA, au PBZT, et à l'AMNH par NR.

RESULTATS

Diversité spécifique

L'étude morphométrique a permis de découvrir 13 espèces dans le groupe. Les résultats morphologiques seront publiés ailleurs. Il s'agit de: (a) 5 espèces valides, *Mantidactylus femoralis, M. mocquardi, M. ambreensis, M. majori, M. zolitschka* (figure 2)*;* (b) 2 espèces qui vont être ressuscitées dans un futur récent, *Mantidactylus poissoni* et *M. catalai*; et (c) 6 espèces nouvelles, *Mantidactylus* sp. nov. A, *M*. sp. nov. B, *M*. sp. nov. C, *M*. sp. nov. D, *M*. sp.nov. E, *M*. sp. nov. F. Ces espèces non décrites et les changement taxonomiques seront publiés ailleurs.

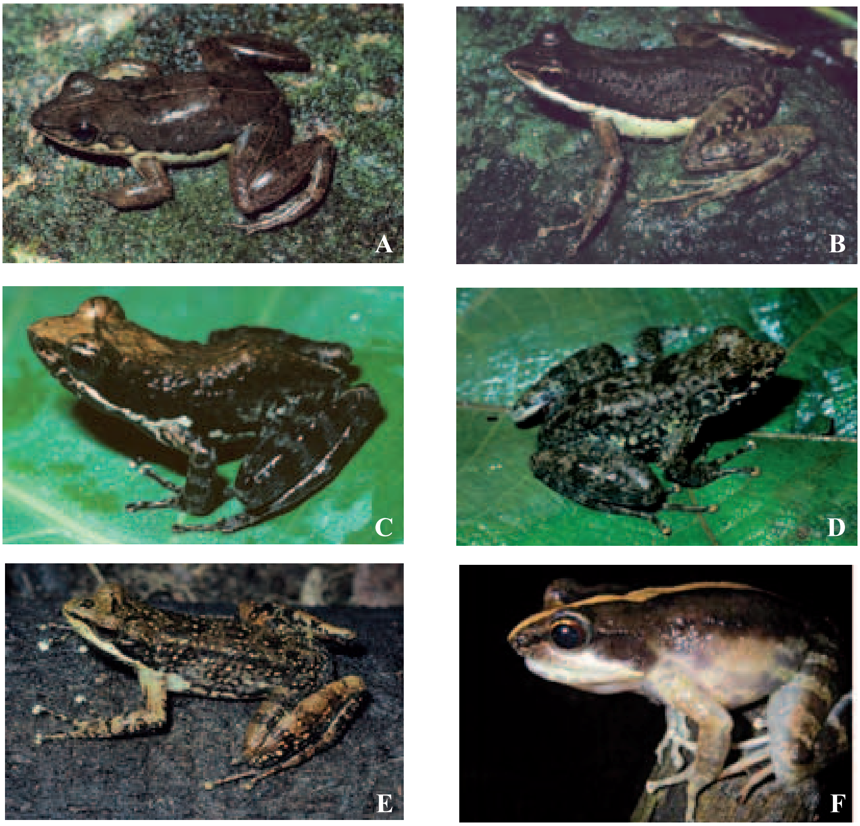

Fig. 2. Espèces représentatives du genre *Mantidactylus*, sous-genre *Ochthomantis* (toutes les photos sont de C.J. Raxworthy, excepté pour la F de P. Bora).(A) *Mantidactylus majori* de Ranomafana, (B) *Mantidactylus ambreensis* de la Montagne d'Ambre, (C) *Mantidactylus* sp. B de Ramena, (D) *Mantidactylus* sp. C de Mantadia, (E) *Mantidactylus* sp. D de Tsaratanana, (F) *Mantidactylus* sp. E de la Montagne d'Ambre.

Espèces	S1	S2	S3	S4	S5	S6	Marojejy	Mt Ambre	Tsaratano	Masoala	Anjanaharibe-Sud	Manongarivo	Région de Sambirano	Région de Centre Nord	Région de Nord-est	Région Nord
M. femoralis							+								+	
M. mocquardi		+	+				+								+	
M. ambreensis	+				+			+				+	+			+
M. sp. nov. A	+												+			
M. sp. nov. B	+	+	+	+			+			+			+	+	+	
M. sp. nov. C		+	+				+		+	+	+		+		+	
M. sp. nov. D	+	+	+	+		+					+	+	+	+	+	
M. sp. nov. E								+								+
M. sp. nov. F					+			+	+			+	+		+	+
Total	4 (1)	4	4	2	2	1	4	3(1)	2	2	2	3	6 (2)	2	6 (2)	3(1)

Tab. II. Distribution des espèces du sous-genre *Ochthomantis* dans les sites d'étude, les autres formations forestières dans le Nord de l'Ile, et dans les 4 sous-régions sous biogéographiques de Angel (1942) et Raxworthy et Nussbaum (1995) (Les chiffres entre parenthèses représentent le nombre des espèces endémiques locales)

Distribution dans le Nord de Madagascar

Un total de 9 espèces est présent dans le Nord de Madagascar: *Mantidactylus femoralis, M. mocquardi, M. ambreensis, M.* sp. nov. A, *M.* sp. nov B, *M*. sp. nov. C*, M.* sp. nov. D*, M*. sp. nov. E et *M.* sp. nov. F. Parmi les six nouvelles espèces découvertes, quatre sont endémiques de la région Nord de Madagascar, soit 31 % de la diversité spécifique du groupe.

Le tab. II présente les distributions du groupe dans les différents sites et leur aire d'occurrence respective dans la région septentrionale de l'Ile. Ainsi:

a) Le corridor Betaolana, la RNI de Tsaratanana et les forêts aux environs de Vohemar rivalisent en richesse spécifique avec Marojejy (4). Manongarivo et Montagne d'Ambre présentent aussi une diversité appréciable (3). Par contre, Lohanandroranga est le moin riche (Corridor Tsaratanana-Marojejy) (1).

b) Deux sites présentent une espèce à endémicité locale. Il s'agit d'Analabe, flanc ouest de Tsaratanana (*M.*sp.nov. A) et de la Montagne d'Ambre (*M.* sp. nov. E).

c) *M. femoralis* est présent uniquement à Marojejy dans les basses altitudes.

d) *M.* sp. nov. C et D sont largement réparties dans le Nord.

e) *M.* sp. nov. F présente des populations à distribution disjointe entre la Montagne d'Ambre et les forêts pluviales, le plus au sud.

f) *M. ambreensis* présente une distribution disjointe dans le Nord-ouest, de la Montagne d'Ambre (à l'extrême nord) à 30 km au Sud de Maevatanana (le plus au sud).

Ainsi du point de vue diversité, 6 sites sont très importants dans le Nord, avec 3 à 4 espèces sympatriques: (1) la RNI de Tsaratanana (Analabe et le flanc est de Tsaratanana), (2) le corridor Betaolana-Ambolokopatrika, (3) le Marojejy, (4) la Montagne d'Ambre, (5) les forêts des environs de Vohemar, et (6) le Manongarivo.

En ce qui concerne l'endémisme, deux sites sont prioritaires: Analabe (flanc ouest de la RNI de Tsaratanana) et la Montagne d'Ambre.

Concernant le Nord de Madagascar, les aires biogéographiques d'O*chthomantis* présentent deux composantes d'un centre d'endémicité: le "Bassin versant Ouest" et le "Bassin versant Est". Le flanc Nord-ouest est formé par le bassin de Sambirano, Mahavavy et Maevarano et la partie Nord de Betsiboka. Il comprend l'axe compris entre 30 Km au Sud de Maevatanana et les formations de la Montagne d'Ambre. L'altitude varie de 50-1250 m. Trois espèces sont endémiques de cette région. Il s'agit de *M. ambreensis, M.* sp. nov. A et *M*. sp. nov. E. Le flanc Nord-est formé du bassin de Bemarivo et d'Antainambalana est composé du flanc oriental de Tsaratanana, d'Anjanaharibe-sud, des forêts aux alentours de Vohemar, Betaolana, Tsararano, Masoala et des forêts aux environs de Bealanana. L'altitude varie de 400- 2700 m. Un total de 7 espèces sont présentes dans la régions mais aucune espèce n'est endémique. Deux espèces endémiques dans le Nord: *M.* sp. B. et D, présentent des distributions inhabituelles. Elles sont largement reparties dans le Nord-incluant les parties orientale, centrale et septentrionale mais sont inconnus dans des localités au sud de Masoala.

En ce qui concerne l'Ile, le Nord est le plus diversifié et il présente une richesse et une endémicité élevées par rapport à d'autres régions (Tab. III). Parmi les 13 taxons connus et identifiés actuellement, neuf sont présents dans le Nord soit plus de 70 % d'entre eux.

Espèces	Nord	Est	Sud-est	Haute terre centrale
M. femoralis	+	+	+	+
M. mocquardi	+	+		
M. ambreensis	+			
M. majori		+	+	
M. zolitschka		+		
M. catalai			+	
M. poissoni		+	+	+
M. sp. nov. A	+			
M. sp. nov. B	+			
M. sp. nov. C	+	+		
M. sp. nov. D	+			
M. sp. nov. E	+			
M. sp. nov. F	+	+		+
Total	**9 (5)**	**7 (1)**	**4 (1)**	**3**

Tab. III. Distribution d'*Ochthomantis* à Madagascar. (Les chiffres entre parenthèses représentent les espèces endémiques de chaque région géographique).

Analyse par parcimonie de l'endémisme à Madagascar

Les matrices des données à double entrée sont présentées dans le tableau IV. Deux mille huit cent quatre vingt six (2886) arbres ont été obtenus avec 31 pas, et in indice de consistance de 0,3571 (excluant les caractères non informatifs), suivant des caractères présentant des poids égaux. Des arbres obtenu à partir des règles à consensus stricte et à majorité ont donné quelques structures biogéographiques, par exemple la reconnaissance des régions biogéographiques suivantes: Haut-plateau et Sud-est, Sambirano, et les massifs de Tsaratanana; mais on a constaté une multitude de polytomies basales pour les autres sites. En conséquence, nous avons réorganisé les données en octroyant des poids aux différents caractères suivant leur valeur maximum en "rescaled Consistency Index". On a répété la même recherche heuristique. Un total de 24 arbres a été trouvé. Ainsi, un arbre à règle du consensus majoritaire est présenté dans la figure 3.

SITES	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Outgroup	0	0	0	0	0	0	0	0	0	0	0	0	0
Andringitra 1-2	0	1	0	1	0	1	1	0	0	0	0	0	0
Ambohijanahary 1-2	0	1	0	0	0	0	0	0	0	0	0	0	0
Ambatovaky-Mananara 1	0	0	1	0	0	0	1	0	0	1	0	0	0
Ambre 2	1	0	0	0	0	0	0	0	0	0	0	1	1
Nord-Ouest 1-2	1	0	0	0	0	0	0	0	0	0	0	0	0
Anjanaharibe-Sud 1-2-3	0	0	0	0	0	0	0	0	0	1	0	0	0
Tsararano1	0	0	0	0	0	0	0	0	1	1	0	0	1
Anjozorobe 2	0	1	0	0	0	0	0	0	0	0	0	0	0
An'ala-Ankeniheny 2	0	1	0	0	1	0	1	0	0	1	0	0	1
Ambohitantely 2-3	0	1	0	0	0	0	0	0	0	0	0	0	1
Bealanana 2-3	0	0	0	0	0	0	0	0	1	0	1	0	0
Betampona 1	0	1	0	0	0	0	0	0	0	1	0	0	0
Betaolana1-2	0	0	1	0	0	0	0	0	1	1	1	0	0
Irony 2	1	0	0	0	0	0	0	0	0	0	0	0	1
Isalo 1-2	0	1	0	0	0	0	0	0	0	0	0	0	1
Itremo 3	0	1	0	0	0	0	0	0	0	0	0	0	0
Kalambatritra 2	0	1	0	0	0	1	0	0	0	0	0	0	0
Mantadia 2	0	1	1	0	0	0	1	0	0	0	0	0	0
Mantadia-Zahamena 1-2	0	1	1	0	0	0	0	0	0	1	0	0	1
Marojejy 1-2-3	0	1	1	0	0	0	0	0	1	1	0	0	0
Masoala 1	0	0	0	0	0	0	0	0	1	1	0	0	0
Manongarivo 1-2	1	0	0	0	0	0	0	0	0	0	1	0	1
Mangerivola 1-2	0	1	1	0	0	0	0	0	0	1	1	0	0
Ramena 1-2	1	0	0	0	0	0	0	1	1	0	0	0	0
Ranohira 2	0	1	0	0	0	0	0	0	0	0	0	0	0
Ranomafana 2	0	0	1	1	0	0	1	0	0	0	0	0	0
Ranomafana-Andringitra 1-2	0	1	0	0	0	0	0	0	0	0	0	0	1
Tolagnaro-Andohahela 1-2	0	1	0	1	0	1	0	0	0	0	0	0	1
Tsarafidy 2	0	1	0	0	0	0	0	0	0	0	0	0	0
Tsaratanana 2-3	0	0	0	0	0	0	0	0	0	0	1	0	0
Tsinjoarivo 2	0	1	0	0	0	0	0	0	0	0	0	0	1
Vohemar 1-2-3	0	0	1	0	0	0	0	0	1	1	1	0	0
Zahamena 1-2	0	1	1	0	0	0	1	0	0	1	0	0	1

Tab. IV. Matrice des données biogéographiques. 1: *Mantidactylus ambreensis*, 2: *M. femoralis*, 3: *M. mocquardi*, 4: *M. majori*, 5: *M. zolitschka*, 6: *M. catalai*, 7: *M. poissoni*, 8: *M.* sp. nov. A, 9: *M.* sp. nov. B, 10: *M.* sp. nov. C, 11: *M.*. sp. nov. D, 12: *M.* sp. nov. E, 13: *M.* sp. nov. F.

L'analyse en PAE a identifié les cinq régions biogéographiques d'*Ochthomantis* suivantes: (1) les massifs de Tsaratanana (y compris Bealanana), (2) le Sambirano (y compris la Montagne d'Ambre), (3) la région Nord-est (y compris Anjanaharibe, Tsararano et Masoala), (4) la région de la formation de l'Est de basse et moyenne altitudes qui s'étend de Vohemar à Ranomafana, et (5) la région formée par le complexe Haut-plateau et Sud-est. La dernière région inclut le clade formé par le groupement Andohahela à Kalambatritra et Andringitra, et le clade qui regroupe Ambohitantely, Tsinjoarivo, Isalo, et le corridor Andringitra-Ranomafana. Ces régions biogéographiques identifiées sont présentées sur la figure 4.

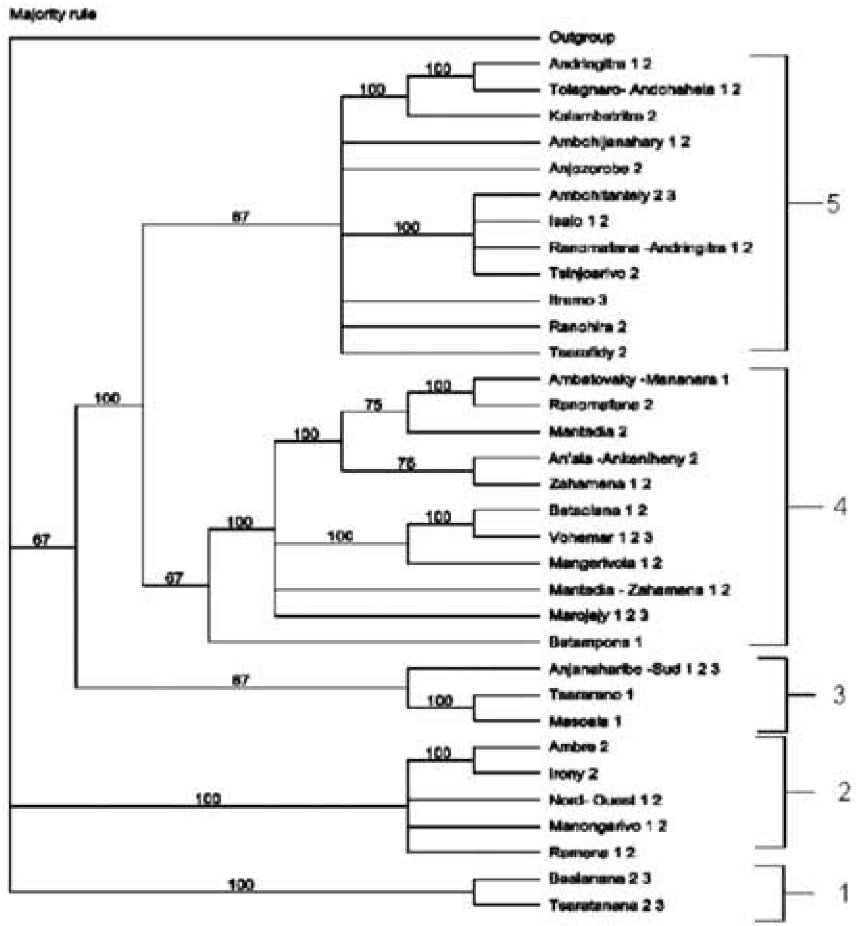

Fig. 3. Arbre APE à “majority rule consensus” du sous-genre *Ochthomantis* 1) Le massif régional de Tsaratanana (y compris Bealanana), 2) le Sambirano (y compris la Montagne d’Ambre), 3) la région Nord-Est (y compris Anjanaharibe, Tsararano et Masoala), 4) la région orientale de basse et moyenne altitude qui s’étend de Vohemar à Ranomafana, et 5) le groupement régional Haut Plateau et Sud-Est.

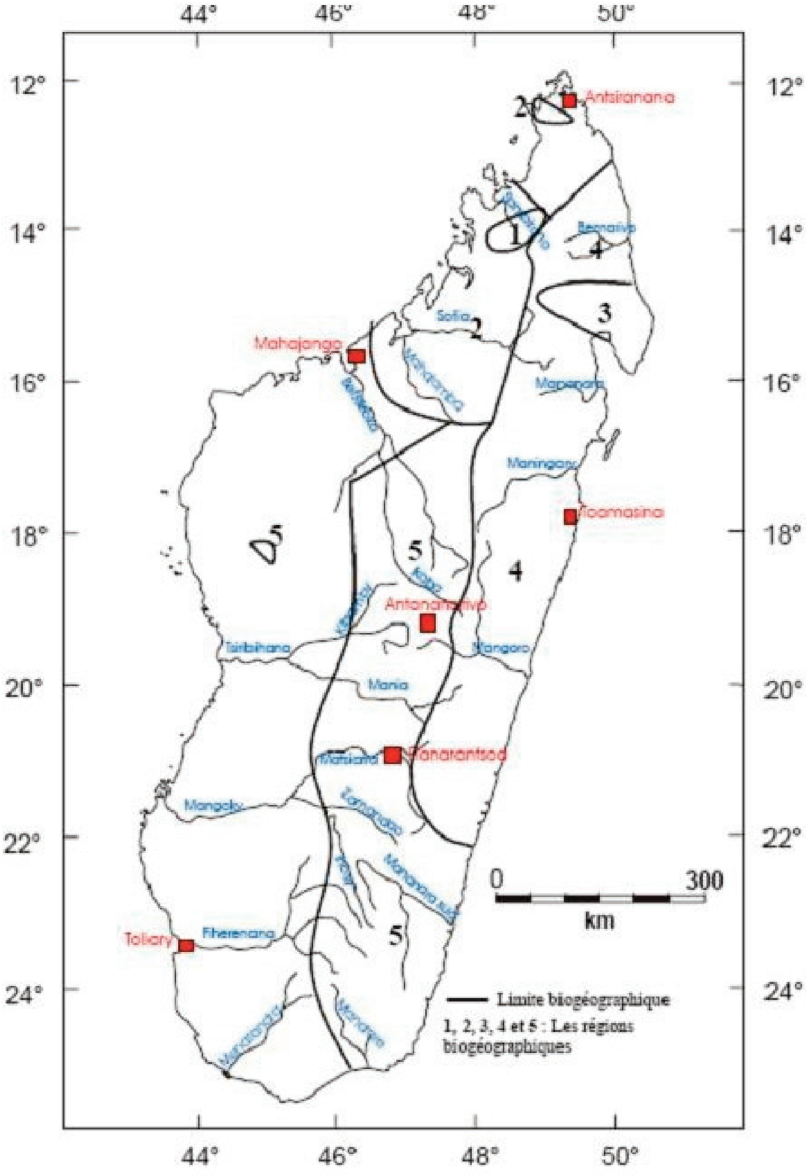

Fig. 4. Les régions biogéographiques majeurs du sous-genre *Ochthomantis*. 1: le massif régional de Tsaratanana (y compris Bealanana), 2: le Sambirano (y compris Montagne d'Ambre), 3: la région Nord-Est (y compris Anjanaharibe, Tsararano et Masoala), 4: la région orientale de basse et moyenne altitude qui s'étend de Vohemar à Ranomafana, et 5: le groupement régional Haut Plateau et Sud-Est.

DISCUSSIONS

Biogéographie des taxons présents dans le Nord

Pour le sous-genre *Ochthomantis* leur distribution dans le Nord dépend principalement du système hydrographique, de l'altitude, et de l'habitat (l'écoulement des cours d'eau et des rivières des forêts humides primaires). Car malgré la présence des grands escarpements de Tsaratanana comme barrières topographiques (sommet à 2786 m) certaines espèces sont largement réparties dans le Nord (*M.* sp. nov. B, C et D), témoignant du rôle joué par les cours d'eaux forestiers (zone tampon) qui présentent des sources au-dessus de 2000 m, comme lieu de refuge et de migration dans les deux bassins Est et Ouest (Wilmée et al. 2006), durant la période minimum de glaciation, de quaternaire (Burney, 1997). Ces systèmes hydrographiques jouent potentiellement le rôle de corridor entre les deux bassins en maintenant les conditions locales écologiques (cf. Wilmée et al., 2006). *M.* sp. nov. C, largement répartie le long des flancs Est et Nord-est de l'Ile, de Moramanga à Vohemar et, en traversant le massif de Tsaratanana, vers le Sambirano, est comprise entre 13°-19° Sud et 48°-50° Est et entre 100-1550 m de dénivellation altitudinale, des forêts de basse à haute altitude appartenant à la formation de l'Est de Humbert (1955). Pourquoi ces espèces ont-elles une distribution inhabituellement large? Peut être en raison de leur confinement, à des forêts de moyenne altitude, résultat de leur distribution historique peu perturbée par des changements climatiques.

Par contre, pour les zones à endémicité locale, exemple le cas d'Analabe, *M*. sp. nov. A (qui est confiné entre le basin de Sambirano et de Mahavavy) remplace *M*. sp. nov. D dans la cuvette restreint de Ramena. Les deux taxons sont actuellement séparés par une grande différence d'altitude. Dans la cuvette de Ramena, *M.* sp. nov. A se retrouve entre 600 à 1180 m, et *M.* sp. nov. D est par contre observée entre 1056-2650 m d'altitude dans les sites voisins. Le cas de *M*. sp. nov. E, à la Montagne d'Ambre (1000-1150 m) peut aussi s'expliquer par une évolution due à son isolement. Elle est séparée par des régions arides des formations humides plus au sud et est reconnue par son «endémique-massif» pour la faune et la flore (IUCN/UNEP/WWF, 1987).

Mantidactylus sp. nov F présente une distribution disjointe. Elle se trouve à la Montagne d'Ambre, Manongarivo et Tsararano. Cette distribution indique clairement que dans un passé lointain le flux etait possible entre ces trois formations en dépit de l'isolement actuel de la Montagne d'Ambre. L'explication la plus possible est que ce massif nordique était auparavant relié à des forêts humides plus au sud, pendant une certaine période paléoclimatique, telle que l'époque des glaciations du Pléistocène (voir Burney, 1997). De même, *M. ambreensis* présente une distribution disjointe entre Manongarivo et la Montagne d'Ambre. Cette discontinuité témoigne que l'espèce était largement répartie auparavant dans le Nord-ouest et que la distribution actuelle est probablement le résultat des événements paléoclimatiques du quaternaire. Cette espèce est aussi largement répartie dans le Nord-ouest dont la limite orientale est le flanc Ouest de la haute montagne de Tsaratanana et la limite Sud est à 30 km au Sud de Maevatanana (au Nord-ouest de Betsiboka). Quoique une large distribution dans le Nord-ouest puisse apparaître comme exceptionnelle, nous suspectons que ce pattern est originellement caractéristique de plusieurs taxons herpétologiques endémiques du Sambirano. Cependant une vaste déforestation le long de Betsiboka, ainsi que l'absence d'inventaire herpétologique, contribuent à la carence de notre compréhension biogéographique à l'intérieur de cette région.

Deux espèces ont une large distribution qui s'étend jusque au Nord-est de Madagascar. *M. femoralis* est largement répartie entre Marojejy et l'extrême sud (Eminiminy) en passant les haut-plateaux, entre 200 et 1600m d'altitude, avec une limite le plus à l'Ouest à Ambohijanahary. De la même façon, *M. mocquardi* est répartie le long du corridor de la forêt de l'Est, de Vohemar à Ranomafana, entre 400 et 1800 m d'altitude c'est à dire sur le flanc oriental et le Nord-est de l'Ile. Le flux est assuré par les corridors forestiers qui existent le long du flanc Est de l'Ile.

La distribution actuelle de *M. majori* mérite une attention particulière car sa présence à Marojejy (cf. Glaw & Vences, 1994) n'est pas confirmée par notre recherche et d'autres auteurs (Raselimanana & Rakotomalala 2000 et Raselimanana et al. 2000). Nous pensons que les spécimens signalés par Blommers-Schlösser & Blanc (1991) appartiennent à un autre taxon du groupe et que leur détermination est à vérifier avec les critères actuels.

Zones d'endémismes à partir de l'APE du groupe

Parmi les cinq régions majeures d'endémisme identifiées à partir de l'analyse de PAE d'*Ochthomantis*, on constate que quatre d'entre elles renferment les sites dans le Nord de Madagascar. Ce sont respectivement: (1) les massifs de la région de Tsaratanana, y compris Bealanana, (2) le Sambirano, y compris la Montagne d'Ambre, (3) la région Nord-est, y compris Anjanaharibe, Tsararano et Masoala, (4) la région orientale de basse et moyenne altitudes qui s'étend des forêts de Ranomafana à Vohemar. La seule région majeure d'endémisme qui ne renferme pas de site dans le Nord de Madagascar est le groupement Haut Plateau et région Sud-Est. Ce résultat témoigne ainsi du degré d'endémisme régional exceptionnel pour les espèces d'amphibiens qui se répartissent dans le Nord de Madagascar.

Les causes de cette évolution exceptionnelle en diversité et cet endémisme septentrional sont peu compris. Cependant, la topographie et la complexité du climat du massif de Tsaratanana suggèrent un fort gradient environnemental qui peut favoriser d'une part l'isolement par vicariance (résultats des changements climatiques) et d'autre part une adaptation à une condition locale. L'opposition de modèle entre, d'une part l'endémisme local et d'autre part les espèces à large distribution dans le nord de Madagascar indique clairement que les différentes lignées d'*Ochthomantis* avaient des réponses distinctes aux gradients environnementaux. En réalité aucune espèce d'*Ochthomantis* connue actuellement n'est distribuée à l'intérieur de toutes les formations humides du Nord de Madagascar. Ceci prouve que ces espèces se spécialisent davantage pour une niche écologique spécifique.

Conservation

Le degré élevé en diversité et en endémisme observé dans le nord de Madagascar pour *Ochthomantis* crée potentiellement des challenges pour un plan de conservation, à cause des risques élevés d'exclure une diversité spécifique importante dans le système de réseaux d'aires protégées. Pour le Nord de Madagascar, nous avons identifié 4 espèces d'*Ochthomantis* (représentant 31% de la diversité spécifique du taxon) qui présentent une endémicité locale ou régionale nécessitant une prise en considération pour la conservation. Ce sont: *M.* sp. nov. A connue seulement dans le vallée de Ramena (Analabe, fait partie de la RNI de Tsaratanana), *M.* sp. nov. E rencontrée uniquement à la Montagne d'Ambre (PN Montagne d'Ambre), et *M.* sp. nov. B et D limitées dans le nord de Madagascar et le complexe montagneux de Tsaratanana. Ces dernières espèces sont réparties respectivement dans la RNI de Tsaratanana, la RS de Manongarivo, le PN de Marojejy, RS d'Anjananaharibe, et le PN Masoala (Tab. II). En conséquence, pour *Ochthomantis*, les réseaux d'aires protégées devront inclure toutes les diversités spécifiques régionales.

Du point de vue diversité, 4 sites sont très important dans le Nord: (1) la RNI de Tsaratanana (y compris Analabe), (2) le corridor Betaolana-Ambolokopatrika, (3) Marojejy, (4) les forêts aux environs de Vohémar, (5) la Montagne d'Ambre, et (6) la RS de Manongarivo (y compris les forêts aux alentours). A l'échelle de l'Ile, la région septentrionale présente au total 70 % de la diversité du groupe dont 31 % sont endémiques de la région. Ces observations citées précédemment démontrent encore une fois de plus l'importance de cette région en amphibiens qui nécessite une protection large de toute la région biogéographique nord.

On conclue que la conservation du sous-genre *Ochthomantis* dans le Nord permettra à la fois de protéger les formations forestières de Madagascar et les systèmes hydrographiques existants et de préserver la diversité de l'Ile unique au monde. Les actions nécessaires pour assurer ces buts consistent à entretenir les différents corridors du complexe Montagneux de Tsaratanana, de Vohémar à l'Est à Ambanja à l'Ouest et à protéger les bassins de Sambirano-Mahavavy et les bassins de Bemarivo-Antainambalana. Ainsi les zones à proposer, non encore protégées et représentant les cinq régions biogéographiques majeures, sont: (1) les forêts autour de Manongarivo incluses dans le grand bloc de Sambirano qui est parmi les plus riches en espèce des cinq régions majeures d'endémismes (six espèces avec deux endémiques locales) et une diversité spécifique appréciable (3), (2) le corridor entre Tsaratanana et Marojejy (= F. C. Andramanalana) qui joue le rôle de tampon dans l'entretien du flux génétique entre les deux bassins ouest et est, et maintient la connectivité du complexe montagneux de Tsaratanana. En outre, il fait partie du massif régional de Tsaratanana dont le rôle est présenté dans ce manuscrit comme responsable du modèle de distribution des espèces actuelles *d'Ochthomantis* dans le nord, et (3) les forêts aux environs de Vohemar, qui font partie de la région biogéographique Est avec une richesse spécifique élevée (3).

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RÉSUMÉ

Un inventaire réalisé dans le Nord de Madagascar dirigé par l'équipe de l'Université d'Antananarivo, Département de Biologie Animale (UADBA) et l' "American Museum of Natural History" (AMNH) a révélé l'importance de cette région pour la biogéographie et la conservation des *Mantidactylus* du sous-genre *Ochthomantis*. Malgré une surface relativement modeste, neuf des 13 espèces répertoriées dans ce groupe sont réparties dans le Nord de Madagascar dont trois sont déjà décrites (*M. femoralis, M. ambreensis* et *M. mocquardi*) et six sont en cours de description. En outre, des endémicités locales et aussi régionales sont observées dans cette région de l'Ile, avec des espèces endémiques de la Montagne d'Ambre, d'Analabe (Sambirano) et du complexe montagneux de Tsaratanana. En utilisant les données de la distribution de tous les taxons d'*Ochthomantis* de Madagascar, nous avons montré que, parmi les six régions endémiques majeures reconnues, cinq clades d'endémicités sont identifiés par une Analyse par Parcimonie d'endémisme (APE ou PAE), incluant les sites de la région septentrionale de l'Ile. Heureusement, pour le Nord de Madagascar, les espèces connues d'*Ochthomantis* sont toutes réparties dans les systèmes de réseaux d'aires protégées qui existent. Cependant, nous suggérons aussi d'étendre ces aires protégées en incluant (1) les forêts non protégées autour de Manongarivo, (2) les corridors forestiers entre Tsaratanana et Marojejy et (3) les forêts non protégées de la région de Vohemar.

Mots clés: Biogéographie, Conservation, Madagascar, *Mantidactylus*, *Ochthomantis*, Tsaratanana.

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 215-232

Malalan'Ny Aina A. RAKOTONDRAZAFY[1], Christopher J. RAXWORTHY[2]

Distribution et biogéographie des amphibiens pandanicoles dans le couloir forestier du Nord de Madagascar

ABSTRACT

Amphibians specialized for living in screw pines (*Pandanus*) in the humid forest corridor of Northern Madagascar were surveyed during the rainy season in 2001 and 2003. This massive northern massif includes 69386km^2 of humid forest, most of which has not yet been well explored for biological diversity. Our field survey found 7 species of amphibian living in *Pandanus* at the selected survey sites. In addition, as a result of examining other specimens at the Département de Biologie Animale, Faculté des Sciences, Université d'Antananarivo, at total of twelve species known from *Pandanus* were recognized from this region. This study reveals the exceptional specific richness of the Northern Highlands, especially at mid and high elevation (above 800 m). Our results also provide new insights into the biogeographic patterns of montane endemism for these species, and we compare these biogeographic results to previously proposed patterns of endemism for Northern Madagascar. Finally, we also make recommendations for the future expansion of the protected areas in Northern Madagascar, to conserve additional regional amphibian endemism that is currently not protected within the current reserve network.

Key words: Amphibia, Mantellidae, Microhylidae, *Guibemantis, Platypelis, Pandanus*, Biogeography, Madagascar.

INTRODUCTION

Les amphibiens pandanicoles malgaches ont été étudiés depuis quelques décennies par de nombreux chercheurs. Ce groupe de batracien vit largement ou complètement au dépend du *Pandanus*. Il inclut deux familles: Mantellidae et Microhylidae, avec les espèces suivantes: *Guibemantis liber, G. bicalcaratus, G.*

[1] Département de Biologie Animale, Université d'Antananarivo.
[2] American Museum of Natural History, New York.

albolineatus, G. pulcher, G. punctatus, G. flavobrunneus, Platypelis tuberifera, P. milloti et *P. tetra*. Depuis l'époque de Guibé (1978), Blommers-Schlösser & Blanc (1991, 1993), Razarihelisoa (1979; 1988) et même jusqu'à maintenant avec Lehtinen (2002; 2003), ces espèces ont souvent été étudiées sur le plan écologique, biologique, morphologique et anatomique. Récemment, de la révision taxonomique de Glaw & Vences (2006), le sous-genre *Guibemantis* et celui du *Pandanusicola* ont été transférés dans le genre *Guibemantis* qui englobe tous les pandanicoles. Mais malgré les efforts apportés par de nombreux chercheurs, très peu d'informations sont disponibles, relatives notamment à leur distribution et moins encore à la biogéographie. La plus récente étude sur la biogéographie des amphibiens, concernant tout Madagascar, a été faite par Blommers-Schlösser & Blanc (1993). Cependant, les massifs montagneux du nord n'étaient inspectés qu'à quelques sites seulement et que certaines espèces n'ont pas encore été identifiées lors de cette révision.

Le couloir forestier de Sambirano est, parmi les régions où subsiste une superficie assez vaste de forêt dense ombrophile, celle qui reste très peu connue et parmi les moins prospectées. Avec une superficie d'environ 69386 Km², formé par la juxtaposition de plusieurs massifs montagneux dont celui de Tsaratanana au centre, ce complexe est intéressant du point de vue diversité biologique et endémisme puisqu'il englobe tous les types de forêts denses humides qui peuvent être observés dans le domaine de l'Est (ANGAP, 2001). Raxworthy & Nussbaum (1995) ont établi une subdivision biogéographique de cette zone en se basant sur les Caméléons du genre *Brookesia*. Leurs résultats ont confirmé ceux de Humbert (1955) fondés sur les communautés floristiques. D'autres travaux ont été également effectués sur les amphibiens (Glaw & Vences, 2003), ou sur les Lémurien (Mittermeier et al., 2006). Malgré ces différentes recherches biogéographiques, l'étude de la communauté d'amphibiens pandanicoles sera une opportunité pour compléter les travaux biogéographiques antérieurs.

Nous rapporterons les résultats de nos prospections dans les différentes régions du couloir forestier de Sambirano concernant les distributions altitudinale et spatiale des différentes espèces d'amphibiens pandanicoles et préciserons leur rapport à la biogéographie de la région.

METHODOLOGIE

Neuf sites ont été visités durant les saisons des pluies des années 2001 et 2003, répartis dans 4 régions du grand couloir forestier reliant le domaine de l'Est à celui de Sambirano: Ambolokopatrika (Betaolana), visitée le 06 au 12 Décembre 2001; Tsaratanana, visitée le 22 Février 2003 au 02 Mars 2003; Bemanevika, visitée le 16 au 23 Mars 2003; Androranga, visitée le 13 au 19 Avril 2003. Ces sites sont distribués d'est en ouest, le long du couloir forestier de Sambirano. Les détails sur chaque site sont présentés dans le Tab. I.

Région		Site	Latitude Sud	Longitude Est	Plage d'altitude prospectée
Ambolokopatrika (Betaolana)	S1	Ambolokopatrika 1	14°32,302'	49°26,243'	850 m à 1200 m
	S2	Ambolokopatrika 2	14°31,877'	49°25,623'	1200 m à 1650 m
Tsaratanana	S3	Matsaborimaika	14°09,175'	48°57,431'	1800 m à 2300 m
	S4	Ambodinitsaratanana	14°04,807'	48°59123'	2300 m à 2876 m
	S5	Rivière Befosa	14°10,455'	48°56,708'	1450 m à 1800 m
Bemanevika	S6	Matsabarimena	14°19,859'	48°35,240'	1450 m à 1600 m
	S7	Analapakila	14°26,233'	48°36,696'	1350 m à 1450 m
Androranga	S8	Lohanandroranga 1	14°24,990'	49°08,855'	1650 m à 1800 m
	S9	Lohanandroranga 2	14°24,076'	49°10,253'	1400 m à 1650 m

Tab. I. Les 9 sites prospectés dans le couloir forestier de la région Nord de Madagascar.

Des prospections sur le terrain ont été réalisées durant la saison humide des années 2001 et 2003, période pendant laquelle les batraciens sont pour la plupart très actifs. Pour collecter les espèces d'amphibiens pandanicoles, des fouilles et des observations directes ont été faites au sein des microhabitats constitués par les aisselles de feuilles de *Pandanus*, pouvant emmagasiner de l'eau et servir de refuge (Lehtinen, 2002). Seuls les pieds de *Pandanus* dont les feuilles sont larges et la base ne dépasse pas 2 m de haut ont été fouillés, puis localisés dans l'espace et en altitude. Les observations nocturnes et diurnes sont faites le long de transects mesurant environ 2 Km de long et constitués souvent de pistes, de bords de route, de cours d'eau, de marécages (Lehtinen, 2002). Ces transects tiennent compte : des écosystèmes, des milieux écologiques (vallées, versants et crêtes) et du gradient altitudinal. Les identifications des spécimens se sont basées sur les ouvrages de Blommers-Schlösser & Blanc (1991), Glaw & Vences (1994). Des études d'identification basées sur la morphologie et la biométrie ont été menées également sur ces espèces, facilitant les classifications taxonomiques de chaque espèce (Rakotondrazafy, 2006).

Les spécimens récoltés sur le terrain sont disponibles à l'American Museum of Natural History in New York et à la Salle de Collection du Département de Biologie Animale de la Faculté des Sciences de l'Université d'Antananarivo pour servir de référence. D'autres spécimens et/ou d'autres résultats d'inventaires provenant des travaux de publications ont été intégrés dans notre analyse concernant tout le couloir forestier de Sambirano. Ces résultats sont issus des inventaires réalisés par Andreone et al. (2000; 2003a; 2003b), Rakotomalala (2002), Rakotomalala & Raselimanana (2003), Raselimanana et al. (2000), Raxworthy et al. (1998, données non publiées). Les affinités biogéographiques dans le grand complexe Tsaratanana, Marojejy, Anjanaharibe-Sud et la région de Vohémar et Sambirano sont déduites d'une analyse de similarité entre les sites utilisant l'indice de similarité de Jaccard.

$$\text{Indice de Similarité de Jaccard} = \frac{NC}{N1 + N2 = NC}$$

Où N1 est le nombre total des espèces présentes dans le site 1; N2 le nombre total des espèces présentes dans le site 2 et NC le nombre total des espèces communes aux deux sites.

Elle est faite sous le logiciel BioDiversity PRO version 2. Les résultats sont représentés sous forme d'un dendrogramme des affinités entre les localités.

RESULTATS

Distribution dans les sites

Sept espèces d'amphibiens ont été collectées dans les aisselles des *Pandanus*, parmi les sites d'inventaire, au nord de Madagascar (Tab. II, fig. 1). Ces batraciens sont répartis dans 2 familles, 3 appartenant aux Microhylidae, sous-famille des Cophylinae et 4 appartenant aux Mantellidae, sous-famille des Mantellinae. Des études morphologiques sur les spécimens collectés de chaque espèce ont été faites par Rakotondrazafy (2006). Les descriptions des nouvelles espèces seront publiées officiellement sur un autre journal.

Famille /Sous-Famille /Genre	Espèce	Site								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
MANTELLIDAE	*G. bicalcaratus*	+	+							
/MANTELLINAE	*G.* cf. *bicalcaratus* 2						+			
/*Guibemantis*	*G.* cf. *bicalcaratus* 3								+	
	G. liber			+		+	+		+	+
MICROHYLIDAE	*P.* cf. *grandis*					+				
/COPHYLINAE	*P. tetra*								+	+
/*Platypelis*	*P. tuberifera*	+	+							

Tab. II. Liste des espèces d'amphibiens pandanicoles pour chaque site: S1 : Ambolokopatrika 1 (850-1300 m), S2 : Ambolokopatrika 2 (1300-1650 m), S3 : Matsaborimaiky (2000-2300 m), S4 : Ambodinitsaratanana (2300-2876 m), S5 : Rivière Befosa (1500-1800 m), S6 : Matsaborimena (1400-1600 m), S7 : Analapakila (1300-1400 m), S8 : Androranga 1 (1300-1650 m), S9 : Androranga 2 (1650-1800 m).

La distribution spatiale de *Guibemantis liber* est large. Observée dans 5 sites sur 7, l'espèce n'était absente que des sites d'Ambolokopatrika. *Guibemantis bicalcaratus* et *Platypelis tuberifera* n'ont été observés qu' à Ambolokopatrika, dans le couloir forestier de Betaolana reliant Anjanaharibe-Sud à Marojejy. Cette répartition pourrait s'expliquer par le fait que cette région forme avec Marojejy et Anjanaharibe-Sud la limite de la forêt orientale de moyenne altitude (série à *Tambourissa* et *Weinmania*), mais aussi parce que le complexe de Tsaratanana ne présente pas de forêt de moyenne altitude et qu'Ambolokopatrika est le seul couloir d'échange entre les deux aires protégées. La distribution de *Guibemantis* cf. *bicalcaratus* 2 est limitée dans la région de Bemanevika, dans le sud-ouest du complexe. C'est une forêt plus sèche que le domaine de Sambirano et le massif de Tsaratanana, partiellement décidue, d'un type plus ou moins transitionnel entre les couvertures forestières de Sambirano ou de Tsaratanana et celles de l'Ouest. *Guibemantis* cf. *bicalcaratus* 3 et *Platypelis tetra* sont des espèces limitées à la région d'Androranga, un couloir forestier reliant le massif de Tsaratanana à Ambolokopatrika, situé dans les massifs d'Andramanalana, de type de forêt montagnarde. *Platypelis* cf. *grandis* a été collectée dans la région du massif de Tsaratanana; il est confinée à cette région.

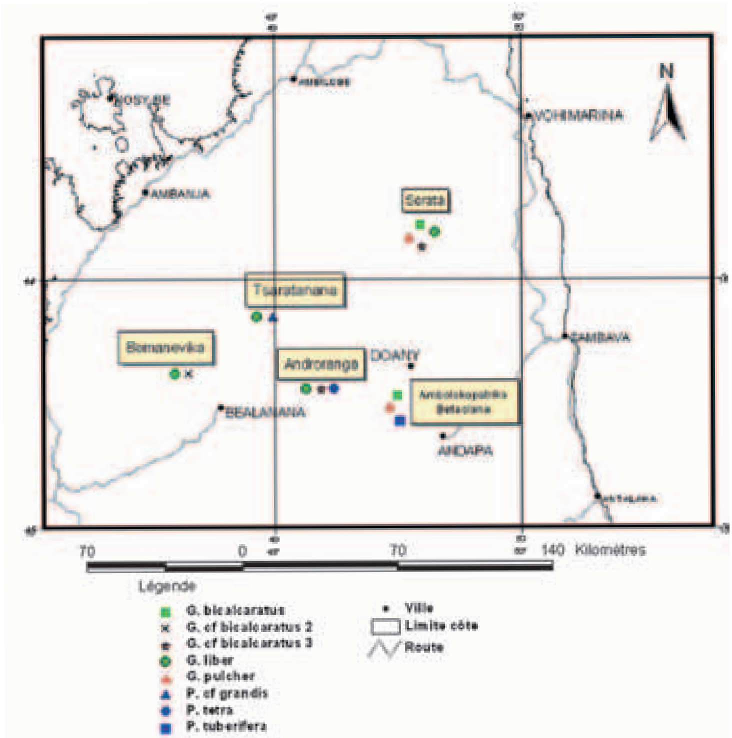

Fig. 1. Distribution des amphibiens pandanicoles observés sur le terrain lors de cette étude.

Distribution altitudinale dans chaque site d'étude

Les espèces observées dans les 9 sites d'études peuvent être réparties en 3 groupes selon l'étendue de leur distribution altitudinale (Fig. 2).

Distribution large: *Guibemantis liber* peut être aperçue de 1400 m (région de Bemanevika) à 2050 m d'altitude (dans le massif de Tsaratanana). Il occupe presque tout l'étage montagnard jusqu'à la limite inférieure des hautes montagnes.

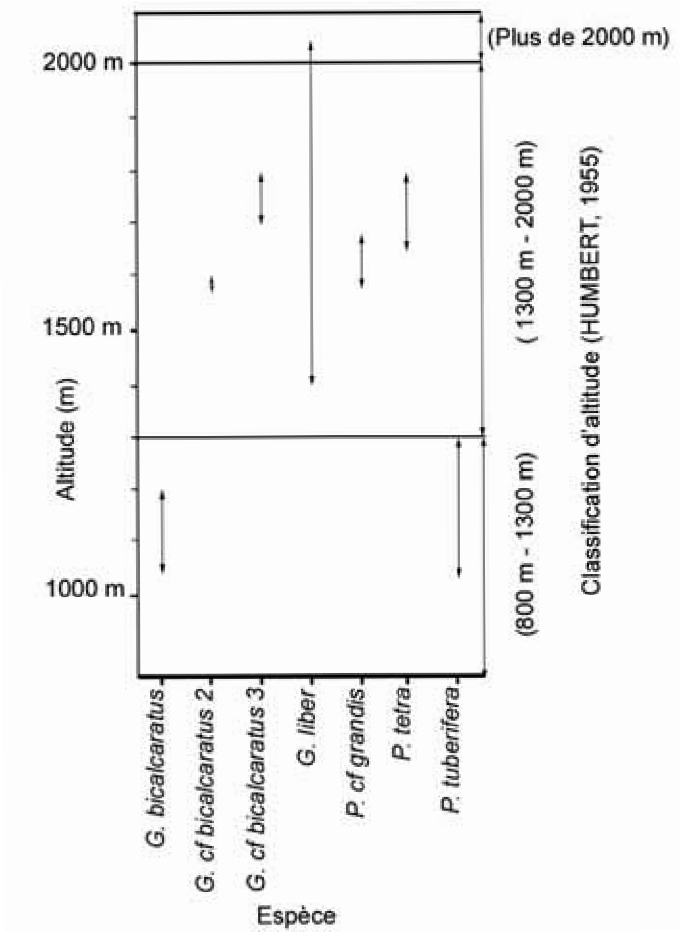

Fig. 2. Distribution altitudinale des espèces et leurs répartitions dans les étages d'altitude (Humbert, 1955).

Distribution moyenne: *Guibemantis bicalcaratus* et *Platypelis tuberifera* sont distribués dans une partie importante de l'étage de moyenne altitude entre 1000 et 1300 m.

Distribution étroite: *Guibemantis* cf. *bicalcaratus* 2 (1550 à 1600 m d'altitude), *G.* cf. *bicalcaratus* 3 (1700 à1800 m), *Platypelis tetra* (1650 à 1800 m) et. *P* cf. *grandis* (1600 à 1800 m) occupent des bandes altitudinales plus étroites, de 50 à 200 m d'amplitude, à diverses hauteurs de l'étage montagnard.

Avec 5 espèces d'amphibiens pandanicoles, l'étage montagnard est nettement plus riche que l'étage de moyenne altitude (2 espèces). Au-delà de 2050 m d'altitude, on n'a observé aucune espèce d'amphibien dans les aisselles des *Pandanus*.

Similarité des sites suivant les espèces

Le dendrogramme (Fig. 3), obtenu par l'analyse de l'affinité de chaque site, à partir de l'indice de similarité de JACCARD, de type «Cluster Analysis, Complete Link», illustre les regroupements des 16 sites de répartition de 12 espèces d'amphibiens pandanicoles (Tab. III). En particulier, ils montrent également les subdivisions biogéographiques présentées ci-dessous.

Le Nord-Est regroupe les massifs d'Anjanaharibe-Sud, de Marojejy, puis de Sorata et d'Ambolokopatrika jusqu'à 1300 m d'altitude. Ambolokopatrika joue le rôle de couloir forestier entre les massifs d'Anjanaharibe-Sud et de Marojejy et présente aussi la limite de cette subdivision du Nord-Est. Il comprend alors tout le versant oriental. Les barrières écologiques naturelles constituées par le climat, l'hydrographie, le relief et la végétation pourront être la cause de cette particularité. La végétation est soumise à un climat du versant oriental qui n'est pas loin de celui des plaines côtières orientales, elle repose sur un socle représentant un relief très encaissé et enfin présente une hydrographie très fournie (Humbert, 1955).

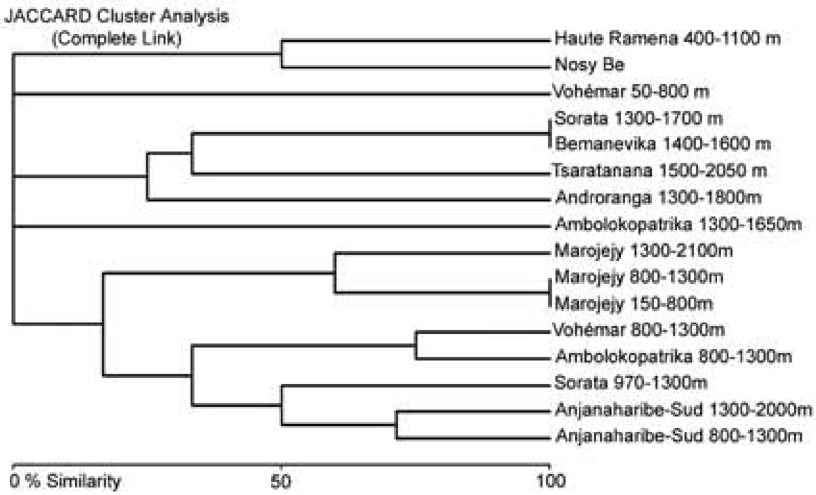

Fig. 3. Dendrogramme de la similarité des localités d'après la présence des 12 espèces dans chacun des 16 sites.

Espèces	Anjanaharibe-Sud		Ambolokopatrika (Betaolana)		Marojejy			Androranga	Tsaratanana	Bemanevika	Vohémar		Nosy-Be	Sorata		Haute Ramena	Manongarivo
	800 m-1300 m	1300 m-2000 m	800 m-1300 m	1300 m-1650 m	150 m-800 m	800 m-1300 m	1300 m-2100 m	1300 m-1800 m	1500 m-2050 m	1400 m-1600 m	50 m-800 m	800 m-1300 m	0 m- 430 m	970 m-1300 m	1300 m-1700 m	400 m-1150 m	400 m- 1600 m
G. bicalcaratus	+	+	+		+	+	+					+		+		+	
G. cf. *bicalcaratus* 1											+	+					
G. cf. *bicalcaratus* 2										+							
G. cf. *bicalcaratus* 3	+							+						+	+		
G. cf. *bicalcaratus* 4					+	+	+										
G. pulcher	+	+	+		+	+					+	+		+			
G. flavobrunneus	+	+															
G. liber	+	+			+	+	+	+	+	+				+	+		
P. tetra	+							+									
P. milloti													+			+	
P. tuberifera	+	+	+	+	+	+						+					
P. cf. *grandis*									+								

Tab. III. Répartition des espèces et des morphoespèces d'amphibiens pandanicoles dans le Nord.

Mais cette entité biogéographique du Nord-Est peut être encore subdivisée en différentes parties selon leur affinité. Ainsi, le massif de Marojejy constitue une entité à part entière due à son endémicité élevée observée et vérifiée par les travaux de Raselimanana et al. (2000). Le massif d'Anjanaharibe-Sud présente un autre groupe également. Il existe d'autres sites appartenant à l'étage de moyenne altitude qui sont intermédiaires entre les deux massifs mais qui sont beaucoup plus proches d'Anjanaharibe-Sud que celui de Marojejy, à savoir Ambolokopatrika (800 m à 1300 m) qui joue le rôle de couloir forestier entre les deux, Vohémar (800 m à 1300 m) et enfin Sorata (970 m à 1300 m) le plus proche d'Anjanaharibe-Sud.

Le Centre-Nord regroupe les massifs de Tsaratanana et d'Andramanalana. L'altitude 1300 m représente la limite basse de cette région. Elle englobe aussi Sorata à partir de 1300 m et Bemanevika à partir de 1400 m. Le massif de Tsaratanana (montagnard) englobe les localités sises dans les étages montagnards. Ce sont les zones aux alentours de Tsaratanana qui coïncident avec la plage altitudinale de 1300 m jusqu'à 2050 m et plus (vers 2876 m). Avec le gradient d'altitude, le climat devient plus accentué car la température baisse, souvent accompagnée de crachins et de brouillards. L'hydrographie est moins fournie par rapport à la région orientale de plus basse altitude car les sources y prennent naissance. A cause de ces rudes conditions, les espèces qui s'y trouvent sont souvent de deux types: les espèces spécialisées et les espèces à large distribution comme le cas de *Guibemantis* cf. *bicalcaratus* 2, *Platypelis* cf. *grandis* et *Guibemantis liber*. Ces régions sont surtout celles de: Sorata, Tsaratanana, Bemanevika et Androranga.

Le Nord-Ouest qui coïncide avec la Haute Ramena, s'étend jusqu'à 1100 m d'altitude, comprend Nosy-Be avec ses îles avoisinantes et Manongarivo bien que cette région ne présente aucune espèce d'après les données collectées par Rakotomalala (2002). Cette partie occidentale est comprise dans le domaine sous le vent, elle est surtout caractérisée par une forte pluie accompagnée d'une température élevée. La végétation y est typique selon Humbert (1955) et le socle est plutôt sédimentaire avec des dépôts d'alluvions de différents âges (Du Puy & Moat, 2003). L'espèce existante dans cette zone lui est endémique, c'est le cas de *Platypelis milloti*.

Le site de Vohémar, compris entre 50 m et 800 m d'altitude est l'une des régions non incluses dans les subdivisions. Il ne présente qu'une très faible similarité avec d'autres sites. La classification pourrait être le reflet de la nature de chaque zone. En effet, Vohémar est située dans la partie extrême Nord, d'où une limite pour la forêt dense ombrophile de l'Est. De plus, elle est constituée dans certaines régions d'une forêt de type littoral, d'où sa nature plus sèche et présentant un caractère moins arrosé. Ce site pourrait être un intermédiaire entre la forêt dense ombrophile de l'Est et la forêt sèche se trouvant au Nord.

L'étage montagnard d'Ambolokopatrika est aussi isolé des autres groupes. Cette zone pourrait montrer la transition entre les étages montagnards dans le groupe de Tsaratanana et les autres de moyenne altitude du versant oriental.

DISCUSSION

Richesse spécifique

D'après les travaux de Blommers-Schlösser & Blanc (1991, 1993), Glaw et Vences (1994, 2003, 2006), puis de Andreone et al (2003a), il existe au total 9 espèces d'amphibiens pandanicoles décrites (cf. Introduction). Mais en tenant en outre compte des spécimens de référence préservés dans le musée du Département de Biologie Animale (UADBA) et des recherches effectuées, une large gamme d'échantillons est alors disponible pour des travaux synthétiques sur les distributions altitudinale et spatiale de ces espèces dans le

Nord de Madagascar. Le nombre total d'espèces d'amphibiens pandanicoles pourrait être estimé à 12 dont 5 morphoespèces qui seraient probablement des espèces nouvelles à décrire ultérieurement. Ce nombre n'est probablement pas exhaustif et d'autres prospections, dans de nombreux sites de toute l'île, s'avèrent nécessaires par exemple: Montagne d'Ambre, Mananara Nord, Nosy Mangabe, Sainte Marie, Ambohitantely, et Fort Dauphin.

Douze espèces ont été retenues dans ce travail de synthèse, dont 7 sont endémiques à différentes localités, dans les différents massifs: Tsaratanana, Marojejy, Anjanaharibe-Sud, Sambirano, Andramanalana jusqu'aux régions de Sorata et de Vohémar. Ceci montre l'importance du couloir forestier de la région Nord de Madagascar, tant sur la richesse spécifique que sur l'endémisme. Le massif d'Anjanaharibe-Sud a la richesse spécifique la plus élevée avec 7 espèces, puis vient celui de Marojejy qui compte 5 espèces. Ces diversités spécifiques pourraient être influencées en partie par beaucoup de paramètres tels que le climat, le relief, la présence du support, son abondance et même la richesse spécifique en *Pandanus*. Par contre, le site de Manongarivo ne présente aucune espèce pandanicole, ce qui demande encore des travaux plus approfondis.

Distribution

L'altitude est un facteur d'un grand intérêt pour la compréhension de la distribution du groupe des batraciens pandanicoles. Il n'existe aucune espèce confinée dans l'étage de basse altitude. *Platypelis* cf. *grandis* et *Guibemantis* cf. *bicalcaratus* 2 n'ont été identifiés que dans l'étage montagnard. *Platypelis* cf. *grandis* est endémique du massif de Tsaratanana et *Guibemantis* cf *bicalcaratus* 2 de la région de Bemanevika. *Platypelis tetra* a été récolté dans l'étage de moyenne altitude du massif d'Anjanaharibe-Sud par Andreone et al. (2003a), puis dans l'étage montagnard de la région d'Androranga. *Platypelis milloti* est endémique de certaines régions de Sambirano. Les travaux de Rakotomalala (2002) à Manongarivo n'indiquent pas sa présence dans la réserve. Il a été observé dans la Haute Ramena suivant les travaux de Raxworthy et al. (non publiées), à Nosy-Be et sur les îles avoisinantes selon Andreone et al. (2003b). *Platypelis tuberifera* a été collecté dans le complexe Anjanaharibe-Sud Ambolokopatrika et Marojejy, puis dans la région de Vohémar. Il occupe une large plage d'altitudinal: les étages de moyenne altitude et montagnards dans le massif d'Anjanaharibe-Sud, seulement l'étage de moyenne altitude dans le couloir forestier d'Ambolokopatrika ainsi qu'à Vohémar; et les étages de basse et moyenne altitudes dans la région de Marojejy.

Guibemantis pulcher présente une distribution allant du complexe Anjanaharibe-Sud, au couloir forestier de Betaolana Marojejy, et à la région de Vohémar jusqu'à Sorata, principalement dans les étages de basse et moyenne altitudes. *Guibemantis flavobrunneus* est distribuée dans les strates de basse et de moyenne altitude d'Anjanaharibe-Sud. *Guibemantis liber* et *Guibemantis bicalcaratus* présentent les plus grandes distributions spatiale et altitudinale. *Guibemantis liber* s'observe du niveau de la mer jusqu'à 2050 m d'altitude, ce qui fait d'elle l'espèce semi-pandanicole ayant la plus grande distribution altitudinale. Elle est observée dans l'étage de moyenne altitude et montagnard, aux alentours du massif de Tsaratanana et dans les massifs d'Anjanaharibe-Sud et Marojejy. *Guibemantis bicalcaratus* est plutôt limité aux strates de basse et moyenne altitudes: basse altitude de la Haute Ramena, moyenne altitude de la région de Vohémar et basse et moyenne altitudes dans les massifs de Marojejy et d'Anjanaharibe-Sud. Les morphoespèces de *Guibemantis bicalcaratus* sont, pour la plupart, isolées et très localisées: *Guibemantis* cf. *bicalcaratus* 1 dans la région de Vohémar; *Guibemantis* cf. *bicalcaratus* 2 dans la région de Bemanevika; *Guibemantis* cf. *bicalcaratus* 3 dans la région d'Androranga, le massif d'Anjanaharibe-Sud et la région de Sorata; *Guibemantis* cf. *bicalcaratus* 4 dans le massif de Marojejy.

Biogéographie

Les résultats concernant la subdivision biogéographique montrent l'importance de cette région et corroborent ceux de Raxworthy & Nussbaum (1995) sur les caméléons terrestres (*Brookesia*) et de Rabibisoa et al. (dans le même volume). Ils suggèrent en effet la division de la région en trois, d'Est en Ouest: le Nord Est, le Centre Nord et le Nord Ouest (Fig. 4). Il serait intéressant d'établir une classification qui tient compte des informations concernant les différentes régions omises telles que: la montagne d'Ambre, la région d'Ambilobe et les forêts situées aux alentours de l'Ankarana. Cette étude a montré que les amphibiens pandanicoles reflètent en partie les communautés faunistiques occupant le couloir forestier de Sambirano. Cette région reste une partie importante de l'île tant sur le plan de richesse spécifique que sur les espèces endémiques qu'elle renferme. Nous pouvons confirmer que c'est un centre d'endémisme pour de nombreuses communautés faunistiques dans le Nord de Madagascar tel qu'il a été vérifié dans les travaux de Rakotomalala (2002), Raxworthy & Nussbaum (1995), Mittermeier et al. (2006). Beaucoup d'espèces sont encore sur le point d'être décrites, d'autres à observer car une grande partie de la zone nécessite encore des investigations.

Les subdivisions biogéographiques pré-établies par Humbert (1955), Raxworthy & Nussbaum (1995), Mittermeier et al. (2006) dans cette région ont été également vérifiées à partir de l'étude de l'affinité de ces sites, en se basant sur la communauté des amphibiens pandanicoles de la région. Malgré que les travaux de Humbert (1955) se sont portés sur le climat et la physionomie de la végétation, ceux de Raxworthy & Nussbaum (1995) sur le genre *Brookesia* et ceux de Mittermeier et al. (2006) sur les Lémuriens, les résultats présentent une cohérence frappante. De même, l'importance de cette région a été également soulignée par Glaw & Vences (2003).

Par rapport aux travaux de Wilmé et al. (2006), une étude se focalisant sur l'évolution de la biogéographie basée sur le microendémisme des vertébrés, on peut remarquer certaines évidences, comme le cas de *Platypelis milloti*,

Fig. 4. Quelques espèces d'amphibiens pandanicoles: (A) *Guibemantis* cf. *bicalcaratus* from Sorata; (B) *Guibemantis bicalcaratus* from Lohanandroranga; (C) *Guibemantis pulcher* from Sorata; (D) *Platypelis tetra* from Lohanandroranga; (E) *Platypelis tuberifera* from Manombo Special Reserve; (F) mature *Pandanus* plant at Lohanandroranga 1. Toutes les photos de C.J. Raxworthy.

qu'on ne trouve qu'au nord de Sambirano et dont la répartition coïncide avec le centre d'endémisme N Sambirano, W Mahavavy de Wilmé et al. (2006). Il existe également le centre d'endémisme S Bemarivo, N Mangoro (Wilmé et al., 2006) qui comprend les aires protégées d'Anjanaharibe-Sud, de Marojejy et qui présente une correspondance avec la subdivision biogéographique du Centre-Est. On peut noter des sites potentiellement riche en espèce et avec un endémisme élevé dans cette zone. En considérant encore cette hypothèse sur le retrait des espèces le long des rivières lors des fluctuations climatiques et environnementales du quaternaire (Wilmé et al., 2006), la région Centre-Nord qui regroupe les zones de Bemarivo, Mahavavy, Sambirano et Maevarano (Wilmé et al., 2006) faisait partie de ce couloire offrant aux espèces les conditions optimales. Néanmoins, certains problèmes liés à la dispersion de quelques batraciens restent à élucider, comme celles de *Platypelis* cf. *grandis* et l'isolement des nombreuses morphoespèces de *Guibemantis* cf. *bicalcaratus*.

Conservation

Ainsi, ces importances mises en exergue dans cette étude nous montre la nécessité de la protection et de la conservation des habitats et des écosystèmes de ce vaste complexe montagneux. Cette obligation s'avère cruciale pour la conservation de cette zone afin d'éviter toute altération de cette richesse et endémisme de toute la biodiversité, y compris les amphibiens. Des mesures sont vitales pour prévenir et gérer les pertes immenses de ces ressources naturelles.

Malgré la présence de certaines aires protégées, à savoir la RNI de Tsaratanana, la RS d'Anjanaharibe-Sud et le PN de Marojejy, elles ne tiennent compte que certaines espèces (Tab. IV). Ce qui pourrait alors orienter la mise en place des nouvelles aires protégées pour augmenter la superficie des zones protégées selon la Vision Durban. Les nouvelles délimitations des aires protégées futures devraient alors englober le massif d'Andramanalana, les régions de Sorata, Vohemar, Betaolana, Tsaratanana le long de l'axe Mangindrano jusqu'à Maromokotro et Bemanevika. Bien que les *Pandanus* ne font pas l'objet d'exploitation directe dans ces endroits, la destruction et la perte des habitats tiennent toujours une part importante (Andreone & Luiselli, 2003) dans la menace sur les amphibiens pandanicoles. La conservation de ces zones constitue alors une assurance, pas seulement pour les amphibiens pandanicoles mais pour toute la faune et la flore de cette région.

Espèce	RS Manongarivo	RNI Tsaratanana	PN Marojejy	RS Anjanaharibe-Sud	RNI Lokobe
Guibemantis liber			+	+	
Guibemantis bicalcaratus		+	+	+	
Guibemantis. pulcher			+	+	
Guibemantis flavobrunneus				+	
Guibemantis cf. *bicalcaratus* 1					
Guibemantis cf. *bicalcaratus* 2					
Guibemantis cf. *bicalcaratus* 3				+	
Guibemantis cf. *bicalcaratus* 4			+		
Platypelis tuberifera			+	+	
Platypelis milloti		+			+
Platypelis tetra				+	
Platypelis cf. *grandis*					

Tab. IV. Liste des espèces pandanicoles observées dans les Aires protégées du grand couloir forestier du Nord.

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RÉSUMÉ

Les amphibiens qui dépendent des *Pandanus* dans le couloir forestier du Nord de Madagascar ont fait l'objet d'un inventaire durant les saisons des pluies des années 2001 et 2003. Ce grand complexe de massifs dans la région septentrionale de l'île comprend environ 69386 Km² de forêt dense ombrophile, dont la diversité biologique est encore peu connue. Nos travaux d'inventaire ont pu récolter 7 espèces d'amphibiens strictement pandanicoles au sein des sites d'étude. En plus, avec l'analyse des spécimens conservés au sein du Département de Biologie Animale, Faculté des Sciences, Université d'Antananarivo, douze espèces ont été identifiées dans cette région comme dépendantes des *Pandanus*. Cette étude montre l'importance de la richesse spécifique des Hautes Terres du Nord, surtout dans les étages de moyenne altitude et montagnard (au-dessus de 800 m). Nos résultats fournissent aussi un nouvel aperçu sur la répartition biogéographique de ces espèces dans les zones d'endémisme et des comparaisons avec les modèles d'endémisme proposés précédemment pour le Nord de Madagascar ont été faites. Enfin, des recommandations sont proposées pour l'expansion des futures aires protégées dans la région septentrionale de Madagascar afin qu'on puisse conserver des zones d'endémisme supplémentaires, non comprises dans le réseau d'aire protégée actuelle.

Mots clés: Amphibien, Mantellidae, Microhylidae, *Guibemantis, Platypelis, Pandanus*, Biogéographie, Madagascar.

Ny Aina Rakotondrazafy
Département de Biologie Animale
Faculté des Sciences
Université d'Antananarivo
BP 906, Antananarivo 101, Madagascar
Email nickyaina@yahoo.fr

Christopher J. Raxworthy
American Museum of Natural History
Central Park West at 79th Street
New York, NY 10024-5192 USA
Email rax@amnh.org

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 233-252

Miguel VENCES[1], Ylenia CHIARI[2], Meike TESCHKE[3], Roger-Daniel RANDRIANIAINA[1], Liliane RAHARIVOLOLONIAINA[4], Parfait BORA[4], David R. VIEITES[5], Frank GLAW[6]

Which frogs are out there? A preliminary evaluation of survey techniques and identification reliability of Malagasy amphibians

ABSTRACT

We provide an estimate of identification reliability of Malagasy frog species based on different methods. According to our estimate, for 168 out of 358 species, a reliable identification based on morphology alone is not possible for reasonably trained researchers. By also considering colouration in life, this number went down to 116 species. Of 252 species for which calls are known, a reliable identification based exclusively on bioacoustics is not possible for 59 species. DNA barcoding performs distinctly better; problems with molecular identification are only known for 61 out of 347 species for which genetic data are available.

In a second approach we also present preliminary data on a comparative study of performance of various inventory techniques applied to three frog communities along eastern rainforest streams. At these streams tadpole collection and their subsequent identification via DNA barcoding allowed for an average detection success of 45% of all species per site, while standardized call surveys detected 28% and visual encounter surveys 29% of the species. However, these results varied widely among rough ecological guilds of frogs, with forest frogs that breed independently from open water, obviously, being undetectable in the tadpole surveys, arboreal frogs being poorly detectable in visual encounter surveys, and stream edge frogs being very poorly detectable in bioacoustic surveys. We suggest that a combination of methods is necessary to obtain a maximum of positively and reliably identified species records in a limited amount of time, and we emphasize the extreme importance of increasing data verifiability by

[1] Technical University of Braunschweig.
[2] Yale University.
[3] Max-Planck Institute for Evolutionary Biology, Plön.
[4] Université d'Antananarivo.
[5] University of California, Berkeley.
[6] Zoologische Staatssammlung München.

listing voucher specimens, and as much as possible, including DNA barcoding, call recording, and photographs in life. For a public and easy access to such supplementary data to any amphibian survey in Madagascar, creation of a joint website is recommended.

Key words: Rapid surveys, Amphibians, DNA barcoding, Identification.

INTRODUCTION

Inventories of Madagascar's amphibian fauna are a major prerequisite for any efficient conservation strategy focused on these organisms (Vallan, 2000; Andreone et al., 2005). Furthermore, inventories are the only means to obtain more complete information on the distribution and biogeography of Madagascar's amphibian species, and even are the main driver of the ongoing discovery of new species. Traditionally, amphibian surveys are carried out in a combination with surveys of the reptile fauna (Andreone, 2004), and the results of both are presented in the form of species lists per site (e.g., Andreone et al., 2000, 2001, 2003; Andreone & Randriamahazo, 1997; Andreone & Randrianirina, 2000; Nussbaum et al., 1999; Rakotomalala, 2002; Ramanamanjato & Rabibisoa, 2002; Raselimanana et al., 2000; Raxworthy & Nussbaum, 1996a,b; Raxworthy et al., 1998; Vences et al., 2002a). Many of these surveys are based on major expeditions with a permanence of sometimes several weeks per mountain massif or forest, with various campsites. In other cases fast inventories of a few days only, so called Rapid Assessments (RAPs) have been carried out even at remote sites. For instance, the MacArthur foundation has funded a rapid assessment program of Malagasy researchers, known as the "RAP Gasy" (A. Raselimanana, pers. comm. in 2006) which over the past years has allowed herpetological surveys of numerous understudied sites in Madagascar, although most of these results are not yet published. There is no major methodological difference between long-term surveys and RAPs except for the study time at a particular site, but short-term studies are often logistically easier in remote areas and an efficient and precise inventorying methodology is particular important in such cases.

However, the existence of multiple sibling species of difficult morphological identification (e.g., Glaw et al., 2001; Köhler et al., 2005; Vences et al., 2002b) and the fast taxonomic progress in understanding the species diversity of this fauna (Blommers-Schlösser & Blanc, 1991; Glaw & Vences, 2000, 2003, 2006) casts doubts on the efficiency of the common amphibian survey practice in Madagascar and claims for comparisons of various detection and identification techniques, and for the development of precise recommendations to carry out surveys in the most cost- and time-effective way, and simultaneously to fully ensure data verifiability.

We here present first data from an ongoing project to develop specific recommendations for the most suitable methods for surveys of Madagascar's amphibian fauna. We estimated the proportions of Malagasy frog species that can unambiguously be identified based on external morphology, morphology plus colour, bioacoustics, and DNA barcoding, and we present data on the survey efficiency of visual encounter, bioacoustic and tadpole-based methods along three short transects in Madagascar's eastern rainforests.

MATERIALS AND METHODS

To obtain estimates on the reliability of identification of Malagasy frogs, we compiled a list of all described species (ca. 232, based on the list of Glaw & Vences, 2003, plus subsequent descriptions) and of a large number of undescribed species which are well enough defined to include them in this analysis (i.e., in most cases by either a highly divergent advertisement call, or by a highly divergent DNA sequence accompanied with at least subtle differences in morphology, colouration, or call). The total number of species included was of 358. For each species we evaluated its similarity to its closest relatives and its morphological variability within and between populations, and estimated whether a moderately trained observer would be able to unambiguously assign a single and well-preserved adult male specimen (males being the specimens with the maximum amount of diagnostic characters such as vocal sacs, femoral glands, etc), without information on the precise locality of provenance, to this species, based on external morphology, or on morphology plus colouration in life. Based on call recordings published by Vences et al. (2006) we also compared for each species where data are available whether the calls can be distinguished from the most similar calls of other species. Large databases of the mitochondrial 16S rRNA gene for almost all species of Malagasy frogs (Vences et al., 2005a,b) were furthermore analyzed to assess whether particular species can be easily identified via DNA barcoding or if potential problems may occur due to known instances of haplotype sharing or of paraphyletic species (see Funk & Omland, 2003).

To obtain comparative data on the efficiency of various survey methods, fieldwork was carried out in February 2006 at various sites in eastern Madagascar and is scheduled to continue in the forthcoming years; in this paper, we present results from three of these sites from where reasonably complete and representative data sets are already available: (1) Imaloka forest in Ranomafana National Park, a stream in largely undisturbed mid-altitude rainforest, surveyed on 23 February 2006 (21°14.527' S, 47°27.909' E, 1020 m above sea level); (2) a stream in highly degraded low-altitude forest along the road from Ifanadiana towards Tolongoina, about 6 km from Ifanadiana, surveyed on 22 February 2006 (21°21.215' S, 47°36.467' E, 468 m a.s.l.); (3) a stream in the largely undisturbed mid-altitude rainforest of An'Ala near Andasibe, surveyed on 8 February 2006 (18.91926°S, 48.48796° E, 889 m a.s.l.). The amphibian community of this latter site has also been studied by Vallan et al. (2004).

At these sites, three different survey types were performed along stream transects of 50 or 100 m. Firstly, 1-2 researchers experienced in tadpole collection and identification collected tadpoles along these transects during daytime for 30-60 minutes, anesthetized them using chlorobutanol solution, and sorted them into series of morphospecies, creating duplicate series especially of the most commonly encountered tadpoles to increase the detection probability of species with similar tadpole morphology. Of each series, a tissue sample was taken from one individual, the whole series preserved in 4-6% formalin, and the DNA voucher specimen identified via DNA barcoding (for detailed descriptions of the methodology employed, see Thomas et al., 2005 and Vences et al., 2005a,b). Secondly, in the evening (roughly within the period of 19-21 h), one researcher experienced with bioacoustic recordings followed the same stream transect and recorded all sounds heard, pointing the microphone both randomly and in the directions of calling frogs, for 10-20 minutes. The recordings were analyzed using the software Cooledit (Syntrillium corp.) and a list of all frogs heard calling was compiled. Thirdly, a group of 3-6 experienced researchers followed the same stream transect for ca. 30 minutes and collected all encountered frogs, by randomly searching on leaves, in the water, on the banks of the stream, and in the adjacent forest to a distance of ca. 3 m from the stream. In this, calls were used as a guidance, but no extreme effort was directed towards collecting frogs calling from difficult positions, e.g., high in the canopy.

At all three sites, additional surveys were carried out on the days before and after the standardized inventories, and we considered all frog species encountered at one site in 2006 by all methods as the frog community present at the time of inventory. Species likely to occur at the site as well, or species encountered at the sites in previous years, were not considered to avoid too heavy biases in our data sets (well-known vs. less well-known sites). Inventory success was measured as the percentage of all species in the community that were detected using one of the three methods described above. We are aware that in such an approach, the data analysed are not independent from the test dataset. More thorough approaches in which the fauna occurring at a site will first be determined by a comprehensive survey, and subsequently the different methods tested against this dataset, are in progress. Considering this caveat, we refrained from performing any statistical analysis of our data.

To understand the dependence of detectability of particular frog species from their general habits, we divided the encountered frog species into four simplified ecological guilds: (1) treefrogs, that is, species that predominantly or exclusively are arboreal, living in bushes or trees and calling from the vegetation along lentic or lotic water bodies; (2) stream edge frogs: species that are terrestrial to semi-aquatic and are mainly found along streams, some species in the water or directly at the edge, some species at some meters from the streams in the leaf litter, all reproducing in the stream; (3) pond edge frogs: species that reproduce in ponds and outside of the reproductive season occur either close to these water bodies or sometimes dispersed in the forest. A last, rather heterogeneous category is (4) forest frogs: these are species that do not reproduce in open lentic or lotic waterbodies and therefore usually occur relatively evenly spaced in the forest, although sometimes they are more common along streams. This category includes tree-hole breeders as well as species with putative direct development. We wish to emphasize that this categorization (as applied in Tab. I-III) is not based on any explicit analysis and is merely used as a convention to be able to refer to groups of frogs with roughly similar habits. A proper definition of ecomorphological guilds of adult frogs is highly needed but lies beyond the scope of the present paper.

RESULTS

A summary of our estimates of identification reliability is given in Fig. 1. As expected, the data show that a large number of frogs cannot be reliably identified using morphology alone. In fact this applied to 168 species, almost half of the total of species included in our analysis. If morphology was combined with colour in life, we still estimate that 116 species cannot be reliably identified if only single male specimens without locality and call data are studied. Also bioacoustic characters are not estimated to provide alone a clear diagnosis: of 252 species for which call data are available, 59 cannot be reliably identified to species level based on calls alone. DNA barcoding performs distinctly better; problems with molecular identification are only known for 61 out of 347 species for which genetic data are available.

The performance of surveys based on tadpole capture, bioacoustics and visual encounters at the three study sites are summarized in Fig. 2. Original data are given in Tables 1-3. At the three study sites Imaloka, Ifanadiana and An'Ala the total number of inventoried frog species was 30, 20 and 52. At all three sites, arboreal frogs were the majority, with 57%, 40% and 44% of all species recorded, followed by stream edge species which made up 33%, 35% and 30%, and forest species which made up 10%, 20% and 21%.

The different survey techniques performed with different success in these three ecological guilds (Fig. 3). Standardized bioacoustic surveys provided records of about one-third of the arboreal and forest species but no single record of any stream edge species. Visual encounter surveys (data only for Imaloka and Ifanadiana) were successful for stream-edge species, with an average of almost one-half of all species recorded, but performed poorly for arboreal and forest species (about one-sixth). Tadpole surveys were most successful, with over one-half of all species detected in arboreal and stream edge species, but with an extremely low but existing success for forest frogs. The latter result was highly surprising, since by definition forest frogs were not supposed to have free-living tadpoles in the streams. Nevertheless, at An'Ala

Species	**Guild**	**Tadpoles**	**Calls**	**Visual Encounter**
Boophis boehmei	arboreal	12	+	-
Boophis bottae	arboreal	-	+?	-
Boophis sp. aff. *goudoti*	arboreal	1	-	-
Boophis elenae	arboreal	8	-	-
Boophis luteus	arboreal	2	-	-
Boophis madagascariensis	arboreal	2	-	-
Boophis majori	arboreal	3	-	-
Boophis marojezensis	arboreal	1	+	4
Boophis picturatus	arboreal	-	+	-
Boophis pyrrhus	arboreal	3	-	-
Boophis reticulatus	arboreal	-	+	10
Boophis sibilans	arboreal	2	-	2
Boophis sp. aff. *sibilans*	arboreal	2	+	-
Boophis tasymena	arboreal	-	-	1
Gephyromantis sculpturatus	forest	-	-	-
Guibemantis tornieri	arboreal	7	-	-
Heterixalus alboguttatus	arboreal	-	-	-
Mantidactylus aerumnalis	stream edge	-	-	-
Mantidactylus sp. aff. *betsileanus*	stream edge	4	-	-
Mantidactylus sp. aff. *biporus*	stream edge	-	-	-
Mantidactylus femoralis	stream edge	-	-	1
Mantidactylus grandidieri	stream edge	-	-	1
Mantidactylus lugubris	stream edge	5	-	-
Mantidactylus majori	stream edge	27	-	15
Mantidactylus melanopleura	stream edge	1	-	-
Mantidactylus sp. aff. *mocquardi* 1	stream edge	1	-	-
Mantidactylus sp. aff. *mocquardi* 2	stream edge	2	-	-
Plethodontohyla sp. aff. *brevipes* 1	forest	-	-	-
Plethodontohyla sp. aff. *brevipes* 2	forest	-	-	-
Spinomantis aglavei	arboreal	-	+	-

Tab. 1. Frog species recorded from Imaloka study site (Ranomafana National Park) during our 2006 survey, their simplified ecological guild, and the efficiency of three different standardized survey methods in their detection along a stream transect of 50 m are indicated: (a) DNA-based identification of tadpole series collected during the day during ca. 30 minutes along the transect; (b) nocturnal bioacoustic recording of 10 minutes along the transect; (c) nocturnal visual encounter survey during 30 minutes along the transect. The table shows the number of tadpole series assigned to a particular species by DNA barcoding, and the number of metamorphosed frog specimens of each species collected during the visual encounter surveys. Bioacoustic data were not analyzed quantitatively. A "+" in the "Calls" column indicates existence of at least one positively identified call record for that species. Surveys were carried out on 23 February 2006.

Species	Guild	Tadpoles	Calls	Visual Encounter
Anodonthyla boulengeri	forest	-	+	1
Blommersia grandisonae	arboreal	-	-	-
Boophis albilabris	arboreal	1	-	-
Boophis madagascariensis	arboreal	3	+	2
Boophis opisthodon	arboreal	-	-	-
Boophis sp. aff. *rappiodes*	arboreal	-	-	-
Boophis pyrrhus	arboreal	1	+	4
Gephyromantis boulengeri	forest	-	+	-
Gephyromantis sculpturatus	forest	-	+	-
Guibemantis timidus	arboreal	-	-	-
Heterixalus alboguttatus	arboreal	-	-	-
Mantidactylus aerumnalis	stream edge	2	-	
Mantidactylus betsileanus	stream edge	-	-	1
Mantidactylus sp. aff. *betsileanus*	stream edge	1	-	
Mantidactylus femoralis	stream edge	-	-	2
Mantidactylus grandidieri	stream edge	-	-	-
Mantidactylus majori	stream edge	-	-	3
Mantidactylus melanopleura	stream edge	-	-	1
Ptychadena mascareniensis	pond edge	-	-	-
Stumpffia sp.	forest	-	+	-

Tab. 2. Frog species recorded from Ifanadiana study site (near Ranomafana) during our 2006 survey, their simplified ecological guild, and the efficiency of three different standardized survey methods in their detection along a stream transect of 100 m are indicated: (a) DNA-based identification of tadpole series collected during the day during ca. 30 minutes along the transect; (b) nocturnal bioacoustic recording of 10 minutes along the transect; (c) nocturnal visual encounter survey during 30 minutes along the transect. The table shows the number of tadpole series assigned to a particular species by DNA barcoding, and the number of metamorphosed frog specimens of each species collected during the visual encounter surveys. Bioacoustic data were not analyzed quantitatively. A “+” in the “Calls” column indicates existence of at least one positively identified call record for that species. Surveys were carried out on 22 February 2006.

we identified several series of tadpoles of *Gephyromantis asper,* previously supposed to have endotrophic development (Blommers-Schlösser, 1979a). This result, which demonstrates the power of tadpole DNA barcoding to understand the life-history of anurans, will be presented and discussed more in detail elsewhere. Averaged over all localities and guilds, tadpole surveys recorded an average of 45% of the species, standardized call surveys recorded 28% of the species, and visual encounter surveys recorded 29%.

Species	**Guild**	**Tadpoles**	**Calls**
Aglyptodactylus madagascariensis	pond edge	-	-
Blommersia blommersae	arboreal	-	-
Blommersia grandisonae	arboreal	-	-
Boophis albilabris	arboreal	2	-
Boophis boehmei	arboreal	9	-
Boophis bottae	arboreal	-	-
Boophis burgeri	arboreal	1	-
Boophis elenae	arboreal	1	-
Boophis liami	arboreal	1	-
Boophis lichenoides	arboreal	1	-
Boophis luteus	arboreal	4	-
Boophis madagascariensis	arboreal	5	-
Boophis marojezensis	arboreal	7	+
Boophis picturatus	arboreal	2	+
Boophis pyrrhus	arboreal	8	+
Boophis reticulatus	arboreal	4	+
Boophis rufioculis	arboreal	17	+
Boophis sibilans	arboreal	2	+
Boophis sp. aff. *sibilans*	arboreal	-	-
Boophis tasymena	arboreal	6	+
Gephyromantis asper	forest	2	-
Gephyromantis boulengeri	forest	-	-
Gephyromantis redimitus	forest	-	+
Gephyromantis sculpturatus	forest	-	-
Guibemantis depressiceps	arboreal	-	-
Guibemantis liber	arboreal	-	-
Guibemantis tornieri	arboreal	1	-
Guibemantis sp. aff. *albolineatus*	forest	-	-
Guibemantis pulcher	forest	-	-
Mantella baroni	stream edge	-	-
Mantella pulchra	stream edge	-	-
Mantidactylus aerumnalis	stream edge	13	-
Mantidactylus albofrenatus	stream edge	1	-
Mantidactylus argenteus	stream edge	6	-
Mantidactylus betsileanus	stream edge	1	-
Mantidactylus sp. aff. *betsileanus*	stream edge	-	-
Mantidactylus sp. aff. *biporus*	stream edge	-	-
Mantidactylus femoralis	stream edge	8	-
Mantidactylus grandidieri	stream edge	-	-
Mantidactylus lugubris	stream edge	-	-

Mantidactylus melanopleura	stream edge	13	-
Mantidactylus sp. aff. *mocquardi*	stream edge	5	-
Mantidactylus opiparis	stream edge	16	-
Mantidactylus sp. aff. *tricinctus*	stream edge	1	-
Mantidactylus zolitschka	stream edge	3	-
Platypelis barbouri	forest	-	-
Platypelis cf. *pollicaris*	forest	-	-
Platypelis tuberifera	forest	-	-
Plethodontohyla notosticta	forest	-	-
Plethodontohyla inguinalis	forest	-	-
Ptychadena mascareniensis	pond edge	-	-
Spinomantis aglavei	arboreal	1	+

Tab. III. Frog species recorded from An'Ala during our 2006 survey, their simplified ecological guild, and the efficiency of three different standardized survey methods in their detection along one stream transect of 50 m are indicated: (a) DNA-based identification of tadpole series collected during the day during ca. 30 minutes along the transect; (b) nocturnal bioacoustic recording of 10 minutes along the transect; no data from nocturnal visual encounter surveys are available from this site. The table shows the number of tadpole series assigned to a particular species by DNA barcoding. Bioacoustic data were not analyzed quantitatively. A "+" in the "Calls" column indicates existence of at least one positively identified call record for that species. Surveys were carried out on 8 February 2006.

DISCUSSION

Identification verifiability - a main theme for surveys

In species inventories and rapid assessments, amphibians and reptiles are usually inventoried together and included as a joint list in the corresponding report or publication. Although the search for calling males is certainly employed by most researchers in the field for frogs, the calls themselves are rarely used for species identification. However, as compared with reptiles, a main problem is the rareness of well-defined morphological characters in amphibians (e.g., Duellman, 1970; Glaw et al., 2001).

The poor performance of bioacoustics in species identification as reported here requires some additional comments, as bioacoustic characters have proven to be an excellent tool in diagnosing new frog species from Madagascar since the pioneering works of Blommers-Schlösser (1979a,b). In fact, the presence of constant bioacoustic differences between two frog species is a reliable indicator for specific distinctness. In general, sympatric species always differ distinctly in their calls. However, and this is reflected by the analysis here, instances of (almost exclusively) allopatric species exist where high genetic and morphological divergences clearly support a status as different species although their calls are still similar. In these cases, a species

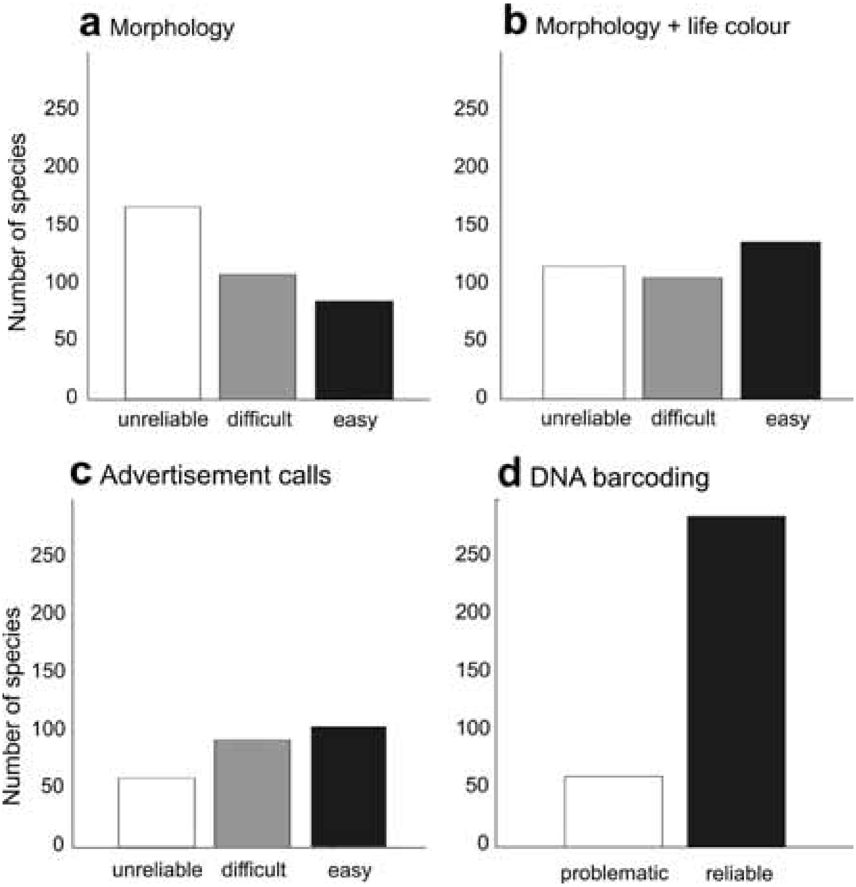

Fig. 1. Estimates of identification reliability for a total of 358 described and undescribed Malagasy frog species (not all species included in each separate estimate, depending on data availability). (a) numbers of species that can be identified, or not, from all other species using morphology of preserved specimens as only character set; (b) numbers of species that can be identified using morphology plus information on colour in life; (c) numbers of species that can be identified based only on call recordings; (d) numbers of species that can be identified using DNA barcoding. In (a) and (b), identification is considered easy if well-preserved adult male specimens can be determined at first glance, looking at only a few distinct characters or colour patterns, difficult if examination of hidden or small characters, or body proportions are necessary, and unreliable if overlap of character values compared to other species occurs or no diagnostic morphological characters are known. In (c), identification is considered easy if calls can immediately recognized by the human observer, difficult if analysis of temporal or spectral patterns in sonograms is necessary, and unreliable if calls are overlapping in all values with those of other species. In (d), identification is considered problematic if instances of haplotype sharing with other species are known, genetic divergences to other species are very low and haplotype sharing is to be expected, or if species are paraphyletic based on their mitochondrial phylogeny or nested within other paraphyletic species.

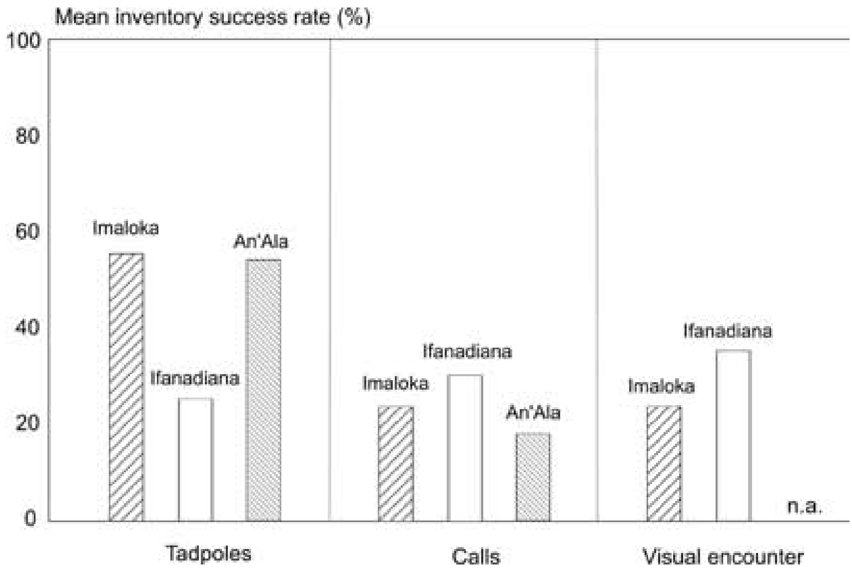

Fig. 2. Mean rate of success in standardized inventories along rainforest streams as described in the text at three sites (Imaloka, Ifanadiana and An'Ala), in percent of the total number of species known from each site. Values are given for three different inventory methods: tadpole surveys based on DNA barcoding identification, bioacoustic surveys, and visual encounter surveys. No visual encounter survey results are available for An'Ala.

identification based solely on advertisement calls must remain unreliable, although in concert with morphological data and/or locality information a better performance can be attained. In general, it remains true that a careful analysis of morphology, colouration in life and advertisement calls would allow to clearly diagnose almost all Malagasy frog species.

It also needs to be remarked that our estimates of identification reliability are based on own experience, and that in some groups, after very intensive study, it would probably become possible to elaborate morphological keys that lead to species identification of high reliability. However, we doubt that such keys would be applicable by less specialized researchers, and certainly such identification would require a very time-consuming study of various morphological characters and possibly morphometric ratios.

Our data on the difficulties in morphological identification of Malagasy frog species, plus the rapid taxonomic changes to which this fauna is currently subjected, have strong implications on the common practice on reporting the results of amphibian surveys in Madagascar in the form of mere species list. Except for a few easily recognizable species, we here make the

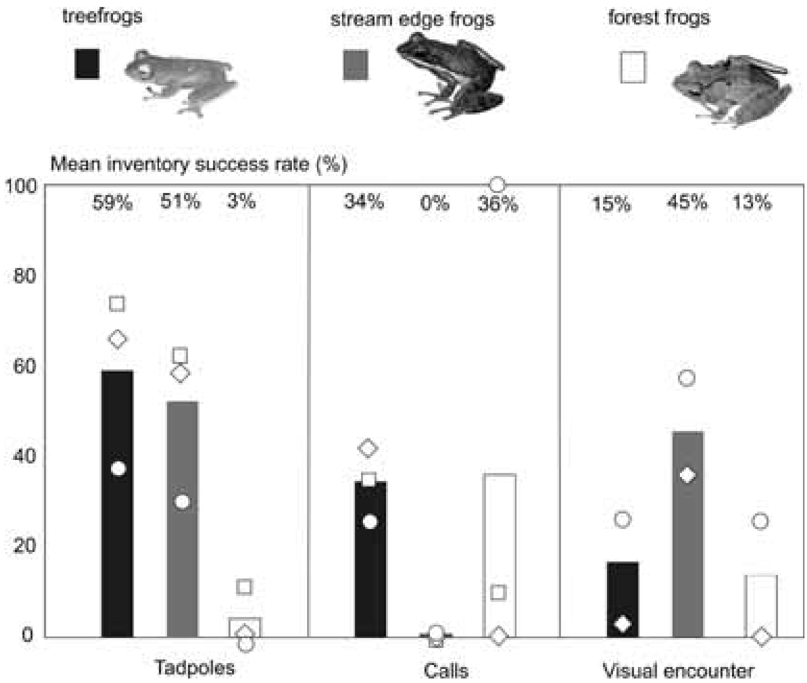

Fig. 3. Mean rate of success in standardized inventories along rainforest streams as described in the text, averaged over three sites (see Fig. 2), and given separately for three tentative ecological guilds of frogs: arboreal frogs (treefrogs), frogs living mainly on the edge of streams, and frogs living mainly dispersed in the forest. Values are given for three different inventory methods: tadpole surveys based on DNA barcoding identification, bioacoustic surveys, and visual encounter surveys. Symbols represent single data points from Imaloka (rhomboid), Ifanadiana (circle) and An'Ala (square).

drastic statement that these lists are almost worthless for amphibians, although such problems occur only to a much lower degree for reptiles. To allow verifiability of such survey data in amphibians, we encourage a practice in which the species lists are accompanied by a list of voucher specimens deposited in an accessible public collection. Collection of tissue samples clearly assignable to individual specimens, and sequencing of a standardized gene fragment from these tissue samples, would be a further ideal complement, and we envisage a future in which standardized DNA isolation and PCR for this purpose can be done in Madagascar, with a commercial or institutional outsourcing of the sequencing. Species lists in publications could then be accompanied by the Genbank accession numbers of the obtained sequences. Furthermore, it would be an enormous improvement if the accompanying data, such as DNA sequences, specimen photographs, and call recordings, would be made available via a centralized website.

The advantages of a DNA-based identification system have often been emphasized (e.g., Savolainen et al., 2005). DNA sequences deposited in Genbank can be easily and quickly retrieved from any part of the world via internet, and directly and unambiguously compared to homologous sequences obtained by other research groups. Identifications even of juveniles or of not collected specimens can therefore be verified, also by researchers in Madagascar despite the less developed local laboratory infrastructure. Morphology-based identification, on the contrary, in a group as diverse and complex as Malagasy frogs is only possible by specialized researchers after intensive morphological training.

Capacities for DNA based identification in Malagasy laboratories

If a DNA based identification system is to be implemented for amphibian surveys in Madagascar, the financial costs are to be considered as well. At the time of writing the current article, no DNA sequencing facility exists at Madagascar, and DNA sequencing is commercially accessible for 3 EUR in some countries. Costs of DNA isolation, PCR and PCR purification can be estimated at a maximum of 2 Euro, although distinctly lower costs can be achieved in high-throughput systems. Altogether, a standardized marker sequence can therefore be obtained for 5-6 Euro in a relatively easy setup that at least partly could function under local conditions in Madagascar. However, automated DNA sequencers are not only extremely expensive machines but also require regular maintenance that is not available in Madagascar. Even without maintenance costs, it would be difficult to achieve sequencing costs as low as those of commercial companies if such a machine would be installed in Madagascar. Under current conditions and technical possibilities, we suggest a system in which DNA isolation and PCR would be carried out in Madagascar and the sequencing itself would be outsourced to commercial companies.

Perspectives and suggested methods for amphibian surveys in Madagascar

Besides the general suggestions for data presentation and listing of voucher specimens outlined above, there are also some obvious recommendations for field techniques in surveys following out of our results. The very good performance of tadpole surveys is encouraging and indicates that standardized tadpole collection should be included in any future species inventory study of Malagasy amphibians, also considering the importance of these larval amphibians for stream ecosystems (e.g., Whiles et al., 2006). At present we lack information on the comparative performance of the various techniques in the dry season, but we believe that the advantages of tadpole surveys are their relative independence from climatic and weather conditions: it should be possible to perform successful tadpole inventories both in dry intervals during the rainy season, and indeed during the dry season, when calling activity, and reproductive activity in general, of most species is strongly reduced and bioacoustic and visual encounter methods will fail to produce sufficient data for the arboreal species. The drawback of tadpole inventories, i.e., the need for routine application of molecular techniques, is a challenge that should be overcome by a major institutional effort rather than by isolated efforts of each single research group.

Furthermore, although bioacoustic methods were not highly successful in our study, they still provide an easy means to reliably identify a large proportion of the arboreal species, and especially of the forest species that mostly do not have free-swimming tadpoles.

Besides tadpoles and bioacoustics, the need for collecting the visually encountered adult frog specimens is obvious: on one hand, these are important as voucher specimens for possible future morphological comparisons or taxonomic studies. On the other hand, for stream edge frogs, visual encounter collecting proved to be an efficient survey technique according to our results.

If surveys are carried out over longer periods, i.e., a week or more, it is likely that a large number of the frog community will be detected and voucher specimens collected even without tadpole surveys or bioacoustic recordings. Hence, it would seem that in such cases, the classical methodologies are sufficient. However, due to the low identification reliability if diagnosing the collected frogs based on their morphology alone, also in such cases the resulting list of species would be likely to be partly unreliable, incomplete and unverifiable. Therefore, also in such longer surveys, recording of calls and routine collection of DNA samples of every collected frog individual should be implemented.

As emphasized in the title and introduction, the data presented here are merely the first results of a more comprehensive comparison of survey techniques that will be carried out within the next years. Furthermore, in the present study we focused on survey techniques along streams, largely ignoring pond frogs and not exploring specific techniques for forest frogs living in leaf axils and tree holes, or in the leaf litter (for the latter group, for example, pitfall trapping is an important survey method). While developing a precise protocol for amphibian surveys is beyond the scope of this paper and would be premature at the present stage, we can advance here that a combination of call recordings, collection of voucher specimens of adult and larval stages, and DNA barcoding will provide a cost-effective means to obtain quick and verifiable inventories of Madagascar's amphibians.

Lessons for frog monitoring in Madagascar

The data presented here were directed towards the development of a more efficient methodology for surveys of the amphibian species diversity at particular sites in Madagascar. Such surveys are and will remain extremely important to understand the status of particular sites and to prioritize conservation efforts. For remote sites, rapid surveys will remain the only feasible option if many localities are to be surveyed in a limited time. However, a second important need is the establishment of a regular monitoring of a number of representative sites in Madagascar: on one hand, to understand population dynamics and status of threatened or commercialized species, on the other hand to understand community dynamics and possible declines, especially in the light of a possible spread of emerging diseases such as chytridiomycosis (e.g., Lips et al., 2006). The protocols used herein are not or only in a limited way directly applicable for such monitoring of communities, but still there are a number of particularities that need to be considered when specific monitoring protocols are to be developed. (1) The high number of arboreal species along streams in Madagascar's rainforests makes it difficult to apply any pure visual encounter technique, since these frogs often call from high in trees, and are not usually encountered when not reproducing. (2) The low-intensity calls of most stream-edge frogs will not be captured sufficiently by approaches relying solely on automated bioacoustic recording (see Peterson & Dorcas, 1994). (3) Although tadpole identification turned out to be the most efficient survey method in our study, this technique relies on routine regular application of DNA sequencing and killing of large number of specimens, and such methods will usually not be applicable to long-term monitoring approaches. (4) Although bioacoustics performed poorly in our results, it remains an excellent and straightforward method to detect arboreal species during the breeding season, and it is a very reliable identification technique if applied at particular sites where the amphibian fauna is known. (5) The problems in identification reliability make an initial intensive inventory of any monitoring site necessary, of which DNA barcoding would be a crucial component to allow subsequent allocation of the monitoring results to changing taxonomies. As a conclusion, approaches to monitor amphibian communities in Madagascar's rainforests need to apply an initial inventory carried out by experts, and subsequently should apply a combination of bioacoustic and visual encounter techniques to detect all major ecological guilds of frogs.

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RÉSUMÉ

Quelle grenouille y a-t-il là-bas? Une évaluation préliminaire des techniques d'inventaire et de la fiabilité d'identification des amphibiens malgaches.

Cette étude présente une estimation de la fiabilité des différentes méthodes d'inventaire et de détermination des espèces de grenouilles malgaches sur le terrain. Ainsi nous présentons les premières données d'une étude comparative de différentes techniques d'inventaire des communautés de grenouilles vivant aux alentours des ruisseaux de la forêt tropicale humide de Madagascar. D'après notre évaluation, une identification crédible basée seulement sur la morphologie n'est pas possible même pour les spécialistes en herpétologie pour 168 sur 358 espèces. En incluant la coloration en vie, ce nombre régresse jusqu'à 116 espèces. Parmi les 252 espèces dont leurs vocalisations sont connus, une identification fiable exclusivement basée sur la bioacoustique n'est pas possible pour 59 espèces. La séquence d'ADN leur permet une meilleure détermination, car seulement 61 sur 347 espèces dont les données génétiques sont disponibles, ont des problèmes avec l'identification moléculaire. Dans trois différents ruisseaux de la forêt tropicale humide de l'Est de Madagascar, la collection des têtards suivie par leur identification par le biais de leur séquence d'ADN a permis de détecter les 45% des espèces inventoriées par site, tandis que l'écoute des cris et l'observation aléatoire des adultes ont permis de découvrir respectivement 28% et 29%. Cependant, ces résultats sont largement variés suivant le type écologique des grenouilles: les grenouilles forestières qui vivent indépendamment des plans d'eau n'ont pas été décelable dans les études de têtards, les grenouilles arboricoles ont été pauvrement dépistable par l'observation aléatoire, et les grenouilles vivant au bord du ruisseau ont été très pauvrement détectable par la bioacoustique. Nous suggérons donc qu'une combinaison de ces trois méthodes soit nécessaire pour obtenir un nombre maximum d'espèces qui sont bien déterminées dans un intervalle de temps limité et nous signalons également l'importance majeure de la vérifiabilité des données par l'existence des spécimens de référence, en incluant autant que possible la séquence d'ADN, l'enregistrement de cris et les photos de l'animal en vie. La création d'un site web commun est recommandée afin de permettre un accès facile et public à de telles données supplémentaires concernant toutes les études des amphibiens de Madagascar.

Mots clés: Inventaire rapide, Amphibiens, séquence d'ADN, Identification.

Miguel Vences
Zoological Institute
Technical University of Braunschweig
Spielmannstr. 8
38106 Braunschweig, Germany
Email m.vences@tu-bs.de

Roger-Daniel Randrianiaina
Liliane Raharivololoniaina
Parfait Bora
Département de Biologie Animale
Université d'Antananarivo, BP, 906
101 Antananarivo, Madagascar

Ylenia Chiari
Department of Ecology and Evolutionary Biology and YIBS-Molecular Systematics and Conservation Genetics Lab.
Yale University
21 Sachem St.
New Haven, CT, 06520-8105, USA

Meike Teschke
Max-Planck Institute for Evolutionary Biology
Department of Evolutionary Genetics
24306 Plön
Germany

David R. Vieites
Museum of Vertebrate Zoology and Department of Integrative Biology
3101 Valley Life Sciences Bldg.
University of California
Berkeley, CA 94720-3160. USA

Frank Glaw
Zoologische Staatssammlung München
Münchhausenstr. 21
81247 München, Germany

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 253-264

Falitiana C.E. RABEMANANJARA[1], Parfait BORA[1], Tokihery J. RAZAFINDRABE[1], Edouard RANDRIAMITSO[1], Olga RAVOAHANGIMALALA RAMILIJAONA[1], Noromalala RASOAMAMPIONONA RAMINOSOA[1], Daniel RAKOTONDRAVONY[1], David R. VIEITES[2], Miguel VENCES[3]

Rapid assessments of population sizes in ten species of Malagasy poison frogs, genus *Mantella*

ABSTRACT

Among the amphibians of Madagascar, the Malagasy poison frogs of the genus *Mantella* are the group that is most heavily collected for the pet trade. Although the taxonomy and genetic diversity of these frogs has been intensively studied in the past, very few data on their population dynamics are available, although such data are badly needed to evaluate and regulate their commercial collecting and export. Here we summarize available population density data on Malagasy poison frogs and report on own data based on rapid mark-recapture population estimates of ten *Mantella* species, carried out between 2003-2007. Population sizes usually were around 50-200 individuals, but these data must be seen as preliminary because they refer to specimens at particular reproduction sites (in swamps or along streams), and in some cases are heavily biased towards males since females were more difficult to collect. These partly very high population densities in our and previous studies refer to specimens gathering in very small areas (down to 50 square meters in *Mantella viridis* where the highest densities were recorded) and therefore can by no means be extrapolated to the whole distribution areas of these species. Long-term studies of the dynamics of particular populations, home ranges and dispersal, and of longevity and recruitment, need to be combined with such short-term density estimates to understand the perspectives of sustainable harvesting of Malagasy poison frogs.

Key words: Amphibians, Conservation, Madagascar, *Mantella,* Population estimate.

INTRODUCTION

Madagascar, because of its unique biodiversity, can be considered as a real living laboratory for biologists, deserving the highest priority for conservation

[1] Université d'Antananarivo.
[2] Museum of Vertebrate Zoology and Department of Integrative Biology, University of Carlifornia at Berkeley.
[3] Technical University of Braunschweig.

(Myers et al., 2000). All currently described 238 species of non-introduced Malagasy amphibians are fully endemic on this fourth largest island of the world, and are not safe from a variety of threats (Andreone & Luiselli, 2003; Andreone et al., 2005). Despite a high intensity of recent research, Madagascar's amphibian diversity still has not revealed all its mysteries. Every year, researchers in Madagascar discover numerous undescribed species, and no full species inventory will be available in the next few years (Vences & Glaw, 2003). In addition, taxonomic revisions at the genus level have proven to be necessary after introduction of new methods, such as DNA analyses (Glaw & Vences, 2006).

The endemic Malagasy genus *Mantella* is currently constituted by 17 species (Vences et al., 1999). The systematics of the group is subject to revision using molecular techniques, which revealed that even within one species, considerable color variations can occur: this case was evidenced by mitochondrial DNA sequence analysis of different populations of *Mantella crocea* (variation of yellow to green), *Mantella milotympanum* (variation of red to green), and *Mantella baroni* (variation of extent of yellow dorsal colour), collected in different areas of Madagascar (Chiari et al., 2004, 2005; Rabemananjara et al., 2007a). The existence of different species groups in the genus has been first evidenced by allozyme analyses (Vences & Kniel, 1998), but until now, full taxonomic stability has not been reached. For example the brown species of *Mantella* in the *M. betsileo* complex are to be divided into various distinct lineages, at least one of which probably represents an undescribed species (Rabemananjara et al., 2007b). Besides major efforts in molecular systematics, a second line of research has, in the past years, focused on the alkaloid components of the skin of these frogs (Daly et al., 1996, 2002), and the biological origin of these toxins that are uptaken from the frog's prey (e.g., Daly et al., 1997; Clark et al., 2005).

Because of their attractive and variable pattern, almost all *Mantella* species are exploited for the international wildlife trade, this genus being the one with more exports in terms of Malagasy amphibians present in the pet trade (>230,000 individuals over 10 years 1994–2003) (Rabemananjara et al., *in press*). All representatives of the genus are actually included in appendix II of the Convention on the International Trade in Endangered Species (CITES) (Nairobi, Kenya, 10-20 April 2000). Madagascar ratified this convention in 1975 (ordinance 75-014 of 5 August 1975) to better protect and control the trade of living animals exported from the island. The Malagasy scientific authority is depending on thorough research results to set up the quotas of *Mantella* species, especially regarding population densities and species distributions which have remained largely unexplored.

Population density studies are difficult to perform in the tropics, because they are resource-intensive (Bailey et al., 2004), especially if carried out in remote areas that are often only reachable after hours of walking. An opportunity for such studies arose as in 2003 when a major project on the biology and alkaloid content of *Mantella* populations was started by the University of Antananarivo. During the fieldwork related to this study, populations of most *Mantella* species were visited and several rapid assessments of population densities obtained. In some cases, these data were already been made available to local authorities in the context of conservation management, but so far most data remained unpublished.

The present paper reviews all data available to us, published and unpublished, on density estimates of *Mantella* species, also adding new surveys that were carried out with similar methodology in the framework of other research projects. Our results refer to ten species of *Mantella* Boulenger, 1882, including *Mantella aurantiaca* Mocquard, 1900*, M. baroni* Boulenger, 1888*, M. bernhardi* Vences, Glaw, Peyrieras, Böhme & Busse, 1994*, M. betsileo* (Grandidier, 1872)*, M. crocea* Pintak & Böhme, 1990*, M. laevigata* Methuen & Hewitt, 1913*, M. madagascariensis* (Grandidier, 1872)*, M. milotympanum* Staniszewski, 1996*, M. pulchra* Parker, 1925 and *M. viridis* Pintak & Böhme, 1988. Four additional species, *M. cowani* Boulenger, 1882*, M. expectata* Busse & Böhme, 1992*, M. haraldmeieri* Busse, 1981 and *M. nigricans* Guibé, 1978*,* were also studied, but sample sizes were too low to obtain adequate mark-recapture estimates of population sizes. As we will emphasize again in the conclusions, the data presented here are far from thorough estimate of populations of *Mantella*, but they give the first and so far most reliable data of the approximate dimension of breeding aggregations of these frogs, across a wide array of species.

MATERIAL AND METHODS

Sites and study periods

Data were gathered over three survey periods per population within one reproductive cycle between June 2003 and April 2004. Some other independent studies were carried out between 2004 and 2007 by different researchers and are included in this manuscript (e.g., Vieites et al., 2005).

The study periods could roughly be classified according to four seasons: pre-reproduction (between September and November), reproduction (between December and February), post-reproduction (between March and April), and hibernation (between May and August). Most of the mark-recaptures took place during the breeding season (December-February) and in several of them (e.g., *M. baroni*, especially in the case of Kidonavo) the captured specimens were mostly males. In addition, the selected areas for the estimates were sites with high prevalence of *Mantella*, species which in general are known to be not continuously distributed but to aggregate at specific places (Daly et al., 1996). Hence, all density estimates for these frogs (previously published and herein) need to be taken with extreme caution as they only refer to particular sites, and the estimates in total numbers must be seen as minimum estimates (rapid assessments) that only refer to the part of the population that was gathering in the mating area at that particular time, and sometimes only to the males. In addition, several species occur along streams, like *M. baroni*, and specimens were collected along a linear transect following the stream which makes it even more difficult to relate population size estimates to a particular area.

Mark-recapture method

Mark-recapture is considered to be an adequate method to estimate population sizes and densities of amphibians (Funk et al., 2003; Bailey et al., 2004). Our surveys were carried out over short periods (2 days minimum and 7 days maximum) with 4 to 7 capture occasions. Considering that no concerted long-distance migrations of *Mantella* have been reported so far, and considering the periods between recaptures were fairly short (1.5 h to 24 h), we assumed that the studied populations were closed (see White et al., 1982). Toe-clipping of one toe was chosen for marking, considering that this technique allows high survival rates (>98%) (Hott & Scott David, 1999) and insures full mark retention, assumptions needed for mark-recapture methods (White et al., 1982). The capture effort was constant in most estimates, with 4 hour-persons (4 persons searching during one hour) per capture event, and recapture rates were up to 10% of previously marked individuals. The release of animals was carried out by each researcher in the plot section where they had been initially captured, to ensure the animals were spread enough over the whole study area and could mix with the rest of the population in a relatively short period. Due to the limited time available at each site it was not possible to apply individual markings to each specimen, and therefore the use of calculation methods available for open populations (such as the Jolly-Seber method) was not possible. We here apply the calculation method of Schnabel (1938) with 95% confidence intervals.

Population size estimates and summary of literature

The population size estimates from our data are summarized in Tab. I and range from 35 to 467 individuals. The original data used to calculate these values are reported in the Appendix. The confidence intervals were not very wide, and minimum and maximum population sizes ranged from 27-683 when confidence intervals were taken into account. From a total of 25 separate population estimates, 12 yielded population sizes below 100 individuals, and 17 yielded values below 200 individuals. Population estimates were highly variable among species, indicating that local conditions exert strong influences on the number of specimens gathering in a particular area for breeding. A slight indication is found that in species of the *Mantella betsileo* group (i.e., in *M. betsileo* and *M. viridis*), population sizes are on average larger than in others species: 4 out of 6 estimates were higher than 200 individuals, and the two highest values, above 400 individuals, corresponded to *M. viridis.* Since the populations of these two species studied here occur in rather dry, seasonal areas, the results may indicate that in these areas, the specimens aggregate even more strongly in a limited number of moist areas suitable for reproduction.

Data available so far, mostly from unpublished reports, always referred to population densities, not absolute numbers of individuals, and were as follows: For *Mantella aurantiaca*, Behra et al. (1995) observed densities between 14 to 230 individuals per hectare (ind/ha). For *M. bernhardi,* a density of 100-500 individuals by square km, thus 1 to 5 ind/ha, was mentioned for the

Species	Localities	Period	Population size N (Schnabel)	Population size with 95% c. i.	Study plot surface	"Density" /ha
Mantella aurantiaca	Andranomandry	21-23 Jan 2004	86	64 - 126	750m²	1267
	Torotorofotsy	20-25 Feb 2004	75	63 - 95	600m²	1317
	Torotorofotsy	21-22 Jan 2007	201	167 - 251	2500m²	836
Mantella baroni	Fanjavala	15-17 Jan 2004	108	81 - 161	2000m²	605
	Ampasimpotsy (Antoetra)	5-7 Dec 2003	92	78 -112	1089m²	872
	Kidonavo	21-29 Jan 2004	49	37 - 72	600m²	900
Mantella bernhardi	Mangevo, inside Ranomafana National Park	11-12 Dec 2003	41	32 - 59	750m²	600
	Mangevo, outside Ranomafana National Park	11-12 Dec 2003	316	254 - 420	750m²	4480
	Tolongoina	16-19 Dec 2003	73	57 - 101	750m²	1053
	Manombo	1-3 Feb 2004	88	60 - 163	480m²	2333
Mantella betsileo	Ankadirano	10-12 Sep 2003	253	207 - 325	400m²	6650
	Kirindy	27-29 Nov 2003	208	182 - 244	625m²	3392
Mantella crocea	Ankosy Marovoay	7-8 Feb 2004	35	27 - 49	200m²	1900
Mantella laevigata	Marojejy	20-21 Dec 2003	189	134 - 319	250m²	9040
		19-21 Mar 2004	154	97 - 378	250m²	9480
Mantella madagascariensis	Fanjavala	15-17 Jan 2004	186	132 - 314	2000m²	1115
Mantella milotympanum	Sahamarolambo (near Fierenana)	18-22 Feb 2003 (Vieites et al. 2005)	283*	---	6000 m²	470*
		11-13 Aug 2003	62	46 - 93	625m²	1120
		30 Jan - 1 Feb 2004	217	181 - 272	625m²	3616
		4-6 Apr 2004	86	69 - 111	625m²	1440
Mantella pulchra	An'Ala	9-11 Jan 2004	98	82 - 124	400m²	2575
Mantella viridis	Andranomantsina	30 Aug - 1 Sep 2003	467	407 - 548	50m²	95400
		26-28 Nov 2003	430	314 - 683	50m²	99600
	Andohatany	30 Aug - 1 Sep 2003	100	81 - 131	50m²	21200
		26-28 Nov 2003	75	49 - 157	50m²	20800

Tab. I. Summary of population size estimates carried out on *Mantella* populations using mark-recapture methods. The definitive densities were calculated based on population sizes averaged from the Schnabel estimator with 95% confidence interval. The population size of *M. milotympanum,* here reproduced from Vieites et al. (2005) (with asterisk) was calculated as average of Petersen (1896) estimates. Note the population "densities" calculated in the last column refer only to densities of the specimens at the study plots, and are merely reported to emphasize these frogs can occur in very dense breeding aggregations in very small areas, but these data should in no case be extrapolated to larger areas.

Ambohimanana zone, a site of intensive collecting using capture without release (Ramanamanjato et al., 1994). For *M. ebenaui,* densities between 100-253 ind/ha were reported in Zahamena during the reproductive period (Ramanamanjato et al., 1994). For this same species, in 1994, densities of 46 to 440 ind/ha and 100 ind/ha have been estimated respectively in Ankarana and Benavony (Rakotomavo, 2001), and in Lokobe, a density of 133-273 ind/ha in

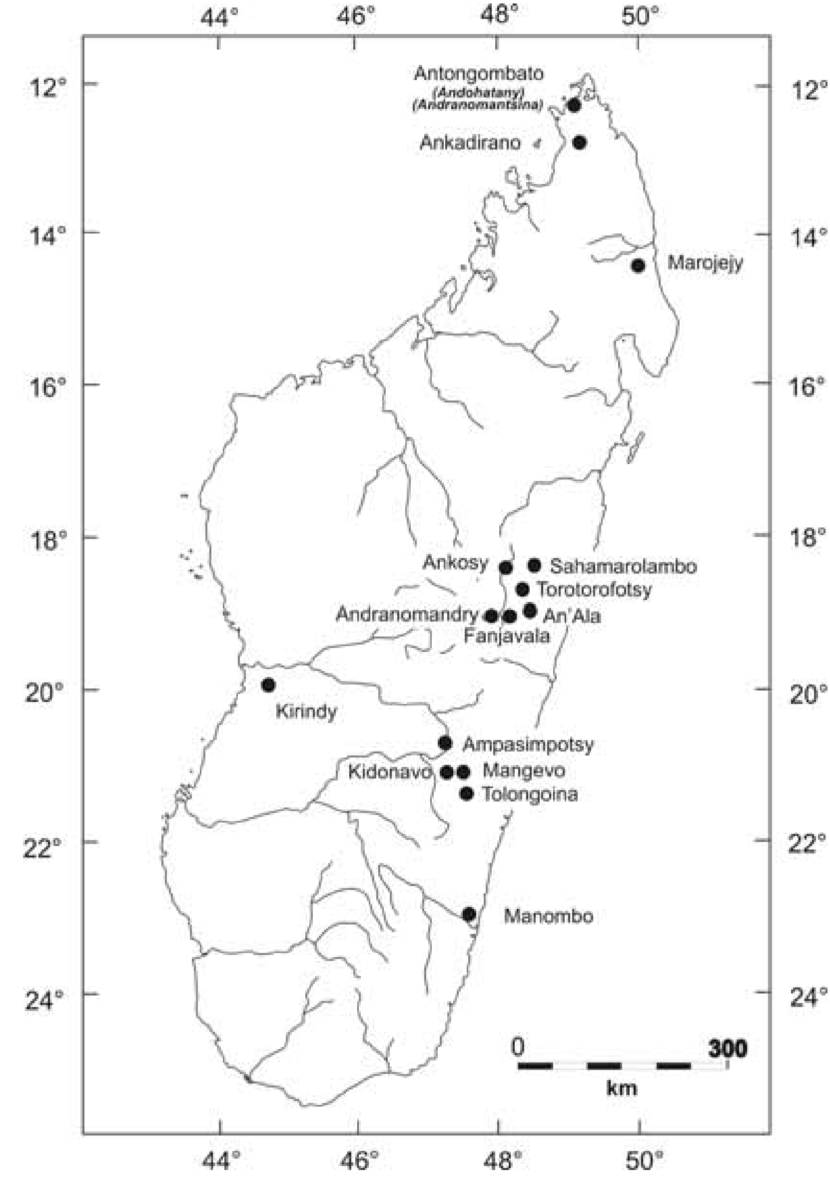

Fig. 1. Map of study localities as listed in Tab. I.

2000 (Rakotomavo, 2001). The methodology used for the estimates was not mentioned, and most of these estimates were reported under the name *M. betsileo* (but the north-eastern and north-western populations previously considered under that name are now assigned to *M. ebenaui;* see Rabemananjara et al., 2007b). For *M. cowani,* species for which we were unable to obtain population size data, the following density estimates in the Antoetra region in 1996, during the reproduction period, have been mentioned: 1050 ind/ha in the marshy area, 750 ind/ha in savannah, 350 ind/ha in eucalyptus forest, 750 ind/ha in edge and 550 ind/ha in bamboo forest, in Andalasakaviro, 110 ind/ha and 190 ind/ha in Amparihimazava (BIODEV ,1996). The methodology used was the cumulative capture without release. For *M. haraldmeieri,* a further species where we could not obtain appropriate sample sizes, 760 individuals per hectare were estimated in the low valley of Manantantely and 50 on the flank in January 1996 (BIODEV 1996). For *M. milotympanum*, earlier studies revealed densities of 1614-3000 ind/ha in March and 500-1652 ind/ha in May 1994 (Ramanamanjato et al., 1994); and 100-500 ind/ha in 2000 during hibernation (Rakotomavo, 2001). For *M. viridis,* at Montagne des Français, densities of 88-492 were observed in August 1994, and 15-242 ind/ha in February 1996 (BIODEV, 1996; Ramanamanjato et al., 1994).

Despite the qualifications applying to the calculation of densities of these frogs per surface area (see Materials and Methods), which clearly is highly dependent on the definition of the study plot, we here calculated “densities” for our populations, in order to be able to compare them with the information available so far in unpublished reports, summarized in the previous paragraph. Except for one estimate of *M. milotympanum* of 3000 ind/ha (Ramanamanjato et al., 1994), all of the estimates obtained previously were below or around 1000 ind/ha. In contrast, most of our data are clearly higher than 1000 ind/ha, and several were distinctly higher than that. Previous estimates, as far as known, usually applied capture without release or transect counting, and were usually also carried out in favourable areas were *Mantella* individuals gathered for reproduction. This indicates that mark-recapture will probably give higher and probably more realistic estimates of population sizes of *Mantella* although long-term methodological comparisons are not available so far.

CONCLUSIONS

According to the data presented herein, it appears that *Mantella* usually gather in areas suitable for reproduction in populations of about 50-200 individuals at a particular moment. However, the actual populations are much larger, since many individuals will be far from the reproduction area at the particular time of survey, especially females after egg deposition and juveniles which were very rarely found in our surveys. It is remarkable that despite the methodological constraints of our short-term mark-recapture studies, the estimated population sizes are quite similar for all species. The “densities” show much stronger differences among species, sites and seasons. This can be explained by the fact that sometimes reproductive sites can be small areas where all specimens concentrate (especially in species from dry regions, as *M. viridis* and *M. betsileo*), whereas in other cases breeding sites can be more evenly spaced. Under such conditions, defining the study plot area will have enormous effects for any spatial analysis of the population size data.

Our data provide important baseline data for conserving *Mantella* frogs and corroborate further indications (e.g., Vences et al., 2004; Vieites et al., 2005) that, for many species in this genus, population sizes in heavily exploited areas are not necessarily lower than in pristine areas without commercial collecting activity (e.g., *Mantella madagascariensis, M. milotympanum, M. aurantiaca*). However, without long-term and more detailed studies on population structure and dynamics of these frogs, our data are insufficient to quantitatively assess strategies for sustainable harvesting of these species.

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RÉSUMÉ

Estimation rapide de la grandeur taille de population en dix espèces de grenouilles poison de Madagascar, gendre Mantella.

De rapides évaluations des dimensions de population de dix espèces de grenouilles poison, le genre *Mantella*, montrent qu'il s'agit du groupe le plus massivement collecté par le marché des animaux de compagnie. Bien que la taxonomie et la diversité génétique de ces grenouilles ait été intensément étudié dans le passé, très peu de données sur sa dynamique de population sont disponibles, quoique de telles données soient mauvaises pour évaluer et réguler leur collecte commerciale et leur exportation. Ici nous résumons des données disponibles sur la densité de population de grenouilles poison malgaches et référençons chaque donnée estimée à partir de balises sur dix espèces de *Mantella*, accomplis entre 2003 et 2007. Les dimensions de la population se situaient généralement autour de 50 à 200 individus, mais ces données doivent être seulement prises comme préliminaires car elles se réfèrent à des spécimens pris sur des sites particuliers de reproduction (dans des marais ou le long de cours d'eau), et dans certains cas sont fortement partiales envers les males puisque les femelles sont beaucoup plus difficile à collecter. Une partie de ces densités de populations très élevées dans nos études et celles qui sont prévues se réfère à des

spécimens ramassés dans de très petites aires (inférieures à 50 mètres carrés où les plus hautes densités ont été enregistrées) et ne peut donc pas être extrapolée à l'ensemble des zones de distribution de ces espèces. Des études sur le long terme sur les dynamiques de populations particulières, ainsi que sur la longévité et la collecte, doivent être combinées avec des études sur le court terme d'estimations de densité, pour comprendre les perspectives de la récolte pérenne des grenouilles poison Malgaches.

Mots clés: Amphibiens, Conservation, Madagascar, *Mantella*, Population éstimée.

Falitiana C.E. Rabemananjara *
Parfait Bora
Tokihery J. Razafindrabe,
Edouard Randriamitso
Olga Ravoahangimalala Ramilijaona,
Noromalala Rasoamampionona Raminosoa
Daniel Rakotondravony
Département de Biologie Animale
Faculté des Sciences, Université d'Antananarivo
B.P. 906, 101-Antananarivo, Madagascar

** Current address:*
Institute for Biodiversity and Ecosystem Dynamics
Zoological Museum, University of Amsterdam
Mauritskade 61, 1092 AD Amsterdam
Email frabeman@science.uva.nl

David R. Vieites
Museum of Vertebrate Zoology and Department of Integrative Biology
3101 Valley Life Sciences Bldg.
University of California
Berkeley, CA 94720-3160. USA
Email vieites@berkeley.edu

Miguel Vences
Technical University of Braunschweig, Zoological Institute
Spielmannstr. 8, 38106 Braunschweig, Germany
Email m.vences@tu-bs.de

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APPENDIX: SUMMARY OF THE ORIGINAL MARK-RECAPTURE DATA USED FOR ESTIMATION OF POPULATION SIZES.

Data for each species and localitiy are presented as N/r/m for each capture occasion, where N is the total number of specimens captured on that capture occasion, r is the number of recaptured specimens on that capture occasion, and m is the number of marked specimens in the population before that particular capture occasion. At the end of each mark-recapture series we give the number of total marked specimens in the population at the end of the experiment, which can be seen as the minimum population size.

M. aurantiaca - Andranomandry 21-23 Jan 2004: 24/0/0, 20/13/24, 25/8/31, 15/6/48, 21/10/57, **68.** *M. aurantiaca* - Torotorofotsy 20-25 Feb 2004: 26/0/0, 24/15/26, 38/18/35, 45/26/55, 34/33/74, **75.** *M. aurantiaca* - Torotorofotsy 21-22 Jan 2007: 50/0/0, 46/17/50, 59/13/79, 51/30/125, 38/34/146, **150.** *M. baroni* - Fanjavala 15-17 Jan 2004: 18/0/0, 10/2/18, 25/5/26, 36/14/46, 19/14/68, **73.** *M. baroni* - Ampasimpotsy Antoetra 5-7 Dec 2003: 38/0/0, 49/18/38, 52/42/69, 37/33/79, 33/28/83, **88.** *M. baroni* - Kidonavo 21-29 Jan 2004: 8/0/0, 9/3/8, 13/6/14, 9/3/21, 10/3/27, 13/12/34, 5/3/35, 5/4/37, 9/4/38, **43.** *M. bernhardi* - Mangevo, inside Ranomafana National Park 11-12 Dec 2003: 16 0 0, 17 4 16, 10 7 29, 22 19 32, 16 14 35, **37.** *M. bernhardi* - Mangevo, outside Ranomafana National Park 11-12 Dec 2003: 20/0/0, 38/0/20, 104/16/58, 90/47/146, **189.** *M. bernhardi* - Tolongoina 16-19 Dec 2003: 22/0/0, 30/9/22, 22/16/43, 21/10/49, 17/15/60, **62.** *M. bernhardi* - Manombo 1-3 Feb 2004: 5/0/0, 21/2/5, 19/5/24, 27/11/38, **54.** *M. betsileo* - Ankadirano 10-12 Sep 2003: 45/0/0, 67/9/45, 27/12/103, 52/28/118, 55/29/142, **168.** *M. betsileo* - Kirindy 27-29 Nov 2003: 49/0/0, 91/28/49, 80/29/112, 70/60/163, 72/62/173, **183.** *M. crocea* - Ankosy 7-08 Feb 2004: 21/0/0, 23/16/21, 22/16/28, 16/15/34, **35.** *M. laevigata* - Marojejy 20-21 Dec 2003: 12/0/0, 12/0/12, 26/2/24, 25/7/48, 36/14/66, **88.** *M. laevigata* - Marojejy 19-21 Mar 2004: 17/0/0, 13/2/17, 12/2/28, 13/1/39, 13/6/51, **57.** *M. madagascariensis* - Fanjavala 15-17 Jan 2004: 38/0/0, 26/5/38, 13/4/59, 17/5/68, 17/9/80, **88.** *M. milotympanum* - Sahamarolambo (Fierenana) 11-13 Aug 2003: 14/0/0, 17/4/14, 22/8/27, 31/22/41, **50.** *M. milotympanum* - Sahamarolambo (Fierenana) 30 Jan-01 Feb 2004: 57/0/0, 68/18/57, 43/27/107, 31/12/123, 59/38/142, **163.** *M. milotympanum* - Sahamarolambo (Fierenana) 4-6 Apr 2004: 25/0/0, 32/12/25, 38/26/45, 31/19/57, 30/17/69, **82.** *M. pulchra* - An'Ala 09-11 Jan 2004: 20/0/0, 43/13/20, 42/24/50, 42/31/68, 41/24/79, **96.** *M. viridis* - Andranomantsina 30 Aug - 1 Sep 2003: 56/0/0, 78/17/56, 127/40/117, 79/40/204, 193/79/243, **347.** *M. viridis* Andohatany 30 Aug - 1 Sep 2003: 27/0/0, 46/10/27, 37/25/63, 43/33/75, **85.** *M. viridis* Andranomantsina 26-28 Nov 2003: 41/0/0, 36/7/41, 43/5/70, 34/8/108, 29/8/134, **155.** *M. viridis* Andohatany 26-28 Nov 2003: 21/0/0, 10/4/21, 12/4/27, 10/3/35, 4/3/42, **43.**

A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 265-276

Fabio M. GUARINO [1], Melissa SACCO [1], Giulia TESSA [2], Franco ANDREONE [2*]

Short life span of two charismatic *Mantella* species: age-structure in the critically endangered *M. cowani* and in the syntopic *M. baroni*

ABSTRACT

Body size, longevity, age at sexual maturity, and egg number in two species of Malagasy poison frogs of the genus *Mantella,* the critically endangered *M. cowani* and the closely related *M. baroni* were studied at a site next to Antoetra (central-southern Madagascar) during the rainy season. As a result, skeletochronology revealed a short life span, up to three years. Although in both the studied mantellas age and body size were positively correlated, the growing appears faster in *M. cowani,* thus allowing reaching a larger body size. We interpreted this difference in terms of different ecology, being *M. baroni* a rainforest species and *M. cowani* a savannah species. This is also confirmed by the count of eggs: *M. cowani* showed a mean egg number of 35.00 ± 13.14, while *M. baroni* 42.09 ± 8.01. The short life and growing characteristics are here commented and are retained important for the better understanding of the population structure and conservation requirements.

Key words: Age determination, Madagascar, *Mantella baroni*, *Mantella cowani*, Skeletochronology, Syntopy.

INTRODUCTION

Among the very rich and diverse amphibian fauna of Madagascar some species are indeed particularly known at a global scale. Usually, they are frogs actively searched and collected for the international pet-trade, such as those belonging to the genera *Mantella, Dyscophus,* and *Scaphiophryne* (Raxworthy & Nussbaum, 2000; Mattioli et al., 2006). In general, these species show peculiar aspects of colouration and morphology. In particular, the Malagasy poison frogs, genus *Mantella,* are very well known due to their resemblance to

[1] Università di Napoli, Dipartimento di Biologia Funzionale e Strutturale, Napoli.
[2] Museo Regionale di Scienze Naturali, Torino.
[*] Corresponding author.

dendrobatids and their diurnal behaviour, and, in general, to a relative facility to be kept in captivity (Staniszewski, 2001).

Currently, the genus *Mantella* is represented by 16 species (Jovanovic et al., 2006; Glaw & Vences, 2007), usually typical of rainforests, but it is also composed by dry environment and altitude savannah species. Almost all the species are very requested by the international pet trade, and this might represent, at least for some populations or species, a conservation problem (Andreone et al., 2005, 2006). For this reason, all the *Mantella* species are currently included in CITES Appendix II, and their exportation is regulated and limited to a fixed quota of individuals. According to the Global Amphibian Assessment some mantellas are also threatened, including 3 critically endangered, 4 endangered, and four vulnerable species (Andreone et al., 2008). Whether the collecting for the pet-trade is cause of threat for the species is still matter of debate, especially because studies on the species in the wild are largely missing (Schlaepfer et al., 2005; Gascon et al., 2007). Despite of the interest for the Malagasy poison frogs, comparatively little information is available on their life history traits. Exceptions to this rule are represented by some of the papers presented in the current volume (Carpenter & Robson, 2008; Rabemananjara et al., 2008).

In this paper we present first age structure and longevity data for two syntopic *Mantella* species of the *M. baroni* group, the harlequin mantella, *M. cowani* and Baron's mantella, *M. baroni.* In amphibians mean age is indeed an important life history trait that should be taken into consideration when establishing quota exportation numbers. The life span is documented for some *Mantella* species in captivity (Staniszewski, 2001), but these data are often anecdotal and difficult to be seriously considered, especially when applied to wild populations. Furthermore, we provide for the first time original data on the egg-number laid by these species.

As a result, the two analysed species show different situations in terms of conservation status, distribution and ecology. *Mantella cowani* is a very rare and localised species inhabiting a few isolated altitude moors and along small streams of the high plateau of Central Madagascar (Andreone & Randrianirina, 2003; Andreone et al., 2005; Chiari et al., 2005; Glaw & Vences, 1994, 2007). Due to a combination of threats for habitat alteration and collecting for pet-trade (carried out until a few years ago) *M. cowani* has been scored as Critically Endangered (CR) (Andreone et al., 2005, 2006, 2008), and considered the top of conservation amphibian priorities for Madagascar (Andreone & Randrianirina, 2003). The other species, *M. baroni* is classified as Least Concern (LC), and with a much more widespread distribution, including most of the central portion of the eastern rainforest belt, often with rather large populations. In terms of ecological preferences, *M. baroni* lives within rainforests from mid to mid-high elevations, but it is also able to survive, and sometimes to thrive, in altered habitats (Andreone & Luiselli, 2003). The study will tell us more regarding the life span of these two species, and if there are parameters of life history that can be useful in the application of conservation strategies.

MATERIAL AND METHODS

The habitat and study site

The study was conducted in the Antoetra region, central southern Madagascar (Fianarantsoa Province). Most of the samples refer to syntopic populations of *M. baroni* and *M. cowani* from Farihimazava (1380-1420 m a.s.l.; 20°50.10'S, 47°19.95'E). At this site the annual average temperature ranges 17-26° C, with high temperature fluctuations and a total annual rainfall of 1700 mm (Andreone et al., 2007). The habitats at Farihimazava are constituted by an original altitude rainforest of undetermined extension, and by nearby degraded fields and altitude savannahs periodically and regularly subject to slash and burn agriculture, with maize, potatoes and manioc cultivations. At Farihimazava *M. cowani* was usually found in rather open areas and along streams, while *M. baroni* was more abundant in the relic rainforest, although some individuals are also present in surrounding degraded habitats, where they may hybridise with *M. cowani* (Chiari et al., 2005).

Due to the fact that the number of sampled individuals of *M. cowani* at Farihimazava was comparatively low, we integrated the analysis including other *M. cowani* samples collected at Antoetra, such as Soamazaka (1600-1650 m a.s.l.; 20°45.38'S, 47°17.64'E, degraded montane savannah), Vohisokina (1580-1620 m; 20°42.31'S, 47°17.24'E; montane savannah with scattered trees) and Vatolampy (1540-1580 m; 20°49.68'S, 47°19.14'E; montane heathland).

Capture and body measurements

Frogs were collected during their breeding season (January–February 2003), when the habitat temperatures are high and facilitate their diurnal activity. Mantellas were searched during daytime in all the available habitats, sometimes orienting the research after their acoustic emissions. This is especially true for *M. cowani* that often calls from underground cavities (Andreone et al., 2006).

After capture the mantellas were measured with a calliper for their snout-vent length (SVL; precision 0.1 mm), and weighed with an electronic digital balance (precision 0.1 g). The third toe of each collected individual was clipped and then stored in 70% ethanol and therein processed for skeletochronology and genetical analysis. A few individuals were conserved as vouchers (list available in Andreone et al., 2007). After the measurements, the remnant frogs were released at the site of capture.

Sex was determined by external analysis at overall body proportion and size, taking into account that females are larger and stouter than males. Anyhow, the absence of evident secondary sexual characters in species of the *Mantella baroni* group prevented us from an unequivocal sex determination in the field (Jovanovic, 2006). Anyway, to ascertain the capacity of the main investigator (FA) in determining the sex on the basis of external morphology we checked the field determination by dissecting preserved specimens of both the species housed in Turin Museum. After the dissection, the gonads (testicles and ovaries) were located. For *M. cowani* in 91% of cases sexes correspond to those determined in the field (10 correct determinations on 11 cases), for *M. baroni* 86% (12 correct cases out of 14 cases). These values do not differ significantly from the expected results ($P > 0.05$). Seen this high determination success we are confident that the sexual determination and overall considerations here reported are pertinent.

Furthermore, to ascertain the species' fecundity and differences in parental investment, we also counted the number of eggs of preserved females of both the species (7 *M. baroni* and 4 *M. cowani*). In these case, the ovaries, once identified, were removed by the body cavity, and eggs counted under stereoscope.

Skeletochronology

Totally, phalanges from 41 individuals of *Mantella cowani* (24 males, 16 females, and 1 juvenile) and 42 individuals of *Mantella baroni* (28 males and 14 females) were used for the skeletochronological analysis. We did not analyse phalanges of hybrids as determined by Chiari et al. (2005).

Skeletochronology was performed following the standard protocol generally used for others Malagasy amphibians (Guarino et al, 1998, Andreone et al., 2002), with some slight adaptations. Phalanges were decalcified in 3% nitric acid for a time of 45-60'. Then, they were cross-sectioned at diaphyseal level (12 µm thick) using a cryostat stained with Ehrlich's haematoxylin for about 20', and mounted in aqueous resin. Two researchers observed sections independently, using a light microscope.

Based on habitat features and altitude of the site, which is characterized by montane climate with marked seasonal variation, we assume that visible lines of arrested growth (LAGs) are formed annually. In fact, frogs were collected in the middle of rainy season, thus corresponding to the period of maximum growth as documented by the observation that, after the last LAG, a conspicuous bone layer is present. This finding suggests that the sampled individual is concluding a further year of life and a new LAG was not yet formed. In this paper we consider only visible LAGs plus those completely resorbed, if any, estimated by osteometric analysis (Guarino et al., 2003) but it is important to bear in mind that to obtain the actual age of the frogs we should add another life season.

RESULTS

Bone structure and LAG count

In both the species the phalangeal sections was composed by two concentric bone layers similar in texture and not always separated by a clear reversal line (RL), even if a gap between the two bone layers was often observed (Fig. 1a). The innermost layer was usually well developed and only in seven *M. cowani* and eight *M. baroni* a defined lamellar structure was visible (Fig. 1b). Consequently, it was not always easy to discriminate endosteal from periosteal bone. Nearly circular hematoxynophilic lines sometimes faint but with features of LAGs, were observed in periosteal bone (Figs. 1c-1d) whereas, metamorphosis lines, false and double LAGs were very rare.

The count of periosteal LAGs was possible in 14 males and 12 females of *M. cowani*, and in 15 males and 9 females of *M. baroni* (Tab. I). In *M. cowani* the LAG number ranged in *M. cowani* ranged 0-2, for males and 1-3 for females. In *M. baroni* the LAG number ranged 0-3 in males and 1-2 in females. In both the species the maximum number of 3 LAGs was occasionally found (three females of *M. cowani* and one male of *M. baroni*), and the same for individuals showing no LAGs (one male *M. cowani* and one male *M. baroni*). Total endosteal resorption of the first LAG was observed in 11.1% *M. cowani* and in 8.3% *M. baroni*. In three *M. cowani* individuals (two males of 24.2 and 26.3 mm SVL; 1 female 36.3 mm SVL) without LAGs, and in two individuals of *M. baroni* (a male of 25.1 mm and a female of 26.9 mm) perimeter of RL passed perimeter of first LAG observed in the other frogs: consequently we assumed a LAG completely removed.

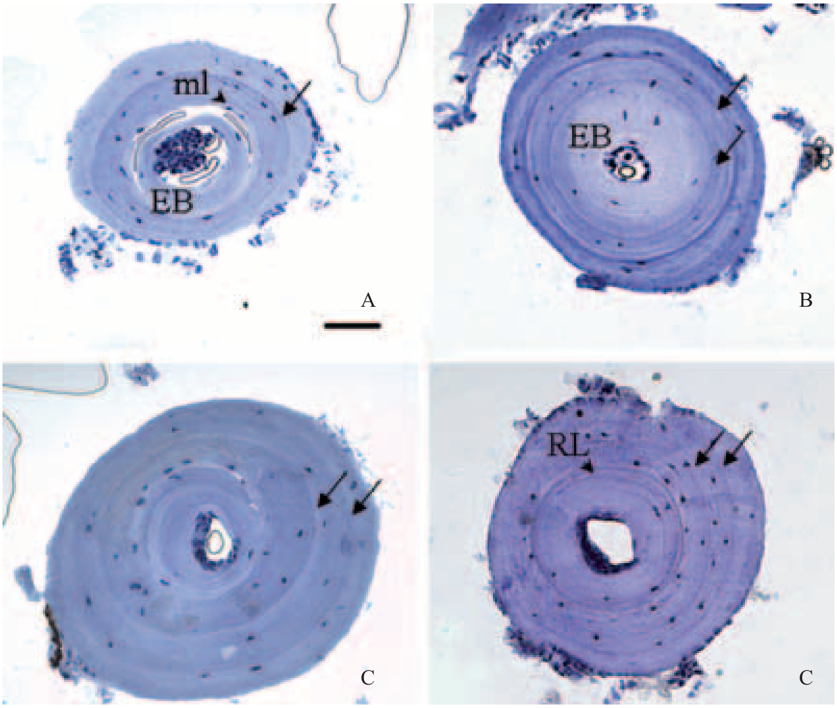

Fig. 1. Representative hematoxylin-stained cross-sections of phalanges *M. cowani* and *M. baroni*. EB = endosteal bone; RL = reversal line, ml = metamorphosis line. Arrows indicate lines of arrested growth. A) Male of *M. cowani*, 22.3 mm SVL, 1yr old; B) female of *M. baroni*, 28.9 mm SVL, 2 yr old; C) female of *M. cowani*, 27.9 mm SVL, 2 yr old; D) male of *M. baroni*, 27.8 mm SVL, 2 yr old. Scale bar corresponds to 280 µm.

Sex	Snout-vent length (mm)	Weight (g)	LAG number
Mantella baroni			
Males	25.6 ± 2.4 18.6-28.5 (15)	1.3 ± 0.3 0.5-1.6 (15)	1.64 ± 0.20 0-3 (15)
Females	28.6 ± 1.2 26.9-30.1 (9)	1.7 ± 0.2 1.3-1.9 (9)	1.89 ± 0.11 0-2 (9)
Mantella cowani			
Males	25.7 ± 1.7 15.1-28.9 (14)	1.2 ± 0.2 0.4-1.6 (14)	1.21 ± 0.18 0-2 (14)
Females	29.3 ± 1.1 27.9-31.4 (12)	1.9 ± 0.3 1.6-2.5 (12)	2.17 ± 0.17 1-3 (12)

Tab. I. Biometric and age data on males and females of *Mantella baroni* and *M. cowani* at Antoetra. Values are given as mean ± standard deviation, range and, between parentheses, the number of examined individuals.

Body size and egg-number

Males of *M. cowani* reached a maximum SVL of 28.90 mm (mean ± SD = 25.7 ± 1.7 mm), and a body weight of 1.6 g (mean ± SD = 1.2 ± 0.2 g), while females reached 31.40 mm (29.3 ± 1.1 mm), and a weight of 2.5 g (1.9 ± 0.3 g). Males of *M. baroni* reached a maximum SVL of 28.50 mm (25.6 ± 2.4 mm) and a weight of 1.6 g (1.3 ± 0.3 g), while females reached a maximum of 30.1 mm (28.6 ± 1.2 mm) and weighed 1.9 g (1.7 ± 0.2 g). The SVL and body weight in males were significantly smaller than in females in both species (*M. cowani*: $t = 6.73$, d.f. = 22, $P < 0.001$, $t = 7.11$, d.f. = 22, $P < 0.001$; *M. baroni*: $t = 3.92$, d.f. = 20, $P < 0.001$, $t = -3.55$, d.f. = 21, $P < 0.001$). However, taking into consideration the whole sample, females of *M. baroni* were smaller than females of *M. cowani* (SVL: $t = 2.45$, d.f. = 25, $P = 0.01$; weight: $t = 3.05$, d.f. = 22, $P = 0.003$), whereas there was not a significant difference between males of two species.

SVL and weight appeared to be positively correlated in both species (*M. cowani*: $r = 0.874$, d.f. = 24, $P < 0.001$; *M. baroni*: $r = 0.803$, d.f. = 21, $P < 0.001$)

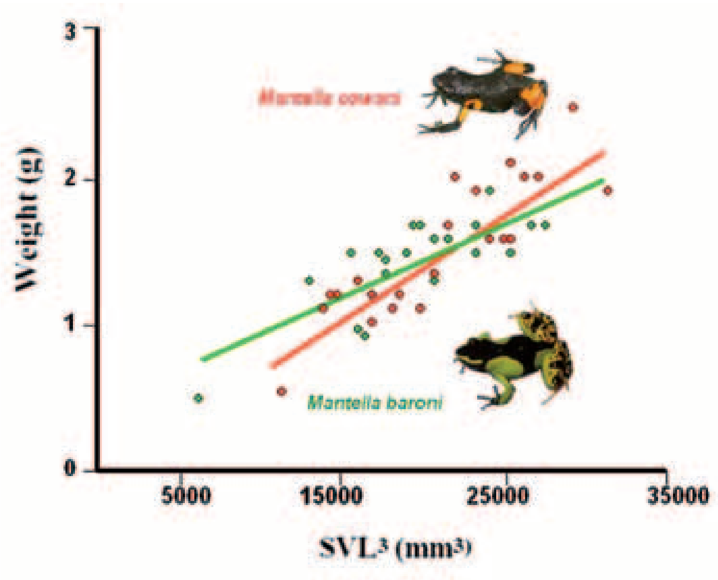

Fig. 2. Relationship between SVL (in mm) elevated at cube and weight (in g) in both sexes of *Mantella baroni* (green) and *M. cowani* (red).

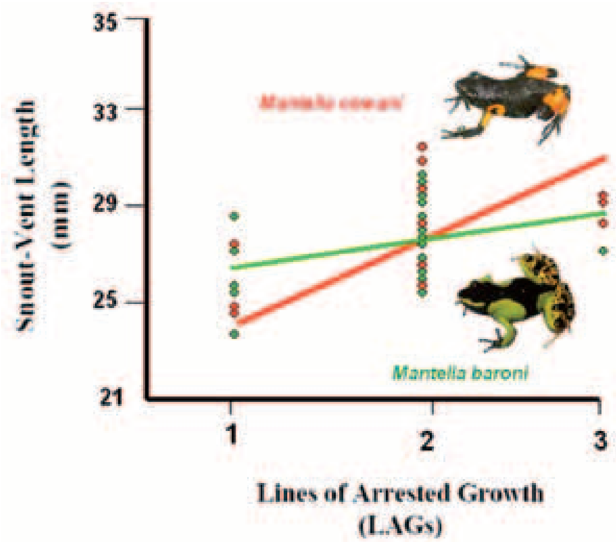

Fig. 3. Relationship between age (expressed as LAG number) and size (expressed as SVL, snout-vent length, in mm) in both sexes of *Mantella baroni* (green) and *M. cowani* (red).

(Fig. 3). The two mantellas also showed a significant difference about the correlation between SVL and body weight (ANCOVA: $F = 103.223$, $P < 0.001$).

Age and SVL were positively correlated in both species and sexes (Fig. 2), statistically significant in *M. cowani* males ($r = 0.727$, d.f. = 11, $P = 0.005$) and *M. baroni* males ($r = 0.661$, d.f. = 13, $P = 0.007$), but not in females.

Considering all samples, analysis of covariance showed a significant difference between the two species in SVL and LAGs number (ANCOVA: $F = 15.631$, $P < 0.001$). The smallest adult male and female were: 22.2 mm and 28.5 mm, respectively, both 1 year old, in *M. cowani*; 23.4 mm and 26.9 mm, respectively, both 1 year old, in *M. baroni.*

The number of eggs (± SD) in the analysed females of *M. baroni* from Farimazava was 42.09 ± 8.01, while in *M. cowani* it is 35.00 ± 13.14. Although the comparison between these values is not significant ($t = 1.007$, $P = 0.18$), it appears that *M. baroni* is featured by a higher number of eggs.

DISCUSSION

The current study indicates that LAGs are present and visible in frog species from tropical areas, such as the studied *Mantella*. This is in agreement with what observed for other tropical species (Kumbar & Pancharatna, 2001), and, more in particular, for other larger Malagasy species, such as *Boehmantis microtympanum*, *Boophis occidentalis*, *Dyscophus antongilii* (Guarino et al., 1998; Andreone et al., 2002; Tessa et al., 2007). On the other hand, we also showed that the two syntopic *Mantell*a species from the high plateau show a similar age structure and both share a short life span, reaching at maximum three years. So far, the formerly mentioned Malagasy species are more long living and also much larger. It appears therefore that, a large size is often correlated to a long life span. Anyhow, this might be confirmed by further data and, especially, but a higher number of studied species.

The documented age of wild *Mantell*a individuals near Antoetra appeared much lower than what reported for captive animals. In fact, Staniszewski (2001) referred of a maximum longevity of 7 years in *M. cowani,* and a similar longevity is possibly expected for to *M. aurantiaca* and *M. baroni.* On the other hand, individuals of *M. cowani* turned out to be larger than those of syntopic *M. baroni*. Moreover, they show an almost identical life span, and their phalanges are virtually indistinguishable in terms of morphology and structure. This is likely due to a combination of several factors, among which phylogenetic affinity and similar ecological conditions.

Our findings also indicate that sexual maturity is attained after the first year of life for both the species. Populations of these mantellas are likely characterized by a fast turn over and only three age rough age-classes are represented. As a rule, in anurans the age at maturity is correlated to longevity (Guarino et al., 2003). In both the studied species age was positively correlated with the number of LAGs in males only. On the opposite, females apparently exhibit a faster growth during the first year of life, reaching adult size and the maximum fecundity in one year only: individuals likely allocate energy resources in egg-production increasing fecundity and only a minimum part in body growth.

Correlation between SVL and LAGs number is different in the two species: *M. cowani* shows a faster body growth during the first two years of post-metamorphic life, while *M. baroni* has a more rapid growth in the first year and constant growth for years later. In fact, in the first year of life both species show similar size. On the other hand, at the age of 2 and 3 years *M. cowani* is larger. Correlation between SVL and weight is also different in the two species: *M. baroni* reaches early the ideal weight, that remain stable with the growth. In *M. cowani* the weight increased with the size. Moreover, the number of eggs counted in the two species furtherly shows a potential difference in fecundity.

All these differences could be interpreted as consequences of different habitat adaptations, as already observed in close species of desmognathines salamanders (Bruce et al., 2002) and two populations of *Rana temporaria* (Augert & Joly, 1993). Our observations indicate that *M. baroni* lives in in residual of altitudinal gallery forests or open heathlands (Jovanovic et al., 2006). The life in a more stable environment, such as the rainforest for *M. baroni* is associated with a smaller body size and higher egg-number. On the other hand, *M. cowani* – living in open and less predictable habitats – touches a larger size but with a lower fecundity.

As a final comment we underline how the understanding of age structure plays important consequences on population and species management. *Mantella cowani* is a the most at risk of extinction for living in few sites affected by erosion and slash and burn agricultural practices, composed by a few and populations are represented by a few individuals isolated by hostile landscape (Andreone & Randrianirina, 2003). In addiction the overexploitation for pet trade crushes individuals number (Andreone et al., 2005). In 2003 limits for exportation of this species were restricted and now for this and the other "critically endangered" species captive breeding programs are being developed in American, European and Madagascan research centres. Knowing which are the major constraints of species in nature is indeed important to create a genetic reserve in case of extinction of populations due to amphibian emerging pathologies (Daszak et al., 1999).

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RÉSUMÉ

Courte longévité dans deux espèces charismatiques de grenouilles: structure d'âge de l'espèce critiquement menacée Mantella cowani *et de l'espèce syntopique* M. baroni.

Nous avons étudié la longueur corporelle, la longévité et l'âge à la maturité sexuelle de deux espèces du genre *Mantella,* la plus menacée *M. cowani* et *M. baroni* phylogénétiquement proche, dans un site près d'Antoetra, pendant la saison des pluies. Pour ces deux espèces l'étude squelettochronologique a montré une courte durée de la vie, avec un maximum de 3 ans. Bien que dans les deux mantelles l'âge et la taille corporelle sont corrélées positivement, chez *M. cowani* la croissance semble être plus rapide et permet d'atteindre une plus grande taille. Nous interprétons cette différence en termes écologiques, puisque *M. baroni* est une espèce de forêt, tandis que *M. cowani* est une espèce de savane. La courte durée de la vie est considérée comme un facteur important permettant de mieux comprendre la structure des populations de ces espèces et donc les meilleures solutions de leur nécessaire conservation.

Mots clés: Détermination de l'âge, squelettochronologie, *Mantella cowani*, *Mantella baroni*, syntopie, Madagascar.

Fabio Maria Guarino, Melissa Sacco
Università degli Studi di Napoli Federico II
Dipartimento di Biologia Strutturale e Funzionale
Via Cintia, I-80126 Napoli, Italy
Email fabio.guarino@unina.it

Giulia Tessa, Franco Andreone
Museo Regionale di Scienze Naturali
Via G. Giolitti, 36, I-10123 Torino, Italy
Email franco.andreone@ regione.piemonte.it

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Falitiana C.E. Rabemananjara[1,2], Noromalala Rasoamampionona Raminosoa[2], Olga Ravoahangimalala Ramilijaona[2], Daniel Rakotondravony[2], Franco Andreone[3], Parfait Bora[2], Angus I. Carpenter[4], Frank Glaw[5], Tokihery Razafindrabe[2], Denis Vallan[6], David R. Vieites[7], Miguel Vences[8] *

Malagasy poison frogs in the pet trade: a survey of levels of exploitation of species in the genus *Mantella*[#]

ABSTRACT

Malagasy poison frogs of the genus *Mantella* are small, colourful amphibians that are in high demand for the pet trade. *Mantella aurantiaca* was included in CITES Appendix II in February 1995 and the whole genus in 2000. CITES annual report data indicate reported exports of about 230,000 specimens from 1994 to 2003. The reported trade in the most prominent species, *M. aurantiaca*, increased sharply from 1996 to 1998, with more than 30,000 specimens exported in 1998, but dropped after the implementation of an unofficial quota system in Madagascar. Limited information exists on their distribution, habitat preferences and impacts from potential threats, such as harvesting for commerce, and several species are currently listed as Critically Endangered. Based on field surveys of the trade network, the benefits obtained by local collectors were low (equivalent to 0.05-0.2 US$ per specimen), with usually 100-300 frogs collected per day. Intermediaries sell the frogs to the exporters, who in turn obtain international prices of 2-4 US$ per specimen, with wholesale prices in the USA and Europe of 5-20 US$ (current retail in 2005, up to 40 US$). Due to their probably high population densities and presumably high reproductive potential, it might be possible to exploit some, but probably not all, of these *Mantella* species in a sustainable way. To reach this goal, it should be a priority to transfer the focus of the regulation system more to the local collectors and ensure that substantial benefits remain with local

[1] IBED, University of Amsterdam, The Netherlands.
[2] DBA, Université d'Antananarivo, Madagascar.
[3] Museo Regionale di Scienze Naturali, Torino, Italy.
[4] University of East Anglia, Norwich, United Kingdom.
[5] Zoologische Staatssammlung München, Germany.
[6] Natur-Museum Luzern, Switzerland.
[7] University of California, Berkeley, USA.
[8] Technical University of Braunschweig, Germany.
* Corresponding author.
[#] This paper has been accepted in 2006 for publication in the journal "Amphibian and Reptile Conservation" where publication is pending, expecting the continuation of that journal.

communities that should gain partial control of the actual habitat of these frogs. A system of export quotas has a further potential to avoid overexploitation of single species.

Keywords: Amphibia, CITES, *Mantella*, Madagascar, pet trade.

INTRODUCTION

Madagascar is a biodiversity hotspot (Myers et al., 2000) that receives much conservation effort, yet concerns remain for its future due mainly to habitat destruction (Ganzhorn et al., 1997; Green & Sussman, 1990). Deforestation proceeds largely due to subsistence slash-and-burn agriculture and results in increasing habitat fragmentation and threats for populations of many organisms, including amphibians (Vallan, 2000, 2003; Andreone & Luiselli, 2003; Andreone et al., 2005). However, for some animal and plant groups there is also a particular concern regarding the wildlife trade (Joint Nature Conservation Committee, JNCC, 1993). Trade in wildlife can potentially offer conservation benefits through direct use values to local people (Norman, 1987; Bodmer & Lozano, 2001). However, if the trade is conducted without reference to sustainable exploitation, then the resource may potentially be endangered (Laurance & Yensen, 1991; Wolf and Konings, 2001; Schlaepfer et al., 2005).

Madagascar ratified the Convention on the International Trade in Endangered Species (CITES) in 1975 (Carpenter, 2002). All parties to the Convention are required to submit annual reports including data on transactions under the remit of the Convention. The data are compiled in the CITES Trade Database managed by the United Nations Environment Programme World Conservation Monitoring Center (UNEP-WCMC). These trade data can be used to help understand the dynamics of the global animal trade and the conservation and economic consequences of governance changes. However, detailed studies exist for only a limited number of Malagasy flora and fauna, such as chameleons (JNCC, 1993; Brady & Griffiths, 1999; Carpenter, 2002; Carpenter et al., 2004, 2005; Carpenter & Robson, 2005), geckos (Affre et al., 2005), tortoises (Walker et al., 2004), aquaculture (EarthTrends, 2003), and medicinal plants (Randimbivololona, 1996).

Almost all the Malagasy poison frog species included in the genus *Mantella* (Fig. 1) have apparently been recorded in high numbers in the trade, as stressed by a certain amount of "gray literature" (e.g., BIODIV, 1992, 1993, 1996; Ferraro & Ramandimbison, 1994; Ramanamanjato et al., 1994, Jenkins & Rakotomanampison, 1994; Jenkins, 1994; Louys & Rajaona, 1994; Ramilison et al., 1996; Rakotomavo, 2000).

However, these unpublished reports have suffered from a lack of taxonomic consistency, reflected in various names being used for the same species and incomplete trade data. Recent morphological and genetic studies have clarified *Mantella* systematics (Vences et al., 1999, 2004; Schaefer et al., 2002; Chiari et al., 2004), while the inclusion of *Mantella aurantiaca*, in 1995, and of all *Mantella* spp., in 2000, on CITES Appendix II, now permits more consistent monitoring

Fig. 1. Currently recognized species in the genus *Mantella* (except for *M. aurantiaca*, shown in Fig. 6). (a) *M. betsileo*, Kirindy. (b) *M. ebenaui* (previously considered as *M. betsileo*) from Nosy Faly. (c) *M. expectata*, specimen without precise locality information. (d) *M. viridis*, Montagne des Français. (e) *M. manery*, Marojejy. (f) *M. laevigata*, Marojejy. (g) *M. bernhardi*, Mangevo, Ranomafana National Park. (h) *M. baroni*, near Vohiparara, Ranomafana National Park. (i) *M. cowani*, Antoetra region; (j) *M. haraldmeieri*, Manantantely. (k) *M. nigricans*, Marojejy. (l) *M. crocea*, near Moramanga/Andasibe, without precise locality information. (m) *M. milotympanum*, Fierenana. (n) *M. madagascariensis*, near Vohiparara, Ranomafana National Park. (o) *M. pulchra*, An'Ala near Andasibe. All photos by F. Glaw and M. Vences except (i) by F. Andreone.

Fig. 2. Habitats of *Mantella* species. (a) Forest fragments near Tolongoina, habitat of *M. bernhardi.* (b) Stream with remains of forest at Antakasina near Antoetra, habitat of *M. cowani.* (c) Habitat of *M. viridis* in northern Madagascar. (d) Forest surrounding large swamp at Ambohimanarivo north of Moramanga, habitat of *M. crocea.* (e) Small stream at Malaso, Isalo region, habitat of *M. expectata.* (f) Forest destruction in *M. cowani* habitat through small-scale slash-and-burn agriculture at Ampasimpotsy near Antoetra. All photos by F. Andreone except (c) by V. Mercurio and (d) by M. Vences.

of the numbers traded. At present, five species are listed as critically endangered (*M. aurantiaca*, *M. cowani*, *M. expectata*, *M. milotympanum*, and *M. viridis*), two endangered (*M. bernhardi* and *M. crocea*), three vulnerable (*M. madagascariensis*, *M. pulchra*, and *M. haraldmeieri*), one near threatened (*M. laevigata*), three of least concern (*M. baroni*, *M. betsileo*, and *M. nigricans*), and one as data deficient (*M. manery*) (The World Conservation Union, IUCN, 2004; Andreone et al., 2005), add: "but in a separate in this same volume (Andreone et al., 2008), change in these categories for *M. expectata* and *M. viridis* are being proposed. A further species, *Mantella ebenaui*, has only recently been resurrected from the synonymy of *M. betsileo* (Glaw & Vences, 2006). At the time of analyzing the data for the present paper, it had not yet been classified in any threat category, and it is not further considered here.

The present paper provides data on the reported numbers of species and individuals of *Mantella* traded as well as the structures operating in the trade of *Mantella*. A review of the numbers encountered in the trade and the collection network structures in operation can provide a basis to identify and promote potential conservation benefits from the trade. For example, the exports of *M. aurantiaca* prior to 1994 generated an income of more than 100,000 US$ per year (Food and Agriculture Organization of the United Nations, FAO, 2003), which is a relevant value considering that per capita income in Madagascar remains low ($234 in 1998) and 72.3% of the population is under the poverty line (FAO, 2000).

METHODS

Interviews were carried out between July 2003 and April 2004 by N. Raminosoa (NRR), F. Rabemananjara (FR) and P. Bora (PB) using the "Méthode d'Analyse Rapide et de Planification Participative" (MARP) (Groupe Urgence Réhabilitation Développement, Groupe URD 2002) to the following stakeholders: (1) local collectors, (2) intermediaries, and (3) exporters. These levels of actors were the same as recorded by Carpenter et al. (2005). A fourth level of stakeholders was also interviewed, that of local authorities including the regional agents of the authorities for environment, waters, and forests (Ministère de l'Environnement, des Eaux et Forêts, or "MinEnvEF"). Exporters were asked their purchase and selling prices, the quantities bought, and whether held in stock or sold directly upon capture only, as well as packaging and shipping methods. Intermediaries were asked the structure of the trade network, the species and numbers harvested, purchase and selling prices, and the level to which revenue from the trade contributed to their household economy. Collectors were asked the collection methods, collection periods, frequencies, species harvested, selling prices, and the amount of time assigned to collecting compared with their principal activity. Interview data were corroborated by repeated surveys at many sites in each region that recorded a certain *Mantella* species.

A total of 105 stakeholders throughout Madagascar were orally interviewed. Tab. I and Fig. 3 provides locality names, coordinates, period of interviews and the species discussed with interviewees. Several of the localities are also known under different toponyms and quoted as such in different research papers. Ampasimpotsy is also known as Farihimazava or Farimazava, Soamantsaka is also known as Soamazaka or Soamahazaka, Vohitsokina is also known as Vohisokina (or Fohisokina), and An'Ala is also known as Andohan'i Sity.

Area	Locality	Coordinates	Périods	Species concerned
Andranomandry	Andobo	19°02.373'S, 48° 10.576'E	21 - 25/01/2004 17 – 21/04/2004	*Mantella aurantiaca*
An'Ala	Andohan'i Sity 1	18°55.142' S, 48° 29.257' E	30/07/2003 – 03/08/2003 08 – 12/01/2004 24 – 28/08/2004	
Fanjavala	Fanjavala	19°04.019' S, 48° 17.686' E	21 – 25/08/2003 15 – 19/01/2004 11 – 15/04/2004	
Antoetra	Ampasimpotsy Nord	20°50'02.4''S, 47°19'59.5''E	28 – 31/07/ 2003 05 – 08/12/2003 24 – 28/02/2004	*M. baroni*
	Ampasimpotsy Sud	20°50'08.2''S, 47°19'57.6''E	28 – 31/07/2003 05 – 08/12/2003 24 – 28/02/2004	
Ranomafana	Mangevo Menavava River	21°23'14.8''S, 47°27'22.8''E	14 – 18/08/2003 10 – 13/12/2003	
Ranomafana	Mangevo Farihy	21°23'01.6''S, 47°27'56.8''E	14 – 18/08/2003 10 – 13/12/2003	
Tolongoina	Forêt de Kirenabe	21°28'35.8''S. 47°33'10.2''E	20 – 24/08/2003 16 – 19/12/2003 18 – 22/03/2004	*M. bernhardi*
	Lavadia	21°28'46.9''S. 47°33'30.6''E	20 – 24/08/2003 16 – 19/12/2003 18 – 22/03/2004	
Ankarana	Ankadirano	12°58.481'S, 49°07.328'E	10 – 14/09/2003 02 – 05/12/2003 06 – 10/03/2004	
Kirindy	Rivière Kirindy	20°04'34.8''S, 44°40'30.0''E	02 – 05/03/2004	*M. betsileo*
Isalo	Andrehitogna	22°32'19.1''S, 45°24'39.9''E	02 – 06/09/2003 12 – 16/01/2004 01 – 06/04/2004	
Antoetra	Ampasimpotsy Nord	20°50'02.4''S, 47°19'59.5''E	05 – 08/12/2003 25 – 26//02/2004	*M. cowani*
	Soamantsaka	20°44'52.0''S, 47°17'42.6''E	05 – 08/12/2003 25 – 26//02/2004	
	Vohitsokina	20°42'18.9''S, 47°17'14.1''E	05 – 08/12/2003 27/02/2004	
Marovoay Gara	Ankosy	18°48.559'S, 48°16.857' E	05 – 09/02/2004 27 – 31/03/2004	*M. crocea*
Isalo	Ilakaka region	22°37'08.9''S, 45°21'40.7''E	02 – 06/09/2004 12 – 16/01/2004 01 – 06/04/2004	*M. expectata*
Tolagnaro	Manantantely	24°59'14.8''S, 46°55'33.3''E	19 – 20/09/2003 23 – 25/01/2004 13 – 18/04/2004	*M. haraldmeieri*
	Nahampoana	24°58'09.2''S, 46°57'56.1''E	16 – 18/09/2003 26 – 29/01/2004 19 – 21/04/2004	
Marojejy	Camp Mantella	14°26.333' S, 49°46.566' E	25 – 29/09/2003 19 – 23/12/2003 19 – 23/03/2004	*M. laevigata*
Fanjavala	Fanjavala	19°04.019'S, 48° 17.686'E	21 – 25/08/2003 15 – 19/01/2004 11 – 15/04/2004	*M. madagascariensis*
Fierenana	Sahamarolambo	18°32.378'S, 48°26.728'E	14 – 18/08/2003 29/01/2004 – 02/02/2004 04 – 08/04/2004	*M. milotympanum*
Anjanaharibe Sud	Andranomenabe	14°44.543'S, 49°23.617'E	18 – 22/09/2003 13 – 17/12/2003 13 – 17/03/2004	*M. nigricans*
Marojejy	Camp Marojejia	14°25.948'S, 49°45.588'E	25 – 29/09/2003 19 – 23/12/2003 19 – 23/03/2004	
An'Ala	Andohan'i Sity 2	18°55.173'S, 48°29.603'E	30/07/2003 – 03/08/2003 08 – 12/01/2004 24 – 28/04/2004	*M. pulchra*
Antongombato	Antongombato	12°22.962'S, 49°13.496'E	30/08/2003 – 03/09/2003 25 – 29/11/2003 24 – 28/02/2004	*M. viridis*
Montagne des Français	Montagne des Français	14°25.948'S, 49°45.588'E	25 – 29/09/2003 19 – 23/12/2003 19 – 23/03/2004	

Tab. I. Sites of interviews in the local level with locality names, periods and species concerned. The people interviewed are those closest to the species locality. Localities were visited more than one time to allow the survey of local people activities in each period.

Fig. 3. Sites for interviews at national level located in Antananarivo; and at local level in Moramanga (1), Andranomandry and Fanjavala (2), Antoetra (3), Ifanadiana (4), Tolongoina (5), Andringitra (6), Isalo (7), Manantantely (8), Morondava and Kirindy (9), Antsiranana (Montagne des Français and Antongombato) (10), Ankarana and Nosy Be (11), Andapa (12), and Maroantsetra (13).

Trade data for *Mantella* were compiled from the UNEP-WCMC CITES database on 2 May 2005 and represent the reported net imports and exports recorded by trading states. Data were also obtained from the Malagasy CITES Management Authority, the MinEnvEF, for reported exports between 1988 and 2003. Price data were collected during interviews with the stakeholders, while retail prices were extracted from available price lists. The taxonomy of several species (*M. baroni*, *M. cowani*, *M. haraldmeieri*, *M. pulchra*) was not stable over the period surveyed, and therefore, some caution is required over the numbers reported. For example, *M. nigricans* was originally reported as "Mantella veronica" in the database, which is a nomen nudum (Vences et al., 1999).

A certain number of *Mantella* exports per year are for scientific purposes, such as taxonomic studies and biodiversity surveys. These dead preserved specimens or tissue samples are included in the surveyed numbers and we are currently unable to precisely quantify them. However, we are confident that the number of specimens exported for scientific purpose is small enough to be considered insignificant in terms of resource exploitation.

RESULTS

Species and volumes recorded

The number of *Mantella* reportedly exported from Madagascar totals 233,893 individuals between the periods 1994 to 2003 (Tab. II). Despite the uncertainties over taxonomic assignment, the data highlight a great increase in the number of species of *Mantella* reported as involved in the trade, from one in 1994 to 14 known species in 2002/2003. This increase in species is largely due to the fact that there was no legal requirement before 2000 to report trade in species other than *M. aurantiaca* to CITES, and our anecdotal observations in 1991 and 1994-1996 indicate that already at that time many *Mantella* species were in the trade. Indeed, most species of *Mantella* described in the 1980s and 1990s (*M. bernhardi*, *M. crocea*, *M. expectata*, and *M. viridis*) had initially been collected for the trade, and the type specimens were supplied by exporters. The number of recorded individuals also increased during this period to over 21,000 in 2003, with peaks in 1998 of over 38,000 and 2001 of over 50,000 individuals being traded. Since only *M. aurantiaca* was CITES listed from 1995-2000, the actual trade figures may have been higher and the peak in 2001 be an artifact caused by the need of declaring all *Mantella* exports after the inclusion of all species on CITES Appendix II in 2000.

In 1999, a sudden decrease in the number of species involved in the trade was observed. These variations were probably due to changes in national governance in Madagascar, and in international regulations, as mentioned for the trade of chameleons (Carpenter et al., 2004).

M. aurantiaca accounts for approximately 50% of the total number of individuals reported as traded between 1994 and 2003 (Tab. II). Although this may partly due to the fact that other species were not CITES listed and their exports had not to be declared prior to 2000, it probably also reflects an actual emphasis on this species which still today is the most prominent and well-known *Mantella* species among hobbyists in Europe and North America. The second most traded species are the complex *M. baroni-madagascariensis-pulchra* (approximately 19%). This group contains several species with very similar colour patterns that have probably led to confusion over the species actually being traded by collectors and exporters (Vences et al., 1999). In fact, in the past the highest proportion of specimens exported as *M. madagascariensis* were actually *M. baroni* and *M. pulchra* (Glaw F. & Vences M., personal observation). However, the reliability of the trade data is likely to improve in the future as new identification guides become available (e. g. Jovanovic et al. 2007, Glaw & Vences 2007).

Nevertheless, the export files for the years 2001-2003 (Table II), since the listing of *Mantella* on CITES Appendix II, are to be considered as reliable and corroborate that thousands of specimens were exported each year. Although the values only report the legally exported specimens, we do not expect the actual exported numbers to be much higher during this time. Smuggling is unlikely to take place at a large scale in species of rather low commercial value such as *Mantella*, contrary to what may happen in species of higher value and that are less fragile for transport, such as tortoises.

Species	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**TOTAL**	**%**
Mantella spp.	0	0	0	230	620	200	6760	9853	1420	1291	**20374**	8.71
M. aurantiaca	100	11965	16693	17406	31941	8850	11445	10335	4780	2681	**116196**	49.68
M. baroni	0	0	0	0	0	0	0	0	10	650	**660**	0.28
M. bernhardi	0	0	0	0	0	30	490	1005	650	60	**2235**	0.96
M. betsileo	0	0	0	1000	435	175	150	4040	1215	1465	**8480**	3.63
M. cowani	0	0	0	0	52	150	425	975	1520	500	**3622**	1.55
M. crocea	0	0	0	0	395	250	1157	1750	630	100	**4282**	1.83
M. expectata	0	0	0	100	624	105	1260	1790	2585	1100	**7564**	3.23
M. haraldmeieri	0	0	0	0	0	0	240	310	380	350	**1280**	0.55
M. laevigata	0	0	0	100	435	415	2537	2795	1170	1581	**9033**	3.86
M. madagascariensis	0	0	0	125	2182	1535	6195	8805	5945	4848	**29635**	12.67
M. milotympanum	0	0	0	0	0	0	0	0	1270	1780	**3050**	1.30
M. nigricans	0	0	0	100	200	0	155	490	80	0	**1025**	0.44
M. pulchra	0	0	0	0	784	905	3277	4430	2990	2560	**14946**	6.39
M. viridis	0	0	0	125	690	385	1951	3825	2495	2040	**11511**	4.92
TOTAL	**100**	**11965**	**16693**	**19186**	**38358**	**13000**	**36042**	**50403**	**27140**	**21006**	**233893**	**100**

Tab. II. Export of *Mantella* between 1994 and 2003 from Madagascar as reported in the UNEP-WCMC trade database (date collated on 2 May 2005). The species *M. baroni*, *M. cowani*, *M. haraldmeieri*, *M. madagascariensis*, and *M. pulchra* have gone through stages of profound taxonomic rearrangements between 1991-1999, and they have been largely confounded also in the pet trade. The trade figures of these species therefore need to be viewed with extreme caution. In addition, most of the zero values refer to cases in which no data were available (especially for the years 1994-1996) or different names were used in the trade (especially for the names *M. baroni* and *M. milotympanum*).

The data show that high levels of *M. aurantiaca* were exported between 1996 and 1998, peaking in 1998 with 31,941 individuals, although this certainly includes some *M. milotympanum* traded as *M. aurantiaca.* Exports of *M. aurantiaca* decreased on 2002 and 2003 when a quota system came into force. In this system, the Malagasy authorities decide, for each species, quotas of maximum numbers of individuals per year for which export permits will be issued. For example, the quota for *M. cowani* is currently (since 2005) set to zero for commercial exports, due to the critical status of this species. Since 1999, all *Mantella* species in addition to *M. aurantiaca* were present in the trade with the exception of *M. manery*. *M. aurantiaca* numbers progressively decreased while those of the complex *M. madagascariensis-baroni-pulchra* increased (Tab. II).

Several unpublished reports have provided numbers of Malagasy poison frogs in the trade. These data have often been used in previous conservation decisions in Madagascar. Tab. III summarizes these data, which provide higher numbers than those reported in the UNEP-WCMC database (a total of 275,576 exported specimens between 1988 and 2003).

Species	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
M. aurantiaca	280 (6)		3237 (6)		12000 (6)		100 (8)	12110 (8)	16767 (8)	13700 (8)	26598 (6)	8599 (7)	11545 (6)	9785	570	0
M. bernhardi								230 (6)	10 (6)	400 (6)	2709 (6)		896 (6)	1005	650	305
M. betsileo			330 (6)	500 (6)						1000 (8)	1068 (6)		2677 (6)	3971	1215	1555
M. crocea				150 (5)			1000 (4)				1608 (6)		4049 (6)	3633	1830	1025
M. cowani			5094 (2)	3045 (2)				3732 (3)					1723 (6)	963	1320	170
M. expectata										100 (8)	1115 (6)		1730 (6)	4398	2385	1785
M. haraldmeieri													506 (6)	310	380	280
M. laevigata				100 (6)						100 (8)	1505 (6)		4003 (6)	2875	1170	2368
M. madagascariensis				525 (6)						125 (8)	8626 (6)		11668 (6)	9560	5800	6238
M. milotympanum													650 (6)	800	1260	3115
M. nigricans										100 (8)	200 (8)		335 (6)	2	0	175
M. pulchra											1958 (6)		5896 (6)	4047	3290	2890
M. viridis			1470 (1)	3000 (2)				2055 (3)		125 (8)	515 (8)		4167 (6)	3910	2395	2415
TOTAL	**280**		**10131**	**7320**	**12000**		**1100**	**18127**	**16777**	**15650**	**45902**	**8599**	**49845**	**45259**	**22265**	**22321**

Tab. III. Compilation of information on numbers of *Mantella* specimens exported from Madagascar in the period 1988-2003 as reported in "gray literature" sources. Data were compiled from various unpublished reports, mainly from Rakotomavo (2000), who himself referred to the following unpublished sources without providing complete references: (1) Biodev 1992 1991; (2) Biodev 1993; (3) Biodev 1995; (4) Ferraro & Ramandimbison 1994; (5) Biodev, without precise date; (6) data from the MinEnvEF. Furthermore, data are included from (7) a report of the University of Antananarivo (Département de Biologie Animale) from 2001, and (8) from the IUCN-SSC Wildlife Trade Program. The data for 2001-2003 are from the CITES reports of the Malagasy government. In the case of contradicting information, we chose the source that reported the highest numbers. See caption to Table II regarding taxonomic uncertainties. Since *M. baroni* was not quoted in any of the reports due to taxonomic confusion with *M. madagascariensis*, it is not included in the table.

The discrepancy between data sets can be afforded, in part, to the fact that re-exports were reported as greater than the original imports for certain countries or years (Tab. IV), especially for 1995 to 1998 and 2000 to 2002. These refer to specimens shipped from Madagascar to a certain country but then, often immediately, re-exported into another country. A further caveat in the interpretation of the numbers from the various data sources is that until recently, Madagascar reported the number of specimens for which CITES documents were issued, not the number of actually exported specimens, which may have been lower in some cases. On the other hand, due to relatively high mortalities during transport to exporters, and especially in the farms and animal keeping facilities of some exporters in the past (Glaw F., Vences M. & Andreone F., personal observations), we estimate that up to 50-100% more *Mantella* individuals were collected from the wild than were actually exported.

Country	Imp. Quantity	(Re-)Exp. Quantity	Total	% of Imp. Quantity	% of Total Trade
Austria	0	120	120	0.00	0.04
Bangladesh	0	400	400	0.00	0.12
Belgium	6200	3480	9680	4.46	2.97
Canada	6320	5410	11730	4.55	3.60
Switzerland	2646	2716	5362	1.90	1.65
Czech Rep	70	190	260	0.05	0.08
Germany	7212	6510	13722	5.19	4.21
Denmark	868	540	1408	0.62	0.43
Spain	1425	1302	2727	1.03	0.84
France	3090	3780	6870	2.22	2.11
Great Britain	1499	2800	4299	1.08	1.32
Hong Kong	0	670	670	0.00	0.21
Hungary	0	130	130	0.00	0.04
Indonesia	10	100	110	0.01	0.03
Italy	270	850	1120	0.19	0.34
Japan	2682	6690	9372	1.93	2.88
Mauritius	0	120	120	0.00	0.04
Malaysia	0	102	102	0.00	0.03
Netherlands	7577	5905	13482	5.45	4.14
Philippines	0	10	10	0.00	0.00
Reunion	0	10	10	0.00	0.00
Russian Federation	0	16	16	0.00	0.00
Slovak Rep	50	90	140	0.04	0.04
El Salvador	0	1380	1380	0.00	0.42
Thailand	450	1070	1520	0.32	0.47
Taiwan	0	30	30	0.00	0.01
United States	98641	142094	240735	70.96	73.91
South Africa	0	200	200	0.00	0.06
TOTAL	**139010**	**186715**	**325725**	**100**	**100**

Tab. IV. Number of individuals imported and re-exported for trade purpose per country between 1994-2003 according to the UNEP-WCMC database (collated on 2 May 2005). See caption to Table II regarding taxonomic uncertainties.

The trade network structure

Collectors were local peasant people with a good knowledge of their local fauna and flora. They traded in *Mantella* species present in their locality or, for more specialized collectors, traveled to sites for the purpose of collecting. About half of the collector positions were occupied by family fathers. Younger collectors and women who occupied collector positions were mostly affiliated with the same family as the principal collector. The number of collectors varied according to the international demands from the trade. Collections of specimens were mainly made during the wet season, often after the period of rice harvesting.

The next level in the export network is constituted by the intermediaries. Unlike the local collectors, these stakeholders are solely involved in the wildlife trade. They are equipped with mobile phones to permit quick communication. They are located across different provinces of Madagascar and usually have stable homes and a family. Several intermediaries are concentrated in the Moramanga area, not far from the Malagasy capital Antananarivo.

During the period 2003-2004, there were 17 accredited animal exporters in Madagascar, based in both Antananarivo and Toamasina. For most exporters, if not all, animal and plant export is the main source of income. Exporters usually place specific orders with an intermediary, which includes margins of at least 5-10% higher than the actual needs of the exporter to account for mortality during transport. The intermediaries then travel to the main areas of collection, obtain specimens from the local collectors and either transport personally or ship the consignment to the exporters in Antananarivo. Often after a short period, exporters ship the consignment of specimens by airfreight to their destinations in America, Europe [but currently not to the European Union (EU) due to the ban on most *Mantella*], or Asia. The distinction between local and intermediary collectors is not always a clear one. Some intermediaries do also carry out collection of *Mantella* themselves, such as *M. bernhardi*, *M. betsileo*, *M. haraldmeieri*, *M. laevigata*, and *M. viridis*, which occur in areas without a well-developed and structured collecting network. Alternatively, exporters may also choose in some cases, such as the collection localities close to main roads, to obtain specimens directly from local collectors.

Field surveys and interviews indicate that, for several species (*M. baroni*, *M. crocea*, *M. madagascariensis*, *M. milotympanum*, and *M. pulchra*), an average of five collectors work at a site, with each collecting approximately 300 individuals per day during the peak period (October through January) and 100 individuals per day during the off-peak season (February through April). Based on information gathered during interviews with local collectors, and during times of high exploitation for *M. aurantiaca* (before its inclusion on CITES Appendix II), on average 10 collectors harvested between 500-1000 individuals in peak periods and 100 during off-peak periods. In northern Madagascar about 3000-5000 *M. viridis* individuals were collected per year. Collection of *M. laevigata* and *M. nigricans* is occasional and in low numbers of individuals per year. Collecting of *M. haraldmeieri*, from Manantantely, is occasional. *M. betsileo*, a widespread species in Madagascar, is not exploited in high numbers because of its low demand. There is some trade of this species to the EU, where it is the only species that, currently, can legally be imported.

Collecting is usually carried out in the period between October and March, coinciding with the main activity and reproduction period of *Mantella* (Figs. 4-

6). Previous legal regulations restricted collecting of *Mantella* to between May and September but were not respected. In 2005, this legislation was changed, now allowing collecting during the peak season. After an order has been placed with a collector, collecting takes place, on average, one day per week during the peak season and more often during the off-peak season. Specimens are usually "delivered" within a week after the order being placed. At some localities, such as Andranomandry and Fierenana, each collector has a distinct collecting area, whilst at other sites, such as Alakambato, An'Ala, Beparasy, Fanjavala, and Marovoay, various collectors work at the same sites. Usually, upon placing an order, the exporter pays part of the money (up to 50%) to the intermediary. The intermediary uses this amount to pay the collectors and receives the balance upon delivery of the specimens to the exporter or between a week and a month after delivery.

In terms of governance, the MinEnvEF, through its General Direction (DGEEF), regulates the wildlife trade on Madagascar. Exporters need to obtain approval and be accredited by the DGEEF, which implies that they have the necessary basic infrastructures for the housing and storage of live animals. The collecting permits which the DGEEF issues to the exporters rather than to the local collectors must be renewed every 3 years. Each single consignment exported requires a further export permit from the DGEEF. These export permits need to be agreed by the Scientific Authority, which, since 2003, is

Fig. 4. Local collector searching for *M. cowani* at Soamatsaka near Antoetra, photographed in 2003. Photo by F. Andreone.

Fig. 5. Individual of *Mantella aurantiaca* from Andromena south of Moramanga, one of the areas where this species is intensively collected for the pet trade. Photographed by M. Vences in December 2001.

Fig. 6. Large numbers of *M. aurantiaca* in a cage of a commercial exporter near Antananarivo. Photo by F. Andreone.

formed by the "Département de Biologie Animale" at the University of Antananarivo. Export permits for species included on the Appendix of CITES usually have a validity of 6 months, extendable to 12 months. A schematic representation of the trade network and its legal regulation is shown in Fig. 7.

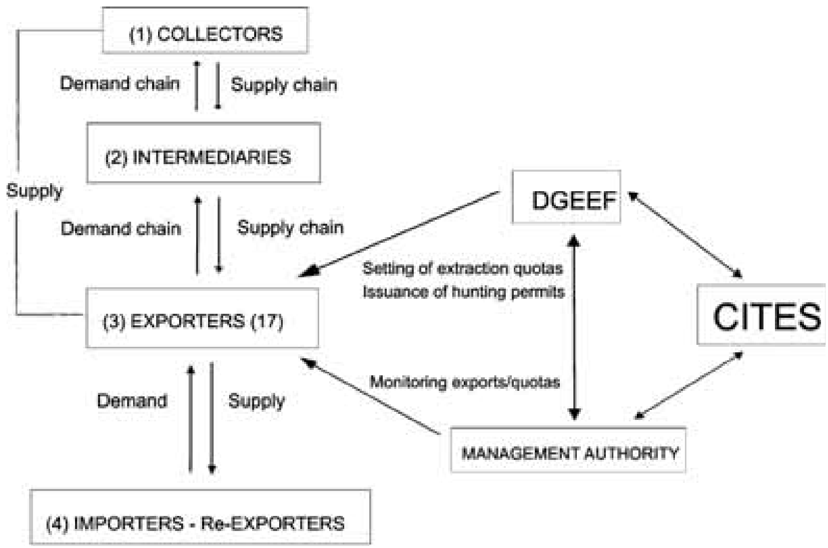

Fig. 7. Schematic flowchart representation of the network for collecting and trade in *Mantella* in Madagascar. See Results for further explanations.

Trade fluctuations and revenues

Only 5 out of 28 importing countries accounted for more than 90% of the total numbers of *Mantella* traded from Madagascar (Tab. IV). The USA (71%) was the greatest importer followed by The Netherlands (5.5%), Germany (5.2%), Canada (4.6%), and Belgium (4.5%). The levels of trade fluctuated between 1994 and 2003 due in part to governance changes (Tab. II). For example, exports to Europe dropped after a decision by the European Commission, in 2001, to suspend all commercial importation of *Mantella*, except for *M. betsileo*. The trade in wildlife can generate enormous commercial benefits. However, this is not necessarily the case for *Mantella*, due to their lower prices, compared with chameleons, for example.

To some degree, captive-bred animals are traded, especially in the EU where the import of wild-caught specimens of most *Mantella* species is banned. However, we estimate that this applies only to a small percentage of the traded individuals. Our surveys in Madagascar also provided no evidence for any successful farming of *Mantella* in that country; such a process (rearing of captive-bred individuals in the country of origin) is extremely laborious, especially at the stage of metamorphed froglets (Glaw et al., 2000), compounding the difficulty of any attempts to captive-breed these frogs commercially.

Table V summarizes the prices paid for individuals of *Mantella* at different levels of the trade network. When no price at the level of collector is given, the specimens are both collected and delivered by the intermediary.

Considering the high number of individuals exported, the trade in *Mantella* constitutes a relevant factor of foreign currency revenue. A calculation based on numbers of exported specimens and mean export prices estimates a total of almost 250,000 US$ for merely 3 years of low-to-moderate export activities (2001-2003) (Table VI).

Species	Collectors (FMG)	Intermediary (FMG)	Export (US$)	Retail abroad (US$)
M. aurantiaca	400 – 500	1000 – 1500	2 – 3	6 – 12
M. baroni/madagascariensis	300 – 500	750 – 1500	2 (3)	5 – 15
M. bernhardi	no data	4000 – 6000	2 – 3	5 – 19.5
M. betsileo	250 – 500	1000	2 (3)	5 – 5.2
M. cowani	1000 – 2000	4000 – 6000	4	6 – 19.5
M. crocea	300 – 500	1000 – 1500	2 (3)	6 – 6.5
M. expectata	1000 – 2000	4000 – 6000	2 – 3 (4)	7.8 - 15
M. haraldmeieri	1000	4000	3	5
M. laevigata	250 – 500	1500	2 (3)	5 – 7.8
M. milotympanum	300 – 500	1000 – 1500	2 – 3 (4)	6.5
M. nigricans	no data	5000	2	10.4
M. pulchra	300 – 500	700 – 1000	2 (3)	5 – 15
M. viridis	no data	4000	2	5 – 6.5

Tab. V. Prices paid for individual specimens of *Mantella* at different levels of the trade network in 2003-2004. Collector, intermediary, and export prices are based on results of interviews in 2003-2005. Retail prices were compiled from price lists of importers (wholesale; lower end of values) and larger retail companies (final retail in small pet stores may have been higher). Export prices in parentheses are current figures (as of May 2005), indicating the rise of prices due to restrictions caused by the unofficial quota system; at this time, retail prices per specimen in some cases were up to ca. 30-40 US$. Exchange rate at the time of survey was ca. 1 US$ = 6500 Franc Malagasy (FMG).

Year	**2001**	**2002**	**2003**	**Total**
Total number of individuals exported	50,403	27,140	21,006	98,549
Foreign currency generated (US$)	126,007	67,850	52,515	246,372

Tab. VI. Global estimation of foreign currency revenue in US$ for Madagascar from the *Mantella* trade, estimated for the 3 last years 2001 to 2003. Calculations are based on total numbers of exported specimens as given in Tab. II, and the mean (2.5 US$) of export prices as given in Tab.V.

DISCUSSION

The current system of regulation and control of the animal trade involves different entities (MinEnvEF, CITES Scientific Authority of Madagascar, airport customs), which are, as are the exporters themselves, based in the capital Antananarivo. If correctly implemented, this system should be effective to avoid overexploitation and control the number and identity of exported specimens relative to national and international legislation and quotas. The recent establishment, within the system, of a scientific authority, with the ability to carry out research on focal, heavily traded species and to suggest maximum quotas for the export, is a positive novelty as well. All issued documents at present (2005) state that they can only be used for an export from Ivato airport at Antananarivo. This restriction should also increase the quality of the controls, although there are still rumors of shipments leaving from Toamasina instead.

In contrast, all problems directly related to the local actors and the sites of collection totally escape from the influence of the regulation system. The fact that the collection permits are issued to the exporters instead of the local collectors, and because of the low prices paid to these per individual, this becomes counterproductive in terms of implementation of a system of sustainable harvesting in which locals would efficiently protect the natural habitat because of the economic benefit created by the collecting of animals. A system assigning control of some areas of *Mantella* habitat to local communities would enable them to demand higher prices and thereby alleviate the price bias of the trade system.

Because of the apparent high density of many *Mantella* populations (e.g., Vieites et al., 2005) and their restricted and patchy distributions, these frogs may be well-suited for a controlled system of sustainable harvesting, although the economic feasibility of such a system requires investigation. Most species of *Mantella* are characterized by a rather high reproductive output, with up to 150 eggs per clutch (Glaw et al., 2000) and probably several clutches per season based on data from captive breeding. Despite the high to very high numbers of several *Mantella* species that have been continuously exported from Madagascar over the past 15 years, for most species there has been no apparent disappearance of populations or permanent decreases in population density. Due to the lack of a standardized monitoring system, this claim is only supported by anecdotal observations, but it is in agreement with the data assembled by the Global Amphibian Assessment for Madagascar (Andreone et al., 2005), where Madagascar differed from other areas in the world in that amphibian declines due to other factors than habitat disappearance have almost not been recorded thus far. For example, we visited populations of *M. aurantiaca* and *M. milotympanum* that local collectors claimed to have heavily exploited during the past years (Vences et al., 2004; Vieites et al., 2005), but *Mantella* were still very common at these sites. A clearly different situation is that of *M. cowani*, where intensive collecting has led to the near disappearance of some of the most accessible populations, after the main habitat of these had been destroyed (Andreone & Randrianirina, 2003). In fact, the estimated population of *M. cowani* at a site near to Antoetra was of about 50 adult animals only (personal observation of F. Andreone). However, there remain few doubts that habitat destruction is a far more severe threat for many *Mantella* populations than overcollecting, especially considering that also the international demand for these frogs is certainly not unlimited. Hence, it may become important to transfer the focus of the trade regulation more toward the sites of collection, which are usually in nonprotected areas threatened by habitat destruction. Possible local measures could consist in (1) disseminating awareness and information on the value and habitat requirements of the respective species, (2) formation and capacity reinforcement of the local forestry authorities, and (3) professionalization of the system at the level of local collectors and intermediaries, possibly by delivery of local collection permits after passing basic tests of knowledge on natural resources. However, these measures imperatively need to be implemented in a flexible way without increasing bureaucracy and hindering the trade system itself.

At the scientific level, we propose to (1) perform surveys of population persistence and density, comparatively in areas with and without commercial collecting, at 2-year intervals, (2) gather more data about the functioning of the trade network and mortality rates at the different levels, (3) implement and survey prudent maximum export quotas for *Mantella* and all commercially relevant amphibian and reptile species of Madagascar, and (4) as test cases, delimit study areas to survey the impact of different collection modes, e.g., local quotas or permits for heavy local collecting at all times except the time of peak reproductive activity of these frogs (January). The goal of these studies should, however, not be to implement further trade restrictions but to optimize the collecting system, potentially even allowing an increase of quotas once that reliable scientific evidence on the trade impact on frog populations and on tolerable quota values has been assembled. Strict control measures should become only active when irregularities or local overcollecting is suspected by conspicuous changes in the number of traded individuals per species or by declines or disappearance of populations recorded by a standardized monitoring system, or noted by casual observations.

Considering the high number of *Mantella* specimens exported, these frogs take a relevant place in the economy of Madagascar. Compared with previous years, this system currently undergoes a crisis because of the ban of imports to the EU, and a decrease of the prices at the world-wide level. The recent announcement of the Malagasy government to significantly increase the country's protected areas, together with progress of professionalizing the wildlife trade, bears the opportunity for organizing this system in a way that provides benefits to the national and local economies as well as to the conservation of species which can be sustainably harvested.

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RÉSUMÉ

Les grenouilles venimeuses de Madagascar dans le commerce international: une analyse des niveaux d'exploitation dans le genre Mantella.

Les Amphibiens du genre *Mantella* de Madagascar sont des grenouilles de couleurs vives qui sont en demande très élevée dans le commerce international des animaux de compagnie. *Mantella aurantiaca* a été inclus dans l'annexe II CITES en Février 1995 et le genre entier en 2000. Le rapport annuel CITES indiquaient des exports reportés de 230 000 spécimens entre 1994 et 2003. Le commerce rapporté de l'espèce *M. aurantiaca* a augmenté abruptement entre 1996 et 1998, avec plus de 30 000 spécimens exportés en 1998, mais a diminué après l'application de quota inofficieux à Madagascar. Des informations sur la distribution, les préférences de l'habitat et des impacts de menace, comme la chasse pour le commerce, sont très limitées, et beaucoup d'espèces sont actuellement classées comme Gravement Menacée. Basée sur les études du réseau commercial, les bénéfices obtenus par les collecteurs locaux sont très bas (équivalent de 0,05-0,02 US$ par spécimen), avec habituellement 100 à 300 grenouilles collectées par jour. Les intermédiaires vendent les grenouilles aux exportateurs qui, à leur tour obtient un prix international de 2 à 4 US$ par spécimen, avec prix de détail de 5 à 20 US$ (prix de détail actuel en 2005, de plus de 40 US$). Dus à la probable densité de population et au potentiel reproductive élevées de ces grenouilles, il serait possible d'exploiter quelques-unes, mais non pas tous, de ces espèces *Mantella* de façon durable. Pour atteindre cet objectif, il est de priorité de transférer le point focal du système de régulation plutôt au niveau des collecteurs locaux et assurer que des bénéfices substantiels soient maintenues pour les communautés locales qui devraient gagner une contrôle partielle des habitats actuels de ces grenouilles. Un système de quotas d'exportation est un autre potentiel pour éviter la surexploitation des espèces.

Mots clés: Amphibia, CITES, Madagascar, *Mantella*, Pet-trade.

Falitiana C.E. Rabemananjara
Noromalala Rasoamampionona Raminosoa
Olga Ravoahangimalala Ramilijaona
Daniel Rakotondravony
Parfait Bora
Tokihery J. Razafindrabe
Département de Biologie Animale
Université d'Antananarivo, BP, 906
101 Antananarivo, Madagascar
Email frabeman@science.uva.nl
Email falyrabemnjr@yahoo.fr

Franco Andreone
Museo Regionale di Scienze Naturali
Via G. Giolitti 36
10123 Torino, Italy
Email franco.andreone@regione.piemonte.it

Angus I. Carpenter
Centre for Ecology, Evolution and Conservation (CEEC)
School of Environmental Sciences
University of East Anglia
Norwich NR4 7TJ
United Kingdom
Email a.carpenter@uea.ac.uk

Frank Glaw
Zoologische Staatssammlung München
Münchhausenstr. 21
81247 München, Germany
Email Frank.Glaw@zsm.mwn.de

Denis Vallan
Natur-Museum Luzern
Kasernenplatz 6
6003 Luzern, Switzerland
Email Denis.Vallan@lu.ch

David R. Vieites
Museum of Vertebrate Zoology and Department of Integrative Biology
3101 Valley Life Sciences Bldg.
University of California
Berkeley, CA 94720-3160. USA
Email vieites@berkeley.edu

Miguel Vences
Zoological Institute
Technical University of Braunschweig
Spielmannstr. 8
38106 Braunschweig, Germany
Email m.vences@tu-bs.de

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Samuel C. FURRER[1]

Madagascar amphibian conservation in Zoo Zürich, Switzerland

ABSTRACT

The Masoala rainforest exhibit in Zoo Zürich was opened in 2003. It is a walk-through 11'000m^2 exhibit displaying the fauna and flora of Masoala. The system contains more than 400 plant and 40 vertebrate species. This conservation project is strongly linked to the Masoala National Park. Through this project, Zoo Zürich is able to support the conservation work in Masoala significantly (by financing, with marketing and by promoting eco-tourism). Many endangered species are kept in the exhibit; most of them breed within international breeding programs. Zoo Zürich can offer space within the Masoala exhibit for amphibians, both 'free-ranging' or within terrariums, according to the specific needs. At the moment we keep (and breed*) *Mantella aurantiaca**, *M. laevigata**, *Dyscophus guineti* and *Scaphiophryne marmorata*. In 2006 Zoo Zürich has opened a separate amphibian exhibit and has started to support amphibian in-situ conservation work in Madagascar (conservation research).

Key words: Amphibians, Madagascar, Masoala rainforest, Zoo Zürich.

The Masoala Project

Masoala, a still primarily wooded peninsula in the North-East of Madagascar, is the habitat of innumerable rare plants and animals, as very many and exclusive amphibian species (Andreone et al., 2006). According to studies carried out by the nature conservation organization "Conservation International" (Myers et al. 2000), Madagascar is what is referred to as one of planet earth's hotspots, namely a region with an extremely large number of different species. The Masoala Peninsula is a hotspot within a hotspot. It is in this rain forest that Madagascar's bio-diversity is at its greatest. Zürich Zoo wishes to help visitors enjoy the flora and fauna as well as sensitizing the local population to the importance of nature conservation. According to the Zoo's strategy, the Masoala Rain Forest is to set new standards as an ambassador of the endangered rain forest and it's fauna and flora (Figs. 1, 2).

[1] Zoo Zürich, Zürich.

Fig. 1. Meanwhile, the impressions within the exhibit are nature-like.

Fig. 2. Free-ranging *Furcifer pardalis* in the Masoala exhibit.

For the National Park to continue to exist, its long-term surveillance by park rangers must be financed continuously. A central issue consists in involving the locals in the protection of the rain forest and ensuring their subsistence without the necessity of their having to destroy the forest. A prerequisite for this is an improved and more profitable agriculture outside the National Park as well as providing the local population with new possibilities to earn a living (Rübel et al., 2003). Means of achieving this include, for example, the construction of rice terraces providing more significant crops than traditional rice cultivation forms or the cultivation of plants producing a better quality of vanilla, coffee and cloves as well as the establishment of a permanent forestry business with tree nurseries that can be used for afforestation.

To fulfil their obligations to, and keep pace with, society's concern for the environment, zoos must become more proactive conservation organisations (Conway 2003). Zürich Zoo has committed to paying an annual contribution to the operating costs of the Masoala National Park. This contribution is funded by donations made by zoo visitors as well as by part of the turnover realized in the Masoala Restaurant and Masoala Shop. These payments cover 25% of the expenses for ranger salaries, infrastructure maintenance, and the general operating costs of the National Park.

The long-term goal of the Swiss-Madagascan cooperation is the conservation of species and their habitats in Masoala. In the ecosystem constructed at Zürich Zoo, visitors can discover the special features of this habitat in a practically authentic section of the Masoala Rain Forest. The adjoining Information Center is to motivate the public to contribute actively to the preservation of the forests and to make voluntary contributions amounting to USD 100,000 per year to the long-term maintenance of the Masaola National Park. Within the scope of this project, Zürich Zoo acts as an ambassador for the conservation of a fascinating animal and plant world. The Masoala Rain Forest in Zürich is also intended to encourage visitors to tour the National Park as tourists and to experience the beauty and variety of the rain forest in all its splendor.

Today, tourists from Switzerland are the largest group of foreign visitors to the Masoala National Park. The upswing of tourism helps to create jobs and income in Masoala. Consequently, the rain forest is becoming increasingly valuable to the population who is now helping to preserve it.

Amphibian conservation

Zoo Zürich has a long successful history of amphibian husbandry and is currently keeping 17 amphibian species. Amphibian species representing Madagascar are *Dyscophus guineti*, *Scaphiophryne marmorata*, *Heterixalus alboguttatus*, *Mantella aurantiaca* and *M. laevigata*. Both *Mantella* species are reproducing. *Mantella laevigata* is kept in self-made, relatively cheap and easy to maintain breeding boxes (Fig. 3). *Mantella aurantiaca* is bred outside the Masoala exhibit in separate terrariums under climatic controlled conditions. We are hopeful to also reproduce the tomato frogs (as soon as they become

Fig. 3. Breeding facilities for *Mantella laevigata.*

mature), as we were breeding *Dyscophus antongili* in 2001. The Malagasy amphibians are an essential part of a new exhibition on Amphibians, illustrating aspects of amphibian biology, causes of the crises and possible solutions (Figs. 4, 5, 6). Simple donation boxes are used very frequently by the visitors and this money helps to fund our amphibian conservation activities.

There are no facilities to accommodate Amphibian Ark species in Zürich at the moment, as they are requested by CNSG/WAZA (2006). But there are many options to keep further species where husbandry research is needed. This would primary be tropical forest species that would accept the climatic conditions in the Masoala exhibit. Some very promising research projects with other taxa have already shown good results (Furrer at al., 2006; Sommerfeld et al., 2006). Furthermore, Zoo Zürich is supporting amphibian conservation research projects in Madagascar, as the Tomato frog project 'Life history traits as useful tool for the conservation of the tomato frogs *Dyscophus antongili* and *D. guineti* (Amphibia: Microhylidae) in eastern Madagascar' supervised by F. Andreone (Fig. 7) (Tessa et al., 2007).

The implementation of husbandry know-how (amphibian training course a.o.) in Madagascar would also be a project to find support by Zürich Zoo, as well as the set up of facilities to develop assurance colonies in situ. Among others, the application of captive breeding programs is one of the emergency responses to the immediate crises. These captive survival assurance colonies must always link to long-term conservation strategies.

Fig. 4. It is 5 minutes to twelve for the class of amphibians.

Fig. 5. Amphibian conservation programmes in Zoo Zürich.

Fig. 6. Donation box in form of a big frog (motivates visitors to spend some 1000 Euro each year.

Fig. 7. Tomato frog (*Dyscophus guineti*) in a terrarium in the information centre.

Within the Global Amphibian Ark, that was formed by WAZA (World Association of Zoos and Aquaria), CBSG (Conservation Breeding Specialist Group) and the IUCN/SSC Amphibian Specialist Group, the EAZA (European Association of Zoos and Aquaria) plays a vital part. EAZA Zoos and Aquaria will focus on Malagasy amphibians and will support and initiate conservation efforts. EAZA's Amphibian Ark (of which Zürich is a member) is already able to provide information's on general amphibian husbandry techniques (including training courses, staff time a.o.) and know-how in capacity building. A list of species that are candidates for to be kept in assurance colonies has been published under http://www.amphibianark.org/prioritizationworkshops.htm. Therefore, EAZA Amphibian Ark is acting in very close relationship with some of the most relevant Malagasy amphibian experts and representatives of the government and conservation institutions.

RÉSUMÉ

La conservation des amphibiens de Madagascar au zoo de Zürich, Suisse.

L'exposition sur Masoala présentée au Zoo de Zürich s'est ouverte en 2003. Il s'agit d'un parcours de 11 000 m2 qui présente la faune et la flore de Masoala. L'ensemble contient plus de 400 plantes et 40 espèces de vertébrés. Ce projet de conservation est fortement lié au Parc national de Masoala. A travers ce projet, le Zoo de Zürich réussi à soutenir significativement le travail de conservation à Masoala (financement, marketing et promotion de l'écotourisme). Beaucoup d'espèces en danger ont été retenues pour l'exposition ; la plupart ont été élevés à l'intérieur d'un programme international d'élevage. Le Zoo de Zürich peut offrir un espace pour les amphibiens dans l'exposition sur Masoala en «liberté» ou dans des terrariums, conformément à leurs besoins spécifiques. Pour le moment on s'occupe (et élève*) des *Mantella aurantiaca**, *M. laevigata**, *Heterixalus alboguttatus, Dyscophus guineti* et *Scaphiophryne marmorata*. En 2006, le Zoo de Zürich a ouvert une présentation distincte d'amphibiens et a commencé à soutenir le travail de conservation in situ d'amphibiens à Madagascar (recherche sur la conservation).

Mots clés: Amphibiens, Madagascar, Zoo de Zürich, Forêt pluviale de Masoala.

Samuel C. Furrer
Zoo Zürich
Zürichbergstrasse 221
CH-8044 Zürich
Switzerland
Email samuel.furrer@zoo.ch

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Claudia Gili [1]

Conservation activities on Malagasy amphibians at Acquario di Genova

ABSTRACT

Acquario di Genova is a large scale Italian aquarium opened in 1992 and, as many other European zoos and aquaria, actively participates to international conservation programs and campaigns. Since 1996 the island of Madagascar has been one of its main *ex-situ* programs, focusing the attention of all the different departments of the aquarium. The overall active participation of the education, scientific, exhibit and marketing staff to this program, has increased and promoted public awareness on emerging Malagasy conservation issues. This success has been also deeply related to specific animal husbandry techniques that support the live habitats, providing emotions for all the different educational programs and promoting exchanges with other institutions.

Key words: Amphibians, Captive breeding, Conservation, Education, Madagascar.

INTRODUCTION

The Acquario di Genova (AdG) opened to the public in 1992 during the celebration of 500 years of discovery of the American continent by Christopher Columbus. It comprises 70 exhibits, 4 of which are oceanic, with 7 million litres of water holding 600 species of invertebrates, fish, amphibians, reptiles, birds and mammals from Antarctic to temperate and tropical habitats, including Madagascar.

The AdG is currently visited approximately by 1,2 million people each year and it's mission is "*to increase public awareness on conservation, responsible management and sustainable use of aquatic environments and resources*". For this purpose from the very beginning AdG has carried out research projects in Madagascar and participated to numerous expeditions in collaboration and

[1] Acquario di Genova.

agreement with universities, ministries and other scientific institutions. The animal husbandry department has successfully concentrated on maintenance and breeding of several species of Malagasy fauna and flora. This participation is certainly one of the best ways to spread global messages reaching millions of visitors throughout Europe and to achieve substantial and effective results through programs of unite intervention.

MATERIAL AND METHODS

The interest toward different species of amphibians in an aquarium setting is easily related to the educational interest of aquatic environments and to the aquarist's expertise in water monitoring, management and global understanding of the dynamics of aquatic species.

Amphibian conservation and breeding efforts at AdG have initially concentrated on local European species, *Pelodytes punctatus* and *Pelobates fuscus*, that were both successfully reproduced (Emanueli et al., 1997; Jesu et al., 2000). Subsequently the attention moved toward Malagasy species collected and studied *in situ* during the following expeditions: (1) Study of herpetofauna of Tsingy de Bemaraha (team members 1993: Emanueli L. and Jesu R.; team members 1995 and 1997: Schimmenti G. and Jesu R.); (2) Study of herpetofauna of Tsaratanana Massif (team members: Andreone F., Mattioli F., Randrianirina J. E. and Vences M.); (3) distribution and ecology of *Mantella expectata* and *Scaphiophryne gottlebei* at Isalo Massif (team members: Andreone F., Mercurio V., Mattioli F., Randrianirina J.E. and Razafindrabe T.J.); distribution and ecology of *Dyscophus antongilii* at Iampirano area (team members: Andreone F., Mattioli F. and Randrianirina J.E.).

Investigations on Malagasy amphibians started by identifying the following representative species and founders for breeding colonies: 12 *M. aurantiaca,* 10 *S. marmorata,* and 6 *D. guineti* obtained through specific accords between the AdG and University of Antananarivo. These individuals were maintained in the AdG facilities by applying amphibian husbandry techniques and including all the observations carried out during the expeditions. Furthermore, the acquired knowledge has been applied in order to appropriately replicate, as much as possible, their natural environment in artificial conditions and to find the best suitable parameters to guarantee maintenance and breeding (Mattioli et al., 2006).

RESULTS

Generally speaking, when wild animals are collected and transferred into an artificial facility, aquarists and keepers face a series of technical and biological challenges aimed to guarantee survival, animal welfare and reproduction of the individuals and populations. The most relevant husbandry problems identified upon arrival into a new facility relate to health, environmental acclimation and food acceptance. Concerning amphibians a description of some captive management conditions utilized at AdG for the 3 Malagasy species above mentioned (*Mantella aurantiaca, Scaphiophryne marmorata, Dyscophus guineti*) will appear in the following paragraphs.

In terms of health and veterinary aspects, the development of stress related diseases due to capture, transport and isolation is a very common issue that needs to be addressed. Careful planning should start even prior to capture and end with the completion of the acclimation process. In order to allow prompt diagnosis and avoid individual and/or even colonial losses, diseases and stress situations must be monitored and identified as soon as possible by utilizing clinical examination, microbiological isolation, parasitic investigations, post-mortem examination of the deceased individuals.Quarantine starts upon arrival in the facility to avoid introduction of infectious agents into the local populations and prevent development of illnesses in the newly arrived specimen as a consequence of transport related stress and immune system malfunctions. During quarantine the animals are checked for infectious diseases and parasites load; diseased animals can often be isolated and treated individually by mouth, by spraying and nebulizing the agent, by immersion or by injection, keeping in mind that manipulation and isolation in separate environment might act as a stress factor itself. With this view, quarantine is not aimed to sterilize the animals, but to identify, contain and reduce problems. Special attention must currently be given to emerging diseases such as the fungus *Batrachochytrium dendrobatidis*, implicated in the decline of amphibians in natural environments; diagnostic investigation and strict monitoring through quarantine procedures can help prevent its introduction into new collections (Wright, 2006).

Acclimatization to new environment is a very important factor that can limit or implement the stress on the individuals if confined space in terms of substrate, humidity, lighting and hiding holes are not comparable to their original natural environment. Simple and clean earth, peat and live plants can provide important substrate for a proper acclimating space in terrariums that also result appreciably nice for public view. The use of plants originating from Madagascar is a useful tool not only for the animals, but also to show integrity in habitat representation on an educational basis.

A proper replication of the natural conditions also includes suitable artificial lighting, photoperiod and seasonality. Variations in photoperiod and seasonality can be considered and gradually adjusted once the animals have overcome the quarantine and the acclimation period. AdG utilizes a photoperiod of 10 to 14 hours of light and dark in northern hemisphere and neon as lighting with 5% UV B emission. The seasonality differs for each of the 3 species as described as follows: (1) *M. aurantiaca* - 6 months of rainy season with temperature of 24-26°C and humidity at 80-90%; and 6 months of dry season with temperature of 21-19°C; (2) *D. guineti* - mostly dry season with temperature of 24-26°C; rain is utilized only to stimulate mating; (3) *S. marmorata* - mostly dry season with temperature of 19-24°C and humidity at 60%; rain used only to stimulate mating reaching humidity of 80-90%.

Appropriate nutrition protocols should include evaluation of the quality, quantity, species and items diversification and individual habituation to different food items. Food has to provide all the necessary ingredients to maintain a correct nutritional status, but generally needs supplementation of vitamins, minerals and nutrients (Brusse et al., 2004). The type of food has to be easily accessible or directly bred by the facility, in quantity and quality suitable to sustain the animals and also to offer "choices" according to different tastes and behaviors. Breeding insects within the facility can provide a wide variety of prey sizes that can be used to stimulate different size animals and can be available at every time (Fig. 1). Providing the right proportion of food items per specimen in a controlled environment is important to avoid competition; even nocturnal feeders can be slowly accustomed to diurnal feeding which allows routine monitoring of real consumption status. The food items cultured at AdG and utilized for amphibians include the following species: *Acheta* sp., *Alphitobius* sp., Collembola spp., *Drosophila* sp., *Galleria mellonella, Gryllus* sp*., Linephitema umile, Tenebrio molitor, Thermobia* sp.

Once completed the quarantine period the animals can be moved to their final environment, meeting their social and colonial needs. At this stage, even if early, it is important to provide all their natural requirements to subsequently conduct proper reproductive programs. A methodical work has allowed to obtain repeated reproductive events in the years following nearly annual cycles.

To guarantee successful and fertile mating with production of living offspring, Amphibians require specific conditions for mating (Fig. 2), egg laying, successful hatching of the eggs and raising of the tadpoles. For this

Fig. 1. Living food facility at the Acquario di Genova.

purposes it is important to reproduce the variation in seasonality and photoperiod and recreate environmental conditions that stimulate mating, such as a sudden temperature and humidity change for *M. aurantiaca*, whilst *S. marmorata* and *D. guineti* need instead a proper raining season that can be simulated by constructing a “rain chamber” that matches the needs of the individual species in terms of climatic changes, quantity and re-circulation of water, creation of small ponds with the appropriate types of substrate. It is also important to identify the proper sex ratio (1:2 for all the 3 Malagasy species) and minimal number of individuals to create enough competition for breeding. Proper survival rates of the larvae and newly metamorphosed can be achieved by utilizing proper food items, optimising the correct ratio of food versus metamorphosed and identifying the behavioural needs in aggressive species that need to be kept individually isolated or in timid species that need cohesion and hiding places. Tadpoles of these 3 species were fed with freshwater fish tablets twice a day until metamorphosis which occurred at day 55 for *M. aurantiaca*, day 30 for *D. guineti* and 17 for *S. marmorata*.

To meet all these goals individual husbandry techniques were identified for each species and constantly improved in order to be repeated consistently “at need” according to the internal exhibit request as well as the one coming from other institutions. Intense breeding activity allows in fact the display of exhibits populated by a large number of captive bred animals; in this case some species such as the colourful diurnal *M. aurantiaca* and the large tomato frog *D. guineti* provide more rewarding display, than *S. marmorata* which is nocturnal and fossorial.

Fig. 2. Optimal stimulating conditions for *Dyscophus guineti*.

Since the first herpetological field expeditions, AdG has therefore directed its attention toward the construction of an exhibit area completely dedicated to Madagascar. In 1998 the Aquarium inaugurated the "second phase" by opening a 3,5 million euro exhibit vessel dedicated to biodiversity (Fig. 3). This exhibit area shows several species of amphibians, reptiles, fish, invertebrates and plants from Malagasy habitats, focusing on the importance of biodiversity understanding and preservation (Fig. 4) and to date, has been visited by approximately 12 million visitors. In this area the public can learn about conservation and biodiversity, admiring different habitats and species of fish, amphibians, reptiles and plants with the dedicated breeding program.

At the entrance of the Malagasy area a large space is dedicated to panels that illustrate the campaigns of conservation with related fund raising promoted by European Association of Zoos and Aquariums (Fig. 5).

Education has been performed with lectures to school children on different subjects (Fig. 6) such as reproduction, research, biodiversity, mimicry, adaptation to semi-aquatic environments, poisonous amphibians, deforestation etc. A new tour "Behind the scenes" has been recently dedicated to guided tours to show the breeding and conservation activities towards freshwater environments and herpeto-fauna. Educational impact, exhibit success and public awareness towards conservation issues have been calculated with questionnaires on feedbacks from the visitors, students or professors utilizing a scale from 4 to 8 of the called "overall index" by Eurisko™ that measures customer satisfaction. This index is based on interviews conducted at the end of the visit (approximately 4000 people each year) and allow us to understand what visitors like or dislike, and how much and where to improve. In the last five years the results of this overview were approximately 7,46.

Fig. 3. Overview of the Madagascar exhibit area at Acquario di Genova.

Fig. 4. On sight view of the Malagasy exhibit area.

Fig. 5. Area dedicated to the 2007 EAZA Madagascar Campaign.

CONCLUSION

According to Wiese & Hutchins (1994), and Mattioli et al. (2006) breeding Malagasy amphibians with conservation purposes is an obligation to all the facilities that maintain these species under artificial conditions in order to: (1) identify specific biological parameters that lead reproductive activity; (2) transfer the acquired husbandry know-how to other facilities and to the country of origin; (3) assure sustainability of the exhibit; (4) educate the public and increase awareness on environmental problems showing animals that are part of an institutional breeding program; (5) improve zoological literature and know-how concerning husbandry protocols for management and breeding of individual species; (6) Promote exchanges with other zoological or commercial

Fig. 6. Schoolchildren in visit at the Acquario di Genova.

institutions or even private owners, in order to reduce uptake from the wild for the species that are not sustainable in their own environment; (7) reduce legal uptake and illegal removals from the wild wherever unsustainable; (8) improve maintenance know-how in foreign importing countries to guarantee the life of confiscated animals to be utilized as possible genetic improvement; (9) create an ark of genetic valuable animals in case of massive destruction and species losses.

The actions conducted by AdG towards conservation of Malagasy amphibians were addressed to different scientific subjects: ecology, taxonomy, education, exhibit and reproduction. Field studies have led to the description of new species of amphibians (Vences et al., 2000, Vences et al., 2002), to population census of little known areas (Emanueli & Jesu, 1996), to the study on ecology, distribution and biology of not extensively known species (Andreone et al., 2005; Andreone et al., 2006), to embryological study (Bottero et al., 1998).

During the years, constant maintenance and continuous trials on all the three species above mentioned have led to successful repetition of breeding events that produced multiple generations from the originating founders and increased biological knowledge of these 3 species. To achieve these results AdG has developed staff expertise that constantly applied the basic aquariological husbandry techniques by replicating all the natural parameters where the animals live in Madagascar and constantly providing different types and sizes of food items; a good part of these information were collected with expeditions on site (e.g., Mercurio & Andreone, 2005).

All these results have guaranteed sustainable presence of animals into the exhibit for the past 8 years and exchanges of captive born animals with several other European institutions, allowing other facilities to keep these same species without further collection from the wild.

This type of work can improve the knowledge of the specific reproductive biology, collect scientific data such as “mating calls” (Vences et al., 2003) and create a basic ark of genetic valuable animals.

The efforts to breed animals in artificial conditions with sustainable costs and labour could even try to match the needs of a pre-existing unsustainable market request. A correct understanding and identification of the economical and biological values of this market immersed in the financial, ecological and social implications of the country of origin, are the basis to achieve efficient conservation programs (Fig. 7).

In this view, the utilization of these species exhibited in AdG to reach the general public and increase the awareness about Madagascar biodiversity during the visit of the aquarium, has been the tool to transfer the profound need for participation and for active intervention. Open public lectures on Madagascar ecology and biodiversity have been carried out on special occasions and with the help of press releases. The individual interviews indicated that our educational and conservation messages have been positively perceived by our visitor (see above ‘overall index’) and approximately 12 millions of people received these same messages in the last 10 years! Several events have also been used to raise money for specific Malagasy projects and campaigns. By sustaining fund raising campaigns, financial help can be given to intensify field studies dedicated to endangered species and threatened habitats and to develop efficacious educational programs (both *ex situ* and *in situ)* for the local populations. The money collected via captive breeding and educational campaigns is used to support: *in situ* breeding, research projects and educational programs for local people (Fig. 8).

Fig. 7. *Scaphiophryne marmorata*, juvenile individual.

May all this effort help development and implementation *in situ* to provide understanding and sustainable livelihood to local people by using a few species as a renewable "*non timber forest product*"… however, these are only a few drops in the sea of conservation, but "*many drops become rain and many frogs will call again*"!

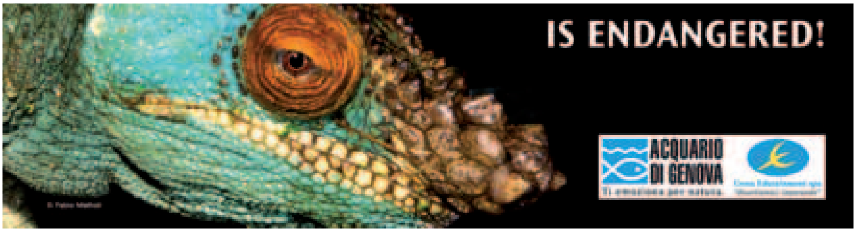

Fig. 8. Leaflet of the 2007 Madagascar Campaign.

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RÉSUMÉ

Activités de conservation sur les amphibiens malgaches chez l'Acquario di Genova.

L'Acquario di Genova est un grand aquarium italien qui a été ouvert en 1992 et qui, comme plusieurs structures zoologiques et aquariologiques européennes, participe activement aux programmes internationaux de conservation. Depuis 1996 il est justement le Madagascar un parmi les principaux programmes "ex situ" sur le quel l'ADG a focalisé son attention de tous ses départements. La participation active de l'équipe éducatif, scientifique, du marketing et de l'exposition a augmenté et promu la sensibilisation du publique sur les problèmes émergents de la conservation à Madagascar. Ce succès a été aussi corrélé profondément aux techniques de gestion animale qui supportent les habitats contents le "vivants", promouvant des échanges avec des autres structures et les émotions utiles pour tous les programmes éducatifs.

Mots clés: Amphibiens, Conservation, Education, Madagascar, Réproduction en captivité.

Claudia Gili
Acquario di Genova
Area Porto Antico - Ponte Spinola 1
I-16132 Genova, Italy
Email cgili@acquariodigenova.it

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 321-342

Gerardo GARCÍA[1], Lise BOCK[2], Samantha EARLE[3],
Richard BERRIDGE[4], Jamie COPSEY[1]

Captive breeding as a tool for the conservation of Malagasy amphibians: how ready are we to respond to the need?

ABSTRACT

The Amphibian Conservation Action Plan has proposed captive breeding as a potential tool to address amphibian declines. However this potential can only be realised if sufficient skills and experience exists within captive breeding establishments to be able to respond. With at least 25% of Madagascar's amphibians categorised as Vulnerable, Endangered or Critically Endangered captive breeding may well have a role to play in the conservation of amphibians on the island. An analysis of world zoos using ISIS databases, a questionnaire to European Zoos and interviews with private breeders holding Malagasy amphibians were used to determine the level of knowledge and expertise gained over the last ten years. Of the 226 Malagasy amphibians, 27 species are currently kept in zoos. Only a few institutions have historical records of breeding for several generations or keeping large numbers of Malagasy frogs. Private breeders are keeping approximately the same number of species as zoos. Intercommunication and collaboration between zoos has been highlighted in this paper through a case study of captive colonies of *Scaphiophryne gottlebei*. Communication between private breeders occurs through the Internet and regular trade meetings. There remains a need to draw up husbandry protocols for captive breeding populations and ensure effective record-keeping for a complete understanding of the success of these captive breeding programmes. Furthermore further collaboration between private breeders and zoos should be encouraged. Finally the reintroduction potential of particular species should be assessed.

The results demonstrate that current expertise in the captive management of Malagasy amphibians is limited. There is a need to develop this capacity through increasing our repertoire of species kept in captivity and developing husbandry guidelines. More rigorous record-keeping would allow for monitoring of future breeding success. Finally we suggest that in order to

[1] Durrell Wildlife Conservation Trust, Jersey.
[2] Roskilde Technical College, Denmark.
[3] Durrell Wildlife Conservation Trust, Summer School student 2006.
[4] European Studbook Foundation, UK.

harness the combined expertise in managing threatened amphibians in captivity collaboration between private breeders and zoos should be encouraged.

Key words: Amphibians, Captive breeding, Categorization, Madagascar.

INTRODUCTION

The plight of amphibians worldwide was recently highlighted by the 2004 Global Amphibian Assessment (GAA, www.globalamphibians.org). As one of the worlds 'biodiversity hot-spots' Madagascar hosts an almost unparalleled concentration of endemic and diverse herpetofauna (Andreone & Luiselli, 2003), which is currently experiencing intense conservation pressure. There are 226 Malagasy amphibian species (arranged in four families: Hyperoliidae, Mantellidae, Microhylidae and Ranidae), of which all but one, (*Ptychadena mascariensis*), are endemic to Madagascar and the adjacent Comoro Islands (Andreone et al., 2005; Mattioli et al., 2006). The conservation status of all these species was recently evaluated for the GAA by Andreone et al. (2005), who found that nine species are Critically Endangered, 21 are Endangered, and 25 are Vulnerable. However, a further 46 species (21% of the total) were categoried as being Data Deficient raising the likelihood that the actual number of threatened species is higher than we currently appreciate (Andreone et al., 2006).

Two specific threats are relevant to Malagasy amphibians: habitat alteration and over-collection for the pet trade (Andreone & Luiselli, 2003; Andreone et al., 2005; Mattioli et al., 2006; Andreone et al., 2006). The eastern rainforest that supports a high concentration of amphibian species (Andreone et al., 2005) and the central high plateau of Madagascar (Andreone et al., 2006), have recently been subjected to heavy anthropogenic pressure, which has resulted in the destruction and consequent fragmentation of amphibian habitat. In addition to such habitat pressures, the commercial exploitation of some amphibian species for the pet trade has the potential to reduce wild populations. It is for this reason that all species of the genus *Mantella*, amongst a few other colourful Malagasy amphibian species, have been listed in CITES Appendix II (Andreone & Luiselli, 2003). Concerning this trade, Andreone et al. (2006) reported that between 2000-2004 the mean exportation rate for *Mantella* species for commercial purposes was 32,332 individuals per year.

Despite this level of specimen collection, there is a lack of scientific data on the influence of harvesting on wild populations (Andreone & Luiselli, 2003). There is also no evidence of any large-scale amphibian extinctions as seen in other parts of the world (Andreone et al., 2005). However, with the potential for species extinctions as a result of the issues so far described, and the potential for novel threats to arise, such as disease (including chytridiomycosis), there is no room for complacency with regards to the future of Malagasy amphibians (Weldon et al., 2004; Ron, 2005; Pounds et al., 2006).

Recent reports (Andreone et al., 2006) have proposed a range of options to control the threats and monitor the status of wild populations: (i) setting of export quotas, (ii) addition of species collected for the pet trade, but not currently listed, into CITES appendices, (iii) implementation of an amphibian conservation project to be supported through co-ordination and complementary communication of research efforts for Critically Endangered and Endangered species, (iv) dedication of protected areas specifically for amphibian conservation, and (v) *ex situ* captive breeding of selected species.

The last option, (captive breeding of selected species), can be an invaluable conservation tool. Examples of captive amphibian colonies that have had a positive impact on wild populations are the Mallorcan midwife toad (*Alytes muletensis*; Buley & García, 1997), the Montserrat mountain chicken frog (*Leptodactylus fallax*; Gibson & Buley, 2004), the Jersey agile frog (*Rana dalmatina*; States of Jersey, 2006), and the Fire-bellied toad (*Bombina bombina*; Pihl et al., 2001). By exhibiting captive Malagasy amphibians, it is also hoped that zoos and aquaria can raise public awareness of conservation issues whilst also supplying the financial resources required for *in situ* conservation programmes.

The success of captive breeding programmes as a component of the conservation of threatened Malagasy amphibians will depend, in part, on the level of existing expertise and the extent to which it still needs to be developed (Andreone et al., 2006; Mattioli et al., 2006). If programmes are to be successful, a detailed understanding of species' biology, husbandry protocols and the species-specific, environmental conditions required for breeding and rearing offspring as well as investment in facilities capable of supporting large captive populations of threatened species are required (e.g., *Alytes muletensis*: Buley & García, 1997; Kraaijeveld-Smit et al., 2005 and 2006).

Captive breeding programmes for Malagasy amphibians can make contributions to conservation if they are involved in research, education or re-introduction programmes. The role of zoos in captive breeding and conservation programmes is continuing to evolve. Nevertheless, the traditional infrastructures in place within zoo organisations for managing endangered species may be inappropriate for many species. The private sector has the potential to make important contributions to conservation through captive breeding although harnessing this capability is problematic.

The Amphibian Conservation Action Plan (ACAP, 2005) recommended developing and implementing captive-breeding programmes of a scale appropriate to respond to the crisis of global amphibian extinctions. The establishment of these programmes should be in conjunction with a disease research programme so rapid-response teams can be deployed, when necessary, to field sites to assess levels of threat and implement emergency triage treatments and specimen collections where warranted. Unfortunately the capacity to deal with the large numbers of amphibians involved is non-existent and, as such, new strategies need to be developed in order to hold colonies in and outside the range country.

The goal of this paper is to establish the extent to which zoos have developed their expertise in the husbandry and breeding of Malagasy amphibians. By achieving this we hope to illustrate where current strengths and opportunities lie for enhancing zoos' capacities to contribute both to the understanding of the taxa and, more importantly, the conservation of currently threatened or little known species. This will be achieved by using species diversity and specimen numbers held by different institutions through time as an index for expertise. The limitations of this approach are believed to be outweighed by the current need for an assessment of captive breeding potential at a global level.

The paper will summarise the responses to a recent questionnaire circulated to all European Association for Zoos and Aquaria (EAZA) institutions to gauge their level of interest to develop their amphibian captive breeding potential. This section will be complemented by an informed assessment of the potential role of the private breeding sector in the conservation of Madagascar's threatened amphibians.

MATERIAL AND METHODS

Current zoo holdings of Malagasy amphibians

A complete list of the species of Malagasy amphibians was obtained from the Global Amphibian Assessment (GAA, www.globalamphibians.org). This list was used to give an overview of the number of species in the different genera and their distribution among the IUCN threat categories.

In January 2007 the data from the GAA were cross-referenced with data from the International Species Information System (ISIS, 2007) to identify which Malagasy amphibians are kept in captivity, and which zoos[1] currently hold them.

Breeding of Malagasy amphibians in zoos

The number of captive births of Malagasy amphibians worldwide over the last 10 years was analysed (ISIS, 2006). Specimens are only included in the analysis if the actual birthing event was recorded in ISIS.

In November 2006 a questionnaire was distributed to all European zoological institutions with the aim of better understanding their institutional capacity and expertise in amphibians. The data for Malagasy amphibian species status in European Zoos were collected from the EAZA draft report compiled by De Jong & Hiddinga (2006). Species were classified as having been successfully bred after completion of the entire metamorphosis process.

Breeding of threatened species in zoos

Focusing on threatened species, the data for current holdings and breeding successes are based on comparisons between ISIS 2006 and 2007.

Collaboration between zoos – Scaphiophryne gottlebei *case study*

Scaphiophryne gottlebei is used as a test case to highlight the types of data that

[1] Throughout the paper "zoo" will be used for zoological gardens and aquariums.

can be extracted from the ISIS database (ISIS, 2006) as well as demonstrate how these data can be used to assess the level of collaboration between zoos. All individuals recorded in ISIS over the last 10 years are included. In this study the history of *S. gottlebei* has been used to investigate the degree of collaboration that exists between institutions; the history for other species may well be different.

The role of the private breeding sector

To gauge the private breeding sector's potential role in the conservation of Madagascar's threatened amphibians, a questionnaire was posted on the 'mantellahobbyists' Yahoo! e-group.

RESULTS

Current zoo holdings of Malagasy amphibians

Of the 226 species of Malagasy amphibians, only 23 (+ 4 genus sp.) are held in zoos (ISIS 2007). The Malagasy amphibian species most commonly seen in zoos (>20) are the golden mantella *Mantella aurantiaca,* the Madagascar tomato frog *Dyscophus antongilii*, and the Sambava tomato frog *D. guineti*, which are represented in 42, 36 and 22 zoos respectively (Fig. 1). The species-rich genera *Boophis* and *Mantidactylus* are rarely seen in zoos (Appendices I and II).

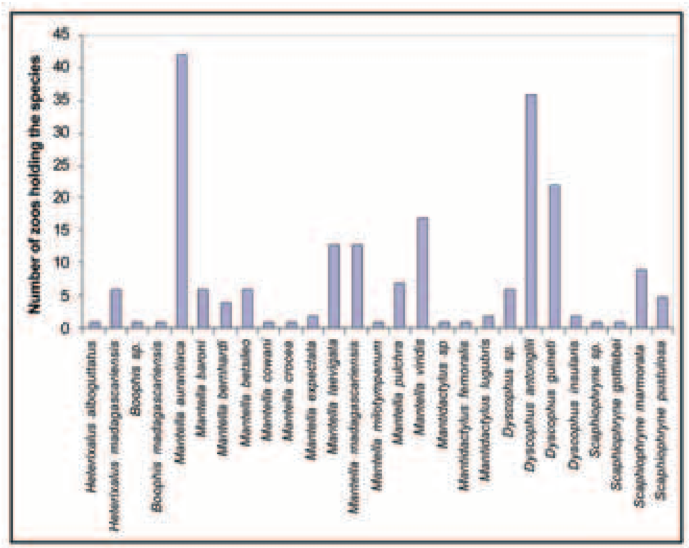

Fig. 1. Number of zoos holding specimens of each species of Malagasy frogs held in captivity.

Ninety-eight zoos worldwide currently hold Malagasy frogs. Thirty-five of these, approximately one third of the total, are situated in Europe. The rest are situated in the USA (fifty-nine), Canada (two), Japan (one) and South Africa (one) (ISIS, 2007). Half of these ninety-eight zoos hold only one species, while sixteen zoos hold four or more species of Malagasy frog. (See Appendix III for a list of these zoos).

Of a total of 208 species-specific captive populations of Malagasy frogs in zoos worldwide, there are 48 occurrences where a single specimen of a species is held (23% of the total captive populations). The European zoos contribute with seven occurrences of only a single individual being held by a zoo. More than twenty specimens of a species are seen in 17 cases (European zoos contribute with ten). 12 of these 17 cases are holdings of *Mantella aurantiaca* (Fig. 2 and Appendix IV).

Breeding of Malagasy Amphibians in zoos

In total 14 (representing 61% of the species in captivity) Malagasy species have been bred in zoos within the last 10 years (Fig. 3). With over 2800 individuals represented in 25 zoos, *Mantella aurantiaca* is the only species to have been bred frequently. *Dyscophus antongilii* has been bred in 7 zoos, *M. laevigata* in 5 zoos and *D. guineti* in 4 zoos (see Appendix V for further details).

The keeping and breeding of Malagasy amphibians in European zoos were further investigated through an EAZA amphibian institutional capacity questionnaire. In total, 98 zoos responded to it and, of these zoos, 87 completed it. Only institutions that keep Malagasy amphibians and completed the questionnaire are included in the analysis (Tab. I).

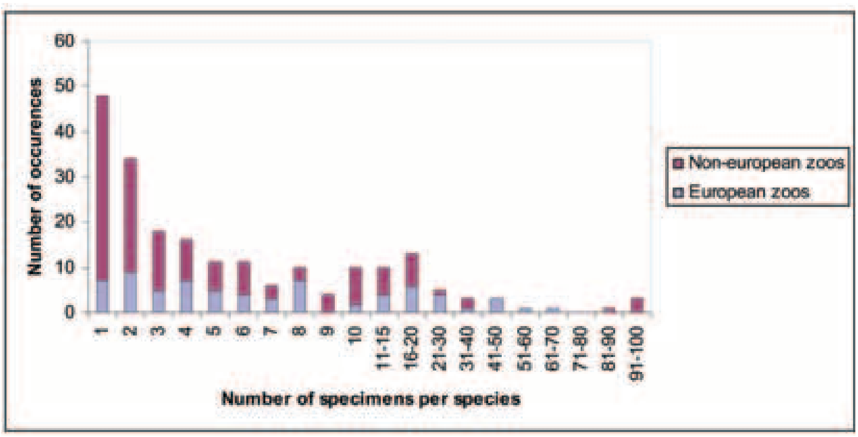

Fig. 2. The number of specimens of species-specific captive populations kept in all zoos.

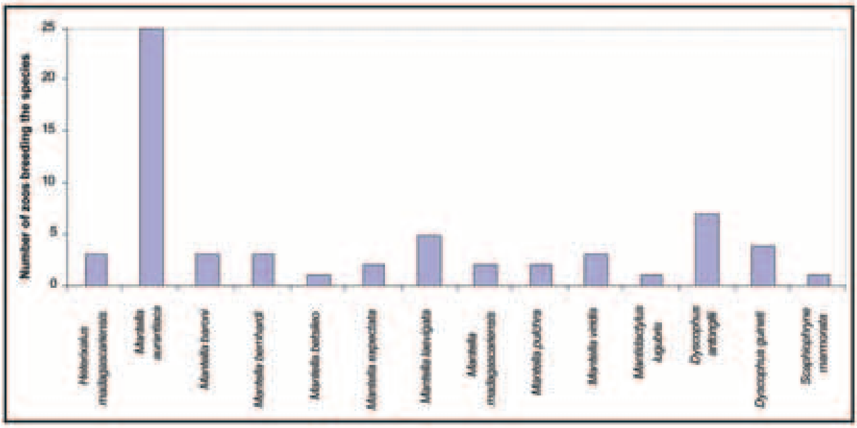

Fig. 3. Number of zoos breeding species of Malagasy frogs (1996-2006).

Species	Keeping	Breeding Success		
		F1	F2	F3
Dyscophus antongilii	6	1	0	0
Dyscophus guineti	11	2	2	0
Dyscophus insularis	1	0	0	0
Heterixalus madagascariensis	4	2	1	1
Mantella aurantiaca	6	5	3	1
Mantella betsileo	1	0	0	0
Mantella expectata	1	1	0	0
Mantella laviegata	1	0	0	0
Mantella madagascariensis	1	1	0	0
Mantella viridis	2	1	0	0
Scaphiophryne gottlebei	1	0	0	0
Scaphiophryne madagascariensis	2	0	0	0
Scaphiophryne marmorata	6	1	0	0

Tab. I. List of Malagasy amphibians kept and bred in European Zoos according to the EAZA questionnaire (2006).

A total of 13 Malagasy amphibian species were reported as being kept during the study period with eight species having been bred successfully. But only two species, (*Dyscophus guineti* and *Mantella aurantiaca*), have a substantial number of institutions keeping and breeding them up to F2 generation: the minimum target to develop an understanding of how to breed the species in captivity. The rest of the species were kept in no more than two institutions and simply breeding the F1 generation (Tab. I).

The majority of institutions are eager to be involved in *ex situ* management of amphibians worldwide (60.9%; n = 53). And some institutions are prepared to dedicate resources (staff time, money, equipment etc.) to help build relevant capacity in other countries with endangered amphibian species. The highest scoring region is Madagascar where 19.5% of the institutions (n = 17) are prepared to dedicate resources.

Breeding of threatened species in zoos

A total of 55 species (24% of total Malagasy amphibians) are categorised as threatened: Vulnerable (VU), Endangered (EN) or Critically Endangered (CR). Eleven of these 55 species are kept in zoos representing 20%. A further 46 species are Data Deficient (DD), some of these might turn out to be threatened. None of these are kept in zoos. Seven species of threatened Malagasy amphibian have been bred in captivity. The species kept and bred in the largest number of zoos is *Mantella aurantiaca* (CR; Fig. 4).

Collaboration between zoos – Scaphiophryne gottlebei *case study*

Scaphiophryne gottlebei is a Critically Endangered species listed on CITES appendix II since 2003 with a yearly export quota of 1000 individuals (CITES 2007).

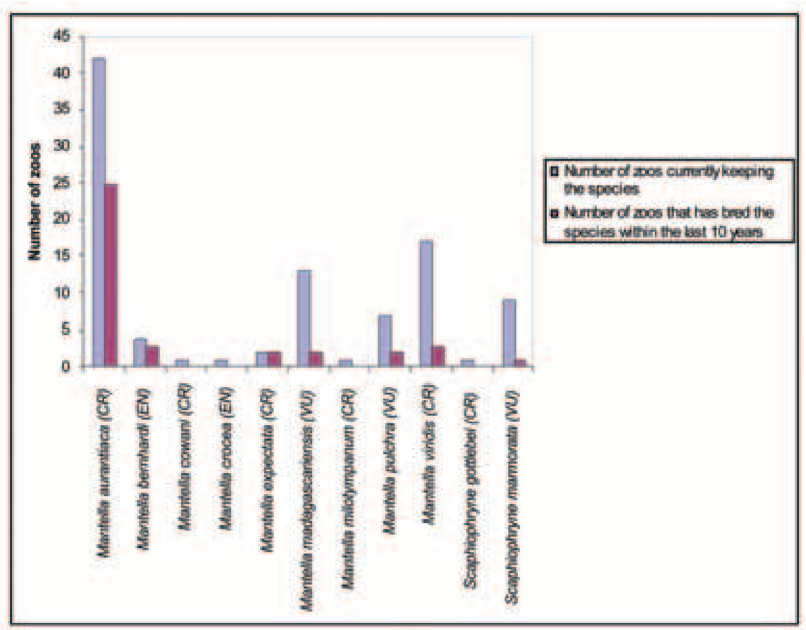

Fig. 4. Number of zoos keeping and those breeding threatened species of Malagasy frogs.

Only a small number of individuals are currently held in zoos (ISIS, 2007). However, during the last 10 years, 168 specimens have been recorded in ISIS (ISIS, 2006). 100 of these are donations from CITES (Europe) or US Fish & Wildlife Service; the rest are purchases or donations. They are almost all wild caught or of unknown origin, and only one is stated as captive born.

Appendix VI illustrates the degree of collaboration between zoos by showing the extent to which specimens of this species have been moved to different zoos. Details regarding the origin and death of each specimen are also included. Different coloured shapes and arrows represent different specimens, thus it is possible to follow the history of all individuals.

In some cases specimens have been acquired by or donated to a zoo and have died without involving any transaction. However, there has been collaboration between some American zoos through the exchange of specimens. This collaboration primarily took place in the latter part of the 10-year period (Appendix VI, USA Part 2).

S. gottlebei seems to be very difficult to maintain in captivity. During the ten-year period, records show that of 168 specimens, 108 of them died within six months at the zoo. The majority of these deaths could perhaps be attributed to the hazards of transporting the frogs from Madagascar or that the frogs were old when captured. However, it seems that the individuals collected in Madagascar are primarily juveniles some even newly metamorphosed (Andreone et al., 2006).

The challenge is, therefore, to find a suitable husbandry regimen in order to sustain *S. gottlebei* in captivity. Key steps towards this achievement would include the exchange of knowledge and the publicising of both successes and failures with the species to ensure that others could build upon that knowledge and avoid making the same mistakes.

The role of the private breeding sector

The holding and breeding history of Malagasy amphibians in the private sector is almost equivalent to that of zoos. Around 25 species are held, most of which are brightly coloured. All *Mantella* species are kept with the exception of *M. manery*. The mantellas are sporadically bred in the private sector and. *M. aurantiaca* has been bred to the F3 generation. *M. cowani* is kept by few breeders and with practically no breeding success. Additionally, all three *Dyscophus* species are kept although few hobbyists keep *D. antongilli*. *Dyscophus*, especially *D. guineti,* have been bred in commercial quantities but it is not known to what generation. *Heterixalus alboguttatus* is kept and occasionally bred in captivity. It has been bred to the F2 generation by one hobbyist. *Heterixalus madagascariensis* also makes appearances in some collections but it is rarely bred. *Boophis luteus* is one of the few *Boophis* species to be kept, but there are no records of this species reproducing in captivity. Other *Boophis* species are kept every now and then as they appear, but with little success. *Scaphiophryne gottlebei, S. marmorata*, and *S. madagascariensis* are often imported to the United States (and sometimes Europe), but as of yet they have not been bred, at least not with any consistency. All other Malagasy amphibian genera are absent from private collections.

The number of specimens per species varies, depending on the species and the person who is keeping the frogs. Most serious hobbyists interested in breeding keep at least one large group.

The number of serious private breeders is probably around ten or so in the United States with a few in Canada and Europe (UK, Germany, the Netherlands and France).

Communication between private breeders primarily takes place on the Internet through online forums and mailing lists. Many hobbyists have their own personal websites that they use to share information such as www.mantella-conservation.org and www.amphibiancare.com. There is also a number of Yahoo! groups dedicated to amphibians and reptiles like the "mantellahobbyists" group (December the 18th, 2001), which has approximately 150 subscribers. There is frequent contact with hobbyists in North America, although exchanging frogs between Europe and USA is problematic. In both the USA and in Europe, private breeders meet at markets and at theme days.

Little record keeping is being done, although there is at least one website that attempts to keep track of genetic lineage. A *Mantella* studbook is being coordinated for the European Studbook Foundation (www.studbooks.org), but there are only 10-15 members, the majority of which obtained frogs from the studbook's creator as opposed to adding their own existing stock.

Limitations of the present study

The principle limitation of the study of zoos is that data have only been extracted from ISIS and the EAZA questionnaire. Subsequently, it has only been possible to obtain records from those zoos that actually use ISIS and/or responded to the questionnaire. In reality, however, there may be a much greater level of collaboration and movement of specimens than has been recorded. It would also appear, based on the number of purchases of specimens by zoos and from the results obtained so far, that there may be significant captive breeding success among private collections. It has only been possible to subject this potential source of expertise to a relatively cursory examination in this project. It would be advantageous to further investigate this area in the future as we suggest that the private sector contains a large source of knowledge and expertise on the breeding of Malagasy amphibians in captivity.

In addition, misinterpretations of the analyses are also possible due to the problems and constraints linked to recording data in ISIS. Recording data is time-consuming, especially for relatively short-lived species such as frogs, and this could lead zoos to consider such data as low priority.

Future studies could analyse the complete history of keeping Malagasy amphibians in captivity. In previous years some species may have been bred to such an extent that there became no need to continue breeding. Consequently, low breeding success within the time span of this project (27th July 1996 to 30th November 2006) may not truly indicate lack of knowledge on or expertise with a particular species.

The merits of the private sector survey are limited in that it has been primarily based on interviews and contains rough estimates rather than solid data. It is clear, however, that further investigation in this sector would be beneficial. Further investigation into exact numbers kept and bred and the motivation for keeping and breeding the species would be particularly fruitful.

DISCUSSION

From the data recorded on ISIS and the EAZA questionnaire there are populations of Malagasy amphibians held in zoological institutions (Fig. 1), even though individual zoos often have just one species and a small number of specimens (Fig. 2).

The extent of breeding success across all species held in captivity is limited: within the last 10 years only 14 species have been bred (Fig. 3). 'Births' according to the data entered on ISIS may refer to the hatching of tadpoles from eggs or could represent the successful metamorphosis to juvenility. Since mortality rates vary markedly between these different life stages, the records may be an under or over-representation depending on the interpretation of the record keeper. This 'grey area' of amphibian record-keeping should be standardised to enable accurate analysis of amphibians in captivity – and thus those areas of concern within captive breeding strategies.

The successful captive breeding of *Mantella aurantiaca* (Fig. 3 and Tab. I) may be attributed to the compilation of a European Aquarium and Zoos Association (EAZA) studbook, currently managed by Craig Walker at Zoological Society of London. As a consequence of management, the studbook may have also been fundamental in the establishment of communication channels between those holding individuals of this species – an activity which perhaps we should strive to achieve in order to report success and failures, and from which valuable lessons can be learnt and transmitted in the zoo world. Furthermore, collaboration between zoos can also ensure that the instances of single specimens (Fig. 2) are eliminated, thus allowing the maximum potential of breeding success.

There does not seem to be any focus on breeding threatened species (Fig. 4). *Mantella aurantiaca* is attractive because of its colours and because it is relatively easy to breed, at least to the F1 generation. In order for captive breeding to be successful saving threatened Malagasy amphibian species, there is a need for breeding programmes for selected species.

Using *Scaphiophryne gottlebei* as a case study shows that collaboration between zoos worldwide is varied (Appendix VI). Three out of the thirteen zoos holding specimens during the last ten years donated individuals to another collection (Lincoln Park Zoo, Detroit Zoological Institute and Chicago Zoo). A low rate of exchange between zoos may be attributed to the low survival rate – approximately two thirds of all specimens died within six months of being imported into a collection.

The results of the private sector survey show that there is considerable skill and expertise available to help with captive breeding programmes. To effectively involve members of the private sector, two specific conditions will need to be met. Firstly, it will be important to find a way to control how 'ownership' of breeding stock is managed when exchanging animals between private breeders and zoos. Legal framework needs to be constructed to ensure that there are no misunderstandings or disillusionment. Secondly, and similarly, private sector breeders will want to know what they stand to gain from involvement in such a programme. This may be the opportunity to participate in a highly important conservation operation, gain more tangible benefits such as financial reward, or the chance to maintain species of amphibian that they might not ordinarily have access to.

Zoological institutions and the private sector would appear to be far from ready to support the needs of a large scale *ex situ* programme for Malagasy amphibians. The small number of successful species breeding to F2 generation, 10% (n = 27) of the total Malagasy species of amphibians only being kept *ex situ* and the threatened status of a significant number of them, calls for immediate and coordinated action to improve skills and carrying capacity to cover the demand of captive breeding programmes for amphibians in Madagascar.

Captive breeding programmes can be fruitful if zoos and private breeders join efforts, but it is not unproblematic. It demands elucidation on the strengths and weaknesses, and willingness to compromise. The strengths of zoos are their continuous nature, experience in record keeping, being recipients of CITES-confiscations, having the overview due to working with many species, and finally the synergy between colleagues in a professional environment with a formal network. The strengths of private breeders lie in their expertise in a specific species, their generosity with their time, and the valuable detailed observations they get from observing their animals day and year round.

Zoos can contribute to amphibian conservation in three main ways: developing conservation research, participating in reintroduction programmes and elaborating education programmes. The scientific research associated with captive breeding programmes for amphibians can adopt several forms as improving captive husbandry, animal welfare and maintenance or directly improving the status of wild populations. The role of zoos in reintroduction programmes for amphibians present certain advantages compared with other groups (small size, lower maintenance costs, high fecundity, 'hard wired' physiology and behaviour etc.). Education programmes focusing on *in* and *ex situ* conservation and captive amphibian husbandry can be implemented whether this be through an official curriculum for school, college or university, or informal educational programmes for the general public.

The main weakness of the zoos regarding involvement in breeding programmes for threatened species is the lack of money and time; whereas the weaknesses of private breeders are their fragile nature (often based on a few enthusiastic people) and their limited access to threatened animals.

Zoos and private breeders can obviously complement one another. But private breeders are a very diverse group with many different objectives and reasons for keeping their animals. Objectives could include keeping a varied collection, holding rarities, earning money, improving husbandry protocols or keeping studbooks. One of the challenges facing zoo-private collaborations is to select serious breeders who seek mutual gain and not purely personal gain. Zoos may also have to take the risk of loaning out animals to private breeders.

Private breeders will also face a number of challenges including giving up ownership of their animals to a studbook and following the directions of a studbook keeper. Additionally, they will have to demonstrate willingness to share knowledge and to enter data into the studbook.

A successful breeding programme is dependent on studbook keeping as it is an essential tool for the exchange of not only knowledge but also genes. If record keeping is done thoroughly and husbandry data – the successes and the failures - are added, it would be possible to extract husbandry information on a larger scale. The recording of failures could be particularly valuable in that the information would provide direction on how to avoid mistakes in the future. However, working with captive bred animals is not without issue and factors to take into consideration include the propensity of some individuals to develop non-natural colouration, preponderances of female offspring or the possibility of decline of fecundity down the generations.

The exchange of knowledge is crucial. It can be shared via the Internet (mailing lists and discussion groups) and in meetings and at courses. By participating in captive breeding programmes and collaborating both zoos and private breeders can benefit from the knowledge gained. Ultimately though it will be the threatened species that benefit from a captive breeding programme in which both zoos and private breeders have an integral role to play.

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RESUMÉ

L'élevage en captivité comme outil de conservation des amphibiens malgaches: Dans quelle mesure sommes-nous prêts à répondre au besoin?

Le Plan d'Action de Conservation des Amphibiens (The Amphibian Conservation Action Plan) a proposé l'élevage en captivité comme outil potentiel adressé au déclin des amphibiens. Cependant, ce potentiel peut seulement être réalisé si on note une grande professionnalité et une bonne expérience dans l'établissement de l'élevage en captivité. Avec au moins 25% des amphibiens de Madagascar catégorisés comme vulnérables, menacés ou en danger critique, l'élevage en captivité pourrait bien avoir à jouer un rôle dans la conservation des amphibiens de l'île. Une analyse des zoos mondiaux qui utilisent la base de données ISIS, un questionnaire adressé aux zoos européens et des interviews d'éleveurs privés Malgaches d'amphibiens ont été utilisés pour déterminer le niveau de connaissance et d'expertise accumulés ses dix dernières années. Sur les 226 amphibiens malgaches, 27 espèces sont actuellement gardées dans des zoos. Seules de rares institutions ont une documentation historique sur l'élevage depuis de nombreuses générations, ou détiennent un grand nombre de grenouilles malgaches. Les éleveurs privés s'occupent à peu près du même nombre d'espèces que les zoos. L'intercommunication et la collaboration entre les zoos ont été soulignées dans ce texte à travers l'étude du cas de colonies captives de *Scaphiophryne gottlebei.* La communication entre les éleveurs privés se déroule sur Internet et par de régulières rencontres d'échanges. Il demeure un besoin de dresser des protocoles d'elevage en captivité pour les populations des élevages en captivité et d'assurer des documentations effectives sur la conservation pour une parfaite compréhension du succès de ces programmes d'élevage en captivité. En outre, on devrait d'avantage encourager la collaboration entre les éleveurs privés et les zoos. Finalement, la réintroduction potentielle d'espèces particulières devrait également être évaluée.

Mots clés: Amphibiens, Catégorisation, Elevage en captivité, Madagascar.

Gerardo García
Jamie Copsey
Les Augres Manor, Trinity
Jersey. JE3 5BP
British Channel Islands
Email gerardo.garcia@durrell.org

Lise Bock
Roskilde Technical College, Denmark

Samantha Earle
Durrell Wildlife Conservation Trust Summer School student 2006

Richard Berridge
European Studbook Foundation, UK

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APPENDIX I

Overview of Malagasy amphibians. Reference: GAA (2007).
Classification follows Glaw & Vences (1994) and is not yet updated
to Glaw & Vences (2007)

Family and Genus		**Total no. of species**	**Number of species per threat category**					
			DD	**LC**	**NT**	**VU**	**EN**	**CR**
Hyperoliidae								
	Heterixalus	11	-	9	2	-	-	-
Mantellidae								
	Aglyptodactylus	3	-	2	-	-	1	-
	Boophis	53	18	26	4	4	-	1
	Laliostoma	1	-	1	-	-	-	-
	Mantella	15	1	3	1	3	2	5
	Mantidactylus	86	15	45	7	9	9	1
Microhylidae								
	Anodonthyla	4	1	1	-	1	1	-
	Cophyla	2	1	1	-	-	-	-
	Dyscophus	3	-	2	1	-	-	-
	Madecassophryne	1	-	-	-	-	1	-
	Paradoxophyla	1	-	1	-	-	-	-
	Platypelis	11	3	3	-	1	4	-
	Plethodontohyla	15	2	7	-	4	2	-
	Rhombophryne	1	-	-	-	1	-	-
	Scaphiophryne	10	3	3	1	1	1	1
	Stumpffia	8	5	1	-	1	-	1
Ranidae								
	Ptychadena	1	-	1	-	-	-	-
SUMMARY								
4 families	**17 genera**	**226 species**	**49 DD**	**106 LC**	**16 NT**	**25 VU**	**21 EN**	**9 CR**

APPENDIX II

Malagasy amphibians kept in captivity. References: ISIS (2007) and IUCN (2006).

Genus and Species kept in captivity	Red List status	Individuals in captivity	Number of zoos keeping the species
Heterixalus			
H. alboguttatus (Whitebelly reed frog)	LC	4	1
H. madagascariensis (Madagascar reed frog)	LC	128	6
Boophis			
B. sp.		2	1
B. madagascariensis (Malagasy tree frog)	LC	2	1
Mantella			
M. aurantiaca (Golden mantella)	CR	879	42
M. baroni (Baron's mantella/Painted mantella)	LC	24	6
M. bernhardi (Bernhard's mantella)	EN	28	4
M. betsileo (Brown mantella/Betsileo mantella)	LC	18	6
M. cowani (Cowan's mantella)	CR	2	1
M. crocea (Yellow mantella/Eastern mantella)	EN	2	1
M. expectata (Blue-legged mantella)	CR	4	2
M. laevigata (Climbing mantella/Arboreal mantella)	NT	80	13
M. madagascariensis (Malagasy mantella)	VU	59	13
M. milotympanum (Black-eared mantella)	CR	34	1
M. pulchra (Beautiful mantella/Splendid mantella)	VU	41	7
M. viridis (Green mantella)	CR	72	17
Mantidactylus			
M. sp.		1	1
M. femoralis (-)	LC	1	1
M. lugubris (-)	LC	4	2
Dyscophus			
D. sp.		27	6
D. antongilii (Madagascar tomato frog)	NT	240	36**
D. guineti (Sambava tomato frog)	LC	99	22
D. insularis (Antsouhy tomato frog)	LC	2	2
Scaphiophryne			
S. sp.		1	1
S. gottlebei (Red rain frog)	CR	5	1
S. marmorata (Marbled rain frog)	VU	63	9
S. pustulosa (Madagascar warty frog)*	NT	20	5

SUMMARY		
6 genera and 23 species kept in captivity	**1842**	

* *Scaphiophryne pustulosa* (ISIS) = *S. madagascariensis* (GAA) (www.iucnredlist.org)

** This number may be an over-estimate given the difficulty of distinguishing *D. antongilii* from *D. guineti.*

APPENDIX III

Zoos holding four or more species of Malagasy Frog (Reference: ISIS, 2007).

10 species	Europe, Czech Republic: Zoological and Botanical Garden, **Plzen**
7 species	USA, Iowa: National Mississippi River Museum & Aquarium (Ms Rvr Mu)
6 species	USA, Michigan: **Detroit** Zoological Institute USA, Nebraska: **Omaha's** Henry Doorly Zoo USA, North Dakota: Red River Zoo, **Fargo** USA, Texas: **Fort Worth** Zoological Park, USA, Texas: **Moody** Gardens Aquarium & Rainforest
5 species	Europe, Belgium: Zoo of **Antwerp** Zoo USA, California: **San Diego, Z**oological Society of
4 species	Europe, Switzerland: Zoo **Zürich** USA, Illinois: John G. **Shedd Aq**uarium USA, Lousiana: **Audubon** Zoo USA, Missouri: **St. Louis** Zoological Park USA, Pennsylvania: **Pittsburg**h Zoo & Aquarium USA, Tennessee: Tennessee Aquarium, **Chattanoo**ga USA, Texas: **Abilene** Zoological Gardens

The zoo's ISIS mnemonic name is in bold.

APPENDIX IV

Occurrences of a zoo holding ≥21 specimens of a certain species.
Reference: ISIS (2007).

EUROPEAN ZOOS		*Heterixalus madagascariensis*	*Mantella aurantiaca*	*Mantella milotympanum*	*Dyscophus antongilli*
Czech Republic	**Usti** nad Labem Zoo				50
Denmark	**Copenhagen** Zoo	64			
Latvia	**Riga** Zoo		34		
Poland	Miejski Ogrod Zoologiczny we **Wroclawiu**	24			
Switzerland	Zoo **Zürich**		50		60
UK	**Bristol**, Clifton, & W. of England Zoo		25		
UK	**London** Zoo (Regent's Park)		30		
UK	**Marwell** Zoological Park		21		
UK	The Living Rainforest, **Newbury**		44		
USA ZOOS					
California	**Oakland** Zoo		86		
Illinois	Miller Park Zoo, **Bloomingt**on		25		
Massachusetts	(Boston) New England Aquarium (**Bos Neaq**)		35		
Missouri	**St. Louis** Zoological Park		94		
Pennsylvania	Clyde Peeling's Reptiland, **Allenwood**		97		
Texas	**Abilene** Zoological Gardens		98		
Texas	**Dallas** Zoo			34	

The zoo's ISIS mnemonic name is in bold.

APPENDIX V

Zoos in which Malagasy amphibians were bred over the last 10 years.
Reference: ISIS (2006)

Country	**Zoo**	*Heterixalus madagascariensis*	*Mantella aurantiaca*	*Mantella baroni*	*Mantella bernhardi*	*Mantella betsileo*	*Mantella expectata*	*Mantella laevigata*	*Mantella madagascariensis*	*Mantella pulchra*	*Mantella viridis*	*Mantidactylus lugubris*	*Dyscophus antongilii *) **)*	*Dyscophus guineti*	*Scaphiophryne marmorata*
EUROPEAN ZOOS															
Belgium	Zoo of **Antwerp**		4 ②												
Denmark	**Copenhagen** Zoo	87 ①											245 ②		
Denmark	**Randers** Regnskov Tropical Zoo		1 ①												
Latvia	**Riga** Zoo		74 ①										27 ①	40 ①	
Netherlands	**Tilburg** Zoo										8 ①				
Poland	Ogrod Zoologiczny, **Opole**	112 ①													
Poland	Miejski Ogrod Zoologiczny, **Plock**	7 ①													
Switzerland	Zoo **Zürich**							1 ①							
UK	**Bristol**, Clifton, & W. of England Zool		1 ①												
UK	Durrell Wildlife Conservation Trust **(Jersey)**		15 ①												
UK	**London** Zoo **(Regent's Park)**		420 ②												
Russian Fed.	**Moscow** Zoological Park													10 ①	
USA ZOOS															
California	**San Diego, Zoological** Society of		42 ②										6 ①		
Florida	**Disneys** Animal **Kingdom**		52 ②					1①							
Florida	Tampa's **Lowry Park** Zoo		1 ①	14 ①											
Hawaii	**Honolulu** Zoo		43 ①												
Illinois	**Chicago** Zoological Park **(Brookfield)**											17 ①			
Illinois	John G. **Shedd** Aquarium		6 ②		9 ①										
Indiana	Potawatomi Zoo, **Southbend**		4 ①												
Kansas	**Sedgwick** County Zoo		14 ②							160 ②					

Lousiana	**Audubon** Zoo		52 ②												
Maryland	The Maryland Zoo in **Baltimore**		89 ④				74 ③	102 ⑥					309 ②		
Michigan	**Detroit** Zoological Institute		903 ⑥	61 ⑤	55 ③					63 ③					
Minnesota	**St. Paul** 's Como Zoo		175 ③												
Missouri	**St. Louis** Zoological Park		254 ②		3 ②						81 ①				
Nebraska	**Omaha's** Henry Doorly Zoo					64 ④	4 ①		18 ②						
New Jersey	**Cape May** County Park Zoo		2 ①												
New York	**Buffalo** Zoological Gardens		482 ②												
New York	**(NY) Bronx** Zoo												2 ①		
Oklahoma	**Oklahoma** City Zoological Park		17 ②					172 ⑥							111 ①
Ohio	**Cincinnati** Zoo & Botanical Garden							5 ①							
Pennsylvania	Clyde Peeling's Reptiland, **Allenwood**		8 ①												
Pennsylvania	The **Philadelphia** Zoo		72 ②								121 ①				
Tennessee	**Memphis** Zoological Garden & Aquarium												7 ①	10 ①	
Texas	**Abilene** Zoological Gardens		130 ②	15 ①					29 ②						
Texas	**San Antonio** Zoological Gardens & Aqua		12 ①										2 ①	6 ①	
	Number of individuals bred	**206**	**2873**	**90**	**67**	**64**	**78**	**281**	**47**	**223**	**210**	**17**	**598**	**66**	**111**
	Number of zoos where the species has been bred	**3**	**25**	**3**	**3**	**1**	**2**	**5**	**2**	**2**	**3**	**1**	**7**	**4**	**1**

The zoo's ISIS mnemonic name is in bold.

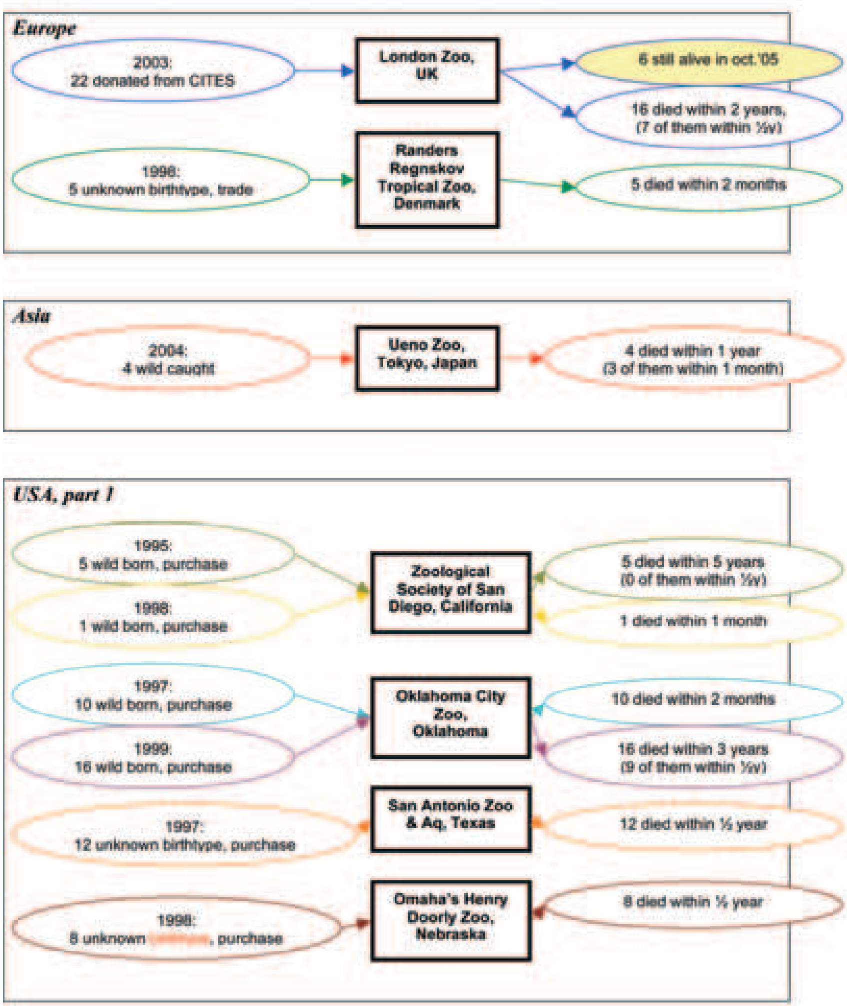
①②③④⑤⑥ refers to the number of years of breeding success (not necessarily consecutive years). Breeding successes for three or more years are highlighted in yellow.

*) Some individuals also bred within the 10-year-period in University of California, Tierpark Chemnitz, Phoenix, Wilhelma Zoo, Zoologischer Garten Basel and Usti nad Labem according to loans and donations.

**) Some of the data obtained from ARKS (Animals Record Keeping System) from Copenhagen Zoo, Denmark.

APPENDIX VI

History of the specimens of *Scaphiophryne gottlebei* kept in zoos worldwide (1996-2006).
Reference: ISIS (2006)




USA, part 2
1996: 10 wild born, donated from USFWS (US Fish & Wildlife Service)
Lincoln Park Zoo, Chicago, Illinois
5 died within 3 months
3 donated (1997)
John G. Shedd Aq., Illinois
??
2 donated (1998)
2 died after 4 and 5 years
1999: 3 wild born, purchase
Detroit Zoological Institute, Michigan
1 died within 4 months, 1 died within 1½ year
32 died within ½ year (24 of them within 2 months)
2003: 68 donated from USFWS
25 donated (2003)
Tennessee Aq, Chattanooga, Tennessee
25 died within 1 year (15 of them within ½y)
1 donated (2004)
10 donated (2003)
Chicago Zoo, Brookfield, Illinois
9 died within 2½ year (2 within ½ year)
2004: 1 captive born, purchase
1 donated (2004)
1 donated (2005)
1 still alive
2004: 2 wild born, donated
Potawatomi Zoo, South Bend, Indiana
1 died after 2½ year
1 died after 6 years
1 died within 2 months
2005: 1 unknown birthtype, donated
2 died within 1 year
1 died within 3 months

A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 343-356

Richard K. B. JENKINS[1,2], M. Nandrianina ANDRIANASOLONJATOVO[3,4],
Karen FREEMAN[3], Andriamanana RABEARIVELO[5],
Roseline L. RAMPILIAMANANA[1,6], Roma RANDRIANAVELONA[1,6]

The exploitation of amphibians for food in Madagascar

ABSTRACT

Amphibians in Madagascar are collected from the wild to supply the international pet trade and the domestic demand for frogs' legs. Four of the five frog species eaten by people in Madagascar are endemic and are mostly forest-dwelling. The introduced Indian tiger frog *Hoplobatrachus tigerinus* is also eaten. Based on observations and interviews in three urban centres (Antananarivo, Toamasina and Moramanga) we documented the commodity chain for frogs' legs. Most collection is by farmer hunters to supplement their income. Frogs' legs are sold in markets in Antananarivo and in restaurants in all three study locations and appear to be a luxury food. A number of frog collectors expressed concern that the abundance of edible species in traditional forest collection sites has decreased in recent years and that they need to invest more effort to obtain the minimum harvest. We provide a list of priority actions to develop a better understanding of the economic and biological impact of the trade in edible amphibians in Madagascar.

Key words: Amphibian, Bushmeat, *Hoplobatrachus*, Hunting, Frog legs, Madagascar, *Mantidactylus.*

INTRODUCTION

Amphibians can make a varied contribution to livelihoods and provide both direct and indirect benefits to people (Carpenter et al*.,* 2007). They are used as food, medicine, ornaments, leather and pets (Pough et al*.,* 1988; Tyler et al*.,*

[1] Madagasikara Voakajy, Antananarivo.
[2] School of Biological Sciences, University of Aberdeen.
[3] Madagascar Fauna Group, Toamasina.
[4] Gestion de Ressources Naturelles et Environnement, Université de Toamasina.
[5] ACCE, Moramanga.
[6] Département de Biologie Animale, Antananarivo.

1998) and over-harvesting for subsistence and commerce is perceived as a threat to the survival of many species (Carpenter et al., 2007). In Madagascar, a good example of the direct benefits from the amphibian resource is the legal sale of frogs for the pet trade (Raselimanana, 2003; Carpenter & Robson, 2008; Rabemananjara et al., 2008). Amphibians may also contribute to livelihoods in Madagascar through attracting ecotourists into parks and conservation sites and also through the sale of frog-related merchandise. An often overlooked form of amphibian exploitation in Madagascar, and the subject of our short study presented here, is the consumption of frogs' legs by humans. Globally, at least 212 amphibian species are used by people for subsistence food but only 20 species feature in international trade (Carpenter et al., 2007). In Europe, many of the frogs are harvested from the wild but the populations have diminished greatly, especially since the 1980s (Collins & Storfer, 2003). For example, in France it is now mostly illegal to collect wild frogs and the frogs destined for consumption are mainly imported (Nevue, 2004). The demand for frogs' legs in Europe and USA is met mainly from Asia and thousands of tons are exported annually. In India, an estimated 70 million frogs were harvested from 1981 until a ban in 1987 (Humkraskar & Velho, 2007). The bans in India and Bangladesh (1989) led to Indonesia becoming the largest supplier to the US and Europe and, even though the latter ban was lifted in 1992, over 5,500 tons were exported from Indonesia in 1997. Between 1998 and 2002 the USA imported over 5,5000 tons of frogs for food from Taiwan, China, Vietnam and Myanmar (Schlaepfer et al., 2005).

Greatest attention has been paid to the international trade in frogs' legs and much less is known about the demand for amphibian meat in domestic markets (Kusrini & Alford, 2006). Although harvesting wild amphibians for the domestic food market is not considered as great a threat as habitat destruction, disease and climate change (Andreone et al., 2005) there are growing concerns that local harvests are unsustainable (Glaw & Vences, 2007). In this report we review the current state of knowledge regarding the consumption of amphibians for food in Madagascar, provide some new information collected during 2007 and 2008, and identify priority steps for the future.

MATERIAL AND METHODS

We interviewed frog hunters, intermediaries who transport and sell frogs to traders, as well as retailers, purveyors and restaurateurs. Our data therefore comprise of results from semi-structured interviews as well as direct observations (Andrianasolonjatovo in prep.). We conducted the work in Antananarivo (February 2008), Moramanga (November 2007 and January 2008) and Toamasina (February and March 2007).

RESULTS

Consumption of amphibians in Madagascar

Five amphibian species, four endemic (*Boehmantis microtympanum, Boophis goudoti*, *Mantidactylus grandidieri*, and *Mantidactylus guttulatus*) and one introduced (*Hoplobatrachus tigerinus)*, are known to be consumed by people in Madagascar (Glaw & Vences, 2007) (Tab. I). The hind limbs of frogs are a delicacy and are the only body parts prepared for the customer, although the head, other limbs and entrails may be eaten by the hunters or cooks (R. L. Rampilimanana and A. Rabearivelo, unpubl. data) (Fig. 1 A). Frogs' legs are available in many restaurants that specialize in Chinese or European cuisine throughout the island. They are sold as either first or main courses in restaurants with dishes typically comprising 12 limbs (6 individuals). Sometimes, individual legs are sold as snacks. They are usually fried in oil and garlic ("sauté"), or deep fried in batter ("beignet") or breadcrumbs ("panée").

Species	IUCN Red List	Legal Status	Length (mm)	Endemism
Boehmantis microtympanum	EN	Category 1; Class I (protected species, no collection)	60-80	Endemic
Boophis goudoti	LC	Category 3	50-70	Endemic
Hoplobatrachus tigerinus	LC	Category 1; Class II (protected species, authorized collection permitted)	120-170	Introduced
Mantidactylus grandidieri	LC	Category 3 Game species (legally hunted within a defined season)	75-108	Endemic
Mantidactylus guttulatus	LC	Category 3	100-120	Endemic

Tab. I. The five amphibian species commonly eaten in Madagascar. IUCN Red List status from IUCN (2007). The legal status refers to Annexe du décret No. 2006-400 du 13 juin 2006 portant classement des espèces de faune sauvages. Length measurements are from Glaw & Vences (2007).

Collection and transportation

In Toamasina, the introduced *Hoplobatrachus tigerinus* (Fig. 1 B) comprises the vast majority of the frog legs ("cuisses de nymphe") sold to the city's restaurants. Our observations constitute the first record of this introduced frog in and around the city of Toamasina (Glaw &Vences, 2007). Most of the frogs are collected from within the town limits, in the areas of Andranomadio, Mangarano and Anjoma, and are harvested from the highly polluted canals that run through these regions. The supply is reportedly augmented by endemic frogs from forests around the towns of Brickaville and Moramanga to the west.

Hoplobatrachus tigerinus is caught by hand in the wet season and most collectors only harvest once per month. Frog hunters, who tend to be young and unemployed people, deliver the animals directly to the restaurant owners. Most hotels and restaurants will only accept live animals so the frogs are sometimes kept in water in a covered bucket until the day of delivery. The animals are transported either by tying their legs together with string or by storing them in damp sacks.

Information based on discussions with three frog collectors in Moramanga revealed a lively trade with a number of collectors operating in the district and supplying frogs to at least five restaurants. In contrast to the urban frog collectors in Toamasina, hunters in forests typically operate at night in teams of one or two people and collection occurs mainly between the months of December and March. We did not find *H. tigerinus* in the frog trade in Moramanga and all observed restaurant deliveries consisted of *Mantidactylus* spp. (Fig. 1 C) Hunters aim to collect around 100 animals per trip and sometimes construct special holding/transportation baskets for the frogs when hunting occurs over two or more nights. The distance between the hunters' homes and forest collecting sites varied between 4 and 12 hours walk. In the north of the district, the frogs are stored in woven-baskets or specially constructed containers (Fig. 1 D) and transported by taxi-brousse, whilst hunters to the south of Moramanga travel on foot or by bicycle. The hunters always travel with their consignment of frogs and make deliveries directly to the restaurants.

The markets of Antananarivo receive frogs from a wide catchment area. Consignments from the west originated near Mahajanga and appear to consist of *H. tigerinus* whilst those from elsewhere are mainly from the south near Ambatolampy and Fianarantsoa and consist of endemic species. The supply chain is more complex than in Moramanga or Toamasina and consists of two intermediaries between the hunters and retailers; the first buys the frogs from hunters in provincial towns and prepares them for transportation (80 frogs per sack sent by overnight taxi brousse to Antananarivo) and the other, usually a family member, awaits the arrival of the frogs in Antananarivo and delivers them to market traders in the city.

Fig. 1. (A) Frog legs for sale alongside fish in a market in Antananarivo (Photo by R. Rampilimanana); (B) A *Hoplobatrachus tigerinus* in a market in Antananarivo (Photo by R. Rampilimanana); (C) An edible forest frog (likely *Mantidactylus guttulatus*) in a restaurant in Moramanga (Photo by R.K.B. Jenkins); (D) Container made from bamboo by an edible frog collector in Fierenana used to transport up to 100 live animals to Moramanga (Photo by A. Rabearivelo).

Prices and income: hunters

The collection and sale of frogs by people for restaurants provides a lucrative supplementary income. Collectors in Toamasina harvest approximately 20 animals per month and earn an average of 500 Ariary per frog during three months of the year, representing a total supplementary income of 30,000 Ariary (US$17) per year. In Moramanga, restaurants pay the collectors between 300 and 400 Ariary per frog depending on body size. Each collector could therefore potentially obtain between 15,000 Ariary (US$8; 50 frogs; minimum price per individual) and 60,000 Ariary (US$30; 150 frogs; maximum price per individual) per hunting trip. This income however, incorporates up to two nights of collection by two people, up to 12 hours travel on foot or the cost of public transport ($10 round trip) and the preparation (killing and skinning) of the frogs for the restaurants. We were unable to talk directly to the frog hunters who supply Antananarivo but they reportedly receive 700 Ariary per frog. The price per kg paid to frog hunters varied between 3,333 Ariary and 4,000 Ariary (Tab. II) and was highest in Moramanga where the frogs were generally smaller and were collected from the forest.

Prices and income: intermediaries and retailers

Individual *H. tigerinus* (150-200 g) retailed at around 2,000 Ariary each or 10,000 Ariary per kilo in the markets of Antananarivo (Tab. II). Frogs are generally not sold in the market in Moramanga or Toamasina. The frogs that arrive in the market in Antananarivo pass through two different intermediaries, the second of whom receives 1,000 Ariary per frog from the retailers in the markets.

	INVESTIGATED LOCALITIES		
	Moramanga	Toamasina	Antananarivo
Hunters' income			
Per frog	400	500	700
Per kg	4,000	3,333	3,500
Collectors' income			
Per frog	n/a	n/a	1,000
Per kg	n/a	n/a	5,000
Retailer's price			
Per frog	n/a	n/a	2,000
Per kg	n/a	n/a	10,000
Restaurateurs' price			
Per frog	1,250	1,500	1,500
Per kg	8,333	10,000	10,000

Tab. II. Results of interviews with people involved in the trade of amphibians for the food in Madagascar. Calculations per kg were based on average frog mass of 100 g in Moramanga, 175 g in Toamasina and 200 g in Antananarivo. The price in restaurants was based on a standard dish of 12 frog legs.

Prices and income: restaurants

The prices of frogs' legs in restaurants varies markedly according to the size of the establishment and the typical customer. In Toamasina, a frogs' legs first course usually costs from 7,000 Ariary (US$3.5) to 9,000 Ariary (US$4.5; range 6,000 Ariary [US$3] to 12,000 Ariary [$6]) whilst Moramanga prices for similar dishes were 6,600 Ariary to 8,500 Ariary. In Antananarivo, the prices ranged from 7,000 Ariary to 12,000 Ariary.

Demand and sustainability

There were indications from hunters, traders and restaurant owners that the demand for frogs is greater than the supply. Hunters reported having to collect for longer and further from home than in the recent past. It is not clear if the anecdotal reports of lower hunting returns is because of habitat degradation or unsustainable harvests.

The sale of live frogs in markets is usually most evident in the austral summer but restaurants keep frozen stocks to supply the demand year round. In Moramanga, the main determinant of whether a hunter travelled to sell frogs in the town was the number of animals collected; only rarely will they make a special journey to sell fewer then 60 frogs. Hunters are guaranteed a sale as long as the average size of the frogs is not too small. In Moramanga, one hunter reported that he usually delivers 400 frogs per month to a single restaurant. Using an average weight of 100 g per frog over the peak 4 month collection period, this equates to 160 kg.

DISCUSSION

Frogs' legs and the law

The three case studies presented here demonstrate that there is a lucrative and widespread trade of wild frogs in Madagascar for food. At least three endemic species of forest-dwelling frogs are collected for consumption in addition to the Indian tiger frog *H. tigerinus* and both native and introduced species are found in the trade in Antananarivo and Toamasina. Whilst there is no evidence yet to suggest that the collection threatens species survival, harvest levels at certain localities are of concern to conservationists (Glaw & Vences, 2007).

The most commonly consumed endemic Malagasy frogs are listed as game species and can be legally collected between February and May every year. The national hunting season for frog collection is designed to allow income generation for people whilst avoiding major negative impacts on wild populations. In reality this law is either deliberately or inadvertently ignored and frogs are collected in most months of the year. *Hoplobatrachus tigerinus* is listed on Appendix II of CITES and is therefore included in Category I, Class II of Malagasy law. The mandatory authorization required to collect this species in the wild is rarely sought by collectors and the necessary data with which sustainability or population trends could be inferred are lacking. The ramifications of the unregulated collection of all large edible frog species needs to be considered, in terms of the impact on local frog populations, ecosystem services and local livelihoods.

Impact on amphibian populations

The provision of frogs' legs for the restaurant trade is considered a threat to wild amphibians because harvests can be unsustainable and can lead to local population crashes (Tyler et al., 2007). In China the exploitation of frogs and the giant salamander for food has caused wide scale local extirpations (Ye et al., 1993) and similar evidence is reported for *Pelophylax* kl. *esculentus* in Europe (Carpenter et al., 2007). In Madagascar data are still lacking on the impact of collection on wild populations and although this issue is regularly raised as one of potential conservation concern (Andreone & Randriamahazo, 2008; Glaw & Vences, 2007) few data are currently available. Priority amphibian species in Madagascar and elsewhere are those listed as threatened on the IUCN Red List (Andreone et al., 2005). As three out of the four endemic edible Malagasy frogs are considered of low conservation concern it is understandable if other species receive greater attention from amphibian conservationists. However, the potential over harvest of local frog populations and the uncertainty surrounding the taxonomy of large edible species are compelling reasons to divert some resources to conserving the endemic edible taxa.

As *H. tigerinus* is an introduced species that lives in rice fields, it is not of conservation concern in Madagascar. This species supplies most of the demand for frog legs in Antananarivo and some coastal towns. It is large, weighing up to 250 g, and is therefore popular amongst traders. Although it has been suggested that the consumption of this species should be actively encouraged to benefit endemic frogs through reducing demand (Glaw & Vences, 2007), it is first necessary to study the ecology of *H. tigerinus*, the sustainability of the existing trade and the potential for harvesting at other sites. Poor management of the *H. tigerinus* harvest could result in unsustainable collection and an increased demand for edible endemic frog species.

Impact on ecosystems

Amphibians are eaten by people in all six bioregions of the world (Carpenter et al., 2007) but there is relatively little information on the impact of this on ecosystem function. The removal of vast quantities of frogs can unsettle the subtle predator-prey relationships and in Asia resulted in an increase in invertebrates and the use of insecticide (Conway, 1998). In Madagascar, *H. tigerinus* preys on rodents that are agricultural pests and the overexploitation of this predator could lead to resurgence in prey populations. In one area of western Madagascar communities actively manage the level of frog hunting to maintain the predation services provided to farmers by frogs (Vences et al., 2003).

In countries that ranch frogs another well-documented threat comes from the impact of escaped exotic species on the native amphibian fauna (Carpenter et al*.,* 2007). In Madagascar, although the introduced *H. tigerinus* is established in a few localities it does not appear to threaten the endemic forest frogs (Vences et al., 2003). The risk of pathogen transfer from importing to exporting countries is also of concern as this may foster the spread of infectious diseases (Mazzoni et al*.,* 2003), as is the difficulty in correctly identifying, and hence managing, the species that are traded (Veith et al*.,* 2000).

Impact on livelihoods and human health

It has been suggested that providing local people with an economic stake in the harvesting of wild animals results in wiser exploitation practices and concomitant benefits for habitat, species and communities (Carpenter et al*.,* 2007). There are therefore good reasons to set conservation plans within the local socioeconomic landscape to ensure that objectives are realistic and that income generating activities that are non-detrimental to wild populations can be supported. The importance of wild meat to rural economies and food security in Madagascar is poorly understood. Our preliminary results suggest that frogs are not an important subsistence meat for local hunters because they are always sold to traders or restaurants, although the offal and other waste may be consumed by the hunters. In mainland Africa, amphibians also appear to be infrequently consumed domestically in comparison to mammals, birds and reptiles. In Nigeria for example, Fa et al. (2006) recorded only 7.2 kg of amphibian bushmeat from a total of 1,127,326 kg in Nigeria and 245 kg from 674,561 kg in Cameroon. Although there are reports of professional *H. tigerinus* hunters in northern Madagascar (Vences et al*.,* 2003) all of the hunters we encountered in the east were part-time. Nevertheless, as many frog hunters are farmers the income from selling frogs is probably an important livelihood contribution because the period from December to March is associated with low income and low food security for rural people in Madagascar. The income generated by hunters in Toamasina, whilst not enough to sustain a family, the profit would certainly be a significant contribution to their household income. In Antananarivo, there are a small number of retailers who sell frogs' legs every day in the city's markets. Additional socioeconomic studies are required to ascertain the precise contribution that the frog harvests makes to the livelihoods of different stakeholders. Furthermore, the potential negative impact on livelihoods in the event of local population crashes can only be estimated with a better understanding of the socioeconomic context of the trade.

Finally, it must be of concern that a large proportion of the *H. tigerinus* sold in Toamasina are collected from the city's polluted waterways. The potential health risk associated with hunting and eating these animals is deserving of further study.

Conservation strategies

The impact of frog collection for domestic markets is difficult to ascertain because they are generally subject to fewer regulations. However, Kusrini & Alford (2006) estimated that the harvest of frogs for local consumption was between twice and seven times that for export in Java. The collection of wild amphibians in Madagascar for international trade is seen as both an opportunity for income generation and a potential threat to population survival and has thus attracted considerable interest (e.g. Raselimanana, 2003). It is appropriate for the collection of amphibians for the restaurant trade to also be considered as an opportunity and threat to conservation and local livelihoods.

One immediate priority is to quantify the relative proportion of each edible frog species eaten in Madagascar and to determine the importance of the introduced *H. tigerinus*. Ideally this would be undertaken in parallel with a revision of the taxonomy of the large edible *Mantidactylus* species. The quantity of each species that is harvested from the wild every year needs to be documented and these data would be most useful if accompanied by information on the collecting locality and hunting duration. Biologists should not assume that the existing harvest is unsustainable but should work alongside hunters and retailers to investigate whether current harvest and methods are viable in the long term.

There is a growing amount of anecdotal evidence that the current demand for frog legs is greater than the supply. Whether this will result in higher harvest rates at traditional collection sites, or the use of new collection sites or innovative efforts to farm certain species remains to be seen. Farming of suitable native species is one potential solution to avoid over-harvesting of wild frog populations and providing a sustainable protein source for rural people and/or an alternative income source though sale to hotels and restaurants.

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RÉSUMÉ

L'exploitation des amphibiens malgaches comme nourriture.

Les amphibiens de Madagascar sont collectés dans leur milieu naturel pour approvisionner le commerce international et les besoins domestique en cuisses de nymphes. Quatre parmi les cinq espèces consommées par les gens à Madagascar sont endémiques et se trouvent principalement dans la forêt. L'espèce introduite *Hoplobatrachus tigerinus* est parmi les consommées. D'après les observations et entretiens effectués dans les trois centres urbains (Antananarivo, Toamasina et Moramanga), nous avons mis en évidence la succession des produits de cuisses de nymphes. La plupart des collectes est faite par des chasseurs ayant le principal métier de fermier pour augmenter leur revenu. Les cuisses de nymphes sont vendues dans les marchés à Antananarivo et les restaurants dans les trois localités d’étude et semblent être considérées comme une nourriture de luxe. Plusieurs collecteurs de grenouilles ont exprimé leur inquiétude envers l’abondance des espèces comestibles dans les sites de collecte traditionnels dans la forêt, qui a diminuée ces dernières années et ils ont besoin d’effectuer beaucoup plus d’effort pour obtenir la récolte minimum. Nous procurons une liste des actions prioritaires pour développer une meilleure compréhension de l’impact économique et biologique du commerce des amphibiens comestibles à Madagascar.

Mots clé: Amphibiens, Chasse, Cuisses de nymphe, *Hoplobatrachus*, Madagascar, *Mantidactylus*, Viande sauvage.

Richard K. B. JENKINS’
Roma RANDRIANAVELONA[1]
Madagasikara Voakajy
BP 5181, Antananarivo (101)
Madagascar

and

School of Biological Sciences
University of Aberdeen
Aberdeen, AB24 2TZ
United Kingdom
Email jenkins@moov.mg

M. Nandrianina ANDRIANASOLONJATOVO
Gestion de Ressources Naturelles et Environnement
Université de Toamasina

Karen FREEMAN
Madagascar Fauna Group
B.P. 442, Toamasina (501)
Madagascar

Andriamnana RABEARIVELO
ACCE
Lot A 422, Moramanga (514)
Madagascar

Roseline L. RAMPILIAMANANA,
Département de Biologie Animale
Faculté des Sciences
Université d’Antananarivo
B.P. 906, Antananarivo (101)
Madagascar

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 357-376

Angus I. Carpenter[1], Onja Robson[2]

Madagascan amphibians as a wildlife resource and their potential as a conservation tool: species and numbers exported, revenue generation and bio-economic model to explore conservation benefits

ABSTRACT

Madagascar is a biodiversity hotspot with much conservation concern. An unknown level of trade exists in a wildlife resource (amphibians), which has the potential to be a conservation tool when developed in synergy with social considerations. UNEP-WCMC CITES and Malagasy government data were reviewed to identify the species, numbers and trends of this trade. These data were combined with village data, on activities and incomes, in bio-economic models to explore any conservation benefits. *Mantella* were in greatest demand by the trade, and highly substitutable, followed by *Scaphiophryne* and *Dyscophus*. Specifically, concerns were given for six amphibian species, however, trading in *Mantella aurantiacai* appeared to have ceased. The trade structure is a three tier system, which generates a relatively large revenue for exporters and intermediaries, but with limited revenues passed to collectors. Anjajavy and Ambohidrapasy were fishing based villages, however, villagers in Ansangabe practiced agriculture and collection of forest products. Ansangabe recorded negative impacts on its surrounding forest. Per capita revenue for Ansangabe (US $10.06) was lower than reported for previous studies. Hill rice, manioc and maize were the main crops requiring cleared forest, thus high impacting. Data collected on the incomes of local people and the exports of amphibians were combined in two bio-economic models, with a financial target of US $720.00 set as the target for wildlife based incomes. Single species based models indicated that over 2000 individual amphibians needed to be harvested to meet financial targets, which potentially have high impacts on populations. However, harvesting between 10 species located in the region allowed revenue targets to be met with reduced impacts on populations. The potential exists for the wildlife trade to assist conservation, especially outside protected areas, but the management of any such trade needs careful supervision, especially with regard to sustainable levels of harvest.

Key words: Amphibians, Biological resources, Bio-economic models, Sustainable harvesting, Wildlife harvesting.

[1] University of East Anglia, Norwich.
[2] Université d'Antananarivo.

INTRODUCTION

Species and population management

The trade in wildlife is stated to be one of the seven major drivers causing the global decline in amphibians (Gibbons et al., 2000). However, the population impacts from the collection of wild amphibians are unknown in most cases due to a lack of data with which to evaluate these impacts. Conservation benefits are often cited as the desired aim of sustainable exploitation of wildlife resources (Norman, 1987; Milner-Gulland & Mace, 1998), yet the sustainable levels of extraction are also mostly unknown. Wildlife extraction has been reported to have had negative impacts on the populations of some species, such as monkeys (Refisch & Koné, 2005), lizards (Shine et al., 1996), fish (Kamukuru & Mgaya, 2004) and seahorse (Martin-Smith & Vincent, 2005). Alternatively, it has also been stated that some species, such as reptiles, are less susceptible to the negative impacts of harvesting because of rapid growth rates, early maturation and high fecundity (Shine et al., 1999).

The long-term consequences of harvesting wild populations depends upon a range of factors, such as the frequency and season of harvest (Freckleton et al., 2003) and the life stage/age of individuals extracted (Cameron & Benton, 2004). Predicting the consequences of harvesting entails understanding the harvesting schedule together with the demography of the species concerned, and how they are affected by population density (Freckleton et al., 2003).

The IUCN's Redlist assigns species to a category (vulnerable, endangered, etc) according to their threat of extinction, though a majority of species are data deficient (DD) and thus unable to be classified. However, it is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) that governs and monitors the trade in wildlife resources. Countries trading in wildlife resources, such as amphibians, provide data on both the source of the individuals and the levels of trade in reports submitted to CITES (Harwood, 1999; Carpenter, 2003).

Social factors

An increasing human population inevitably results in increased pressure on land and resources (Ulph, 1996; Perman et al., 1999), often with the interests of the people taking precedent over conservation concerns. However, since the 1970s, it has been suggested that conservation and poverty alleviation should develop in synergy, since one is not achievable without the other (Low et al., 1999; Milner-Gulland & Mace, 1998; Brown, 1998). Governments with limited finances are often unable to enforce effective protection for conservation designated areas and wildlife laws are difficult to enforce (Rowcliffe et al., 2004; Carpenter, 2006). A further complication is that many species of conservation concern are located outside protected areas (Bruner et al., 2001; Chape et al., 2005). A suggested solution has been to set up wildlife use programs (CBWM, NRM, etc) that both benefit the local people directly and conservation. It is stated that by giving these people an economic interest in a species ensures its long-term survival, and that of its habitat (Milner-Gulland & Mace, 1998; Brown, 1998; Sinclair et al., 2006; Perman et al., 1999). Trading in wildlife products will only assist conservation, through poverty alleviation and/or an income shift, when sufficient revenues are returned to the local people (Eltringham, 1994; Ribot, 1998). However, changes in trading conditions have been observed to decrease revenue allocation to local people (Carpenter et al., 2005), which undermines any potential benefits.

Local people have had little or no involvement in the setting up of National Parks (NP) on Madagascar (Shyamsundar & Kramer, 1997), which now suffer from the negative impacts of local people (Durbin & Ralambo, 1994) as they perceive no benefit from the maintenance of NPs (Nicoll & Langrand, 1989). Villagers utilize forested areas for both subsistence and commerce (Shyamsundar & Kramer, 1997; Durbin & Ralambo, 1994; Carpenter, 2003).

National, yearly per capita values reported for Malagasy incomes range from US $167 to US $300, in 1990 and 1995 respectively (Durbin & Ralambo, 1994; Kramer et al., 1995). However, few studies have identified the specific activities and levels of engagement undertaken by local people. Shyamsundar & Kramer (1997) cite villages in the Mantadia NP region as being subsistence economies based on agriculture and forest products, with incomes of US $39 per household per year. It is imperative that information on the activities and revenues of local people are known, if any trade in wildlife were to be used to offset the negative impacts on forests by local people.

Bio-economic model

Madagascar currently exports a variety of natural, biological resources, such as vanilla, generating US $60 million (Kramer et al., 1995), and chameleons, generating over US $14.5 million (Carpenter et al., 2004). However, habitats are under great pressure from deforestation with Madagascar losing 200,000 ha per year (Kramer et al., 1995), and predictions stating that forest will only remain on the most remote slopes by 2025 (Green & Sussman, 1990). Also, climate change will become an increasing issue that will affect changes within habitats in the future (Jolly, pers comm.; Raxsworthy, 2006).

Therefore, novel, holistic and rapidly applicable approaches are required to mitigate, as much as possible, the current negative impacts observed. Few studies have fully explored the integration between biological extraction rates and socio-economic activities for best conservation outcome (Sinclair et al., 2006). Norman (1987) analyzed the economics of harvesting tegu for both the international skin and local meat trades. It showed how important the income source was for people in the lower socio-economic strata, and how price manipulation facilitated reduction in the harvest rates, a conservation requirement, but without affecting the incomes of the poor. Fitzgerald (1994) expanded the study to include adjacent countries also involved in this trade, and extended the management to form co-operatives to manage local tegu populations for best conservation outcomes.

Models developed to investigate sustainable extraction of wildlife often concentrate on biological factors only (Getz & Haight, 1989; Robinson & Redford, 1991; Reynolds et al., 2001). Sutherland (2001) reviews harvesting models and states ten principles to address when considering exploitation. However, these models are population focused and lack socio-economic considerations required for an interdisciplinary approach. Market dynamics, legislative controls on harvest, short versus long term conflicts and the needs of local people also influence levels of harvest (Sinclair et al., 2006; Perman et al., 1999; Carpenter, 2003; Carpenter et al., 2005) and must be considered too.

This study aims to explore the use of basic bio-economic models, incorporating data on the numbers of amphibians exported together with villager incomes, for best conservation outcomes. Firstly, data are reviewed on the species and numbers reported for the live trade in amphibians exported from Madagascar, with the aim of identifying species contributing highly to the trade, their frequency in the trade and the trading trends. Data were also presented on the trade structures, both network and economic, for the amphibian trade on Madagascar. Secondly, the study details the activities and sources of revenue generation for three villages in North-west Madagascar, presenting the economic background for exploration with harvesting models. Thirdly, basic models are explored with the aim of substituting the current income sources, from high, negative impacting activities to lesser impacting activities on forests conducted by local people, thus providing conservation benefits through the maintenance of habits for all species.

METHODS

Species and numbers traded

Two sets of data were used to review the numbers and species traded: first, data were collated from the UNEP-WCMC CITES database on the 18/12/2006 (using the following categories: criteria = live; source = captive bred, ranched, wild caught and F1; purpose = commercial, zoo, scientific); and secondly, government data were supplied for the period between 2000 and 2006 by Ministére des Eaux et Forét (Rabesihanaka, 2006). Analysis of CITES data were performed on the import data only, due to caveats in the data as highlighted by Carpenter (2003). Data on the network and economic trade structures were collected using semi-structured interviews with personnel from the Ministére des Eaux et Forét, Ministére des l'élevage, exporters and intermediaries during the austral summers 2000/01 and 2001/02. Further economic data were extracted from government invoices filed at the Ministére des Eaux et Forét and published literature (Rabemananjara et al., in press).

Revenue generation within villages

Interviews were firstly conducted with village councils at each of the three North-western Madagascar villages (Fig. 1). At each village, village councils, made-up of representative elders, were, by tradition, approached first and discussions held. At this meeting a request was also made for their permission to approach other village representatives. Interviews were conducted by a Malagasy national during the austral summers of 2000/01 and 2001/02, with data collected on activities, revenues and activity periods.

Economic model

Data presented on amphibian export levels from Madagascar were used as a substitute for biological data. These data do not provide the actual levels extracted from the wild by collectors, however, they are the only data available that indicate the numbers of amphibians being harvested. All amphibians exported from Madagascar were harvested from the wild.

Data on the activities of local people and the level of income were presented for villages located in North-west Madagascar. Only data representing Ansangabe were used in the bio-economic models to investigate potential conservation benefits.

Fig. 1. Main localities in North-western Madagascar where the interviews for economic data regarding village income sources and values were conducted.

RESULTS

Species and numbers traded

Malagasy amphibian species, listed on CITES, were first reported in the trade in 1994. Between 1994 and 2006, a total of over 181,000 individuals, in 17 known species, were reported to be exported from Madagascar using CITES data (Tab. I). However, between 2000 and 2006, Ministére des Eaux et Forét data reported a total of over 221,000 individuals in 91 species exported from Madagascar. Species recorded in the trade represented four genera in the CITES database and nine genera in the government data set. Ministére des Eaux et Forét data show a dramatic decline in the number of individual amphibians exported between the period 2000 and 2006 (Fig. 2), while the trend in the number of species shows a gradual decline (Fig. 3). Conversely, CITES data shows an increase in the number of individuals exported, at a rate of approximately 30% per year over the whole period (logy = 1712.8x +3821.1, $R^2 = 0.48$; Fig. 2).

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	%
Mantella aurantiaca	100	5720	6186	10720	13372	7815	5676	7545	1450	2681			61265	33.8
Mantella baroni								12	10	650	313	2625	3610	2
Mantella bernhardi						30	440	543	400	60	105	60	1638	0.9
Mantella betsileo				1000	435	175	855	2926	460	1490	995	2930	11266	6.2
Mantella cowani					52	150	170	434	241	500	120		1667	0.9
Mantella crocea					395	250	763	1223	330	125	1022	2280	6388	3.5
Mantella expectata				100	624	105	220	660	1390	1126	1280	2560	8065	4.4
Mantella haraldmeieri								180		350	410		940	0.5
Mantella laevigata				100	435	415	869	2155	533	1606	1795	2875	10783	5.9
Mantella madagascariensis				125	2192	1535	450	3243	3325	4873	4245	3255	23243	12.8
Mantella milotympanum									710	1780	850	1575	4915	2.7
Mantella nigricans											200	300	500	0.3
Mantella pulchra					784	905	270	1658	1870	2655	2205	3295	13642	7.5
Mantella spp.				230	620	260	6760	9688	545	1366	495	200	20164	11.1
Mantella veronica				100	200			50					350	0.2
Mantella viridis				125	690	385	1434	2945	1110	2065	955	1310	11019	6.1
Dyscophus antongilii					20			75					95	0.1
Dyscophus spp.				45									45	0
Platylepis spp.													0	0
Scaphiophryne gottlebei										980	775		1755	1
Grand Total	100	5720	6186	12545	19819	12025	17907	33337	12374	22307	15765	23265	181350	100

Tab. I. Data recorded in CITES database collated on the 18/12/2006 for the live amphibian trade from Madagascar between 1994 and 2005 (Source: UNEP-WCMC database). The percentage column displays the value contributed to the total by that species.

CITES data records nearly 34% of the trade being accounted for by *Mantella aurantiaca* followed by *M. madagascariensis* (13%) and *Mantella* spp (12%). Similarly, *Mantella aurantiaca* recorded the highest number of years in the trade (10 years) with five other *Mantella* spp each recording 9 years (Tab. I). The Ministére des Eaux et Forét data recorded 23 species contributing 1% towards the over 221,000 individuals exported from Madagascar. Six species contributed > 5% accounting together for nearly 50% of the total number exported, with *Mantella madagascariensis* recording over 14%, *M. aurantiaca* over 9%, *M. viridis* and *M. pulchra* over 6% (Tab. II).

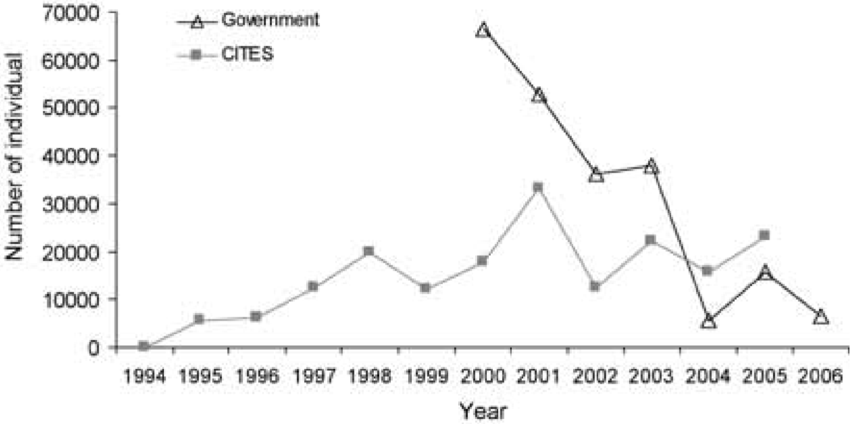

Fig. 2. Trends in trade for the number of individual amphibians exported from Madagascar between 1994 and 2006 as reported in both the CITES (Source: UNEP-WCMC database) and the Ministére des Eaux et Forét (Source: Rabesihanaka, 2006) data sets.

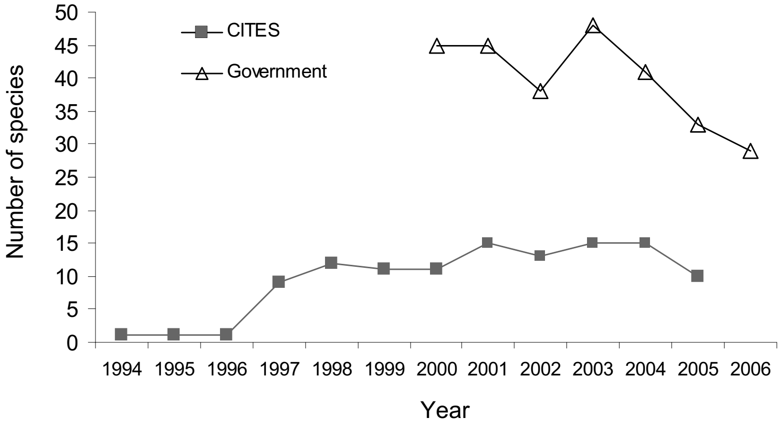

Fig. 3. Trading trends for the number of species exported for CITES listed species (Source: UNEP-WCMC database) between 1994 and 2005 and Ministére des Eaux et Forét data (Source: Rabesihanaka, 2006) between 2000 and 2006 for all amphibian species traded.

Species	2000	2001	2002	2003	2004	2005	2006	Total	% of grand total
Mantella madagascariensis	10909	8825	5030	5233	504	1103	220	31824	14.39
Mantella aurantiaca	8455	8765	3420					20640	9.33
Mantella viridis	4167	3880	2105	2390	342	853		13737	6.21
Mantella pulchra	5896	1	2570	2790	449	1527	285	13518	6.11
Mantella betsileo	2677	3921	1115	1530	577	2147	692	12659	5.72
Mantella laevigata	4003	2845	930	2393	457	1544	191	12363	5.59
Dyscophus guinethi	1709		2606	4914	266	1105	340	10940	4.95
Mantella expectata	1730	4423	1985	1680	268	250	70	10406	4.70
Scaphiophryne marmorata	1833	2946	1731	1860	161	260		8791	3.97
Dyscophus insularis	2938		1103	2752	207	986	779	8765	3.96
Scaphiophryne gottlebei	1596	1231	2495	1510	68	260	115	7275	3.29
Mantella crocea	1933	1723	530	715	383	816	147	6247	2.82
Scaphiophryne pustulosa	1800	928	746	855	454	360		5143	2.32

Tab. II. Ministére des Eaux et Forét (Malagasy government) data showing which species, exported from Madagascar, were traded in the highest numbers for the global amphibian pet trade between 2000 and 2006 (Source: Rabesihanaka, 2006). The percentage column displays the value contributed to the total by that species.

Comparing the CITES and Ministére des Eaux et Forét data sets at the genus level, *Mantella* recorded over 150,000 in both data sets, a magnitude greater than any other amphibian genus exported from Madagascar (Fig. 4). *Scaphiophryne* (26289) and *Dyscophus* (21951) were recorded as the second and third most traded genera; again, a magnitude greater than the remaining genera in the Ministére des Eaux et Forét data set. Since 1997, there has been on average 13 species recorded per year in the CITES data set (Fig. 3). However, the Ministére des Eaux et Forét data peaked with 48 species, in 2003, but has continually declined since then, recording a low of 29 species in 2006.

The wildlife trade network on Madagascar consists of three tiers (1/ collector, 2/ intermediary and 3/ exporter), which is consistent with previous studies (Rabemananjara et al., in press; Carpenter, 2003; Carpenter et al., 2004, 2005). Rabemananjara et al. (in press) reported the average incomes generated from the amphibian trade, with the collector receiving US $00.10 per animal, the intermediary receiving US $00.43 and the exporter receiving US $02.65. A minimum of 27 exporters were recorded operating on Madagascar supplying wildlife to at least 71 importers around the world. However, the actual number of intermediaries and collectors involved in the wildlife trade were unknown but considered to be many, especially as collectors were mostly people in remote villages (Rabemananjara et al., in press; Carpenter, 2003). Using the Ministére des Eaux et Forét total export figure and an average price of US $02.65 per amphibian results in revenue generation for the exporters of nearly US $590,000 from the trade. Alternatively, using the CITES export figure of 181,350 and an arbitrary US $05.00 (CITES listed species demand higher prices) per individual, results in a total revenue generation of US $906,750 from this trade. However, the revenue generated by the amphibian trade is not distributed evenly between all exporters, only 18 of the 27 recorded exporters

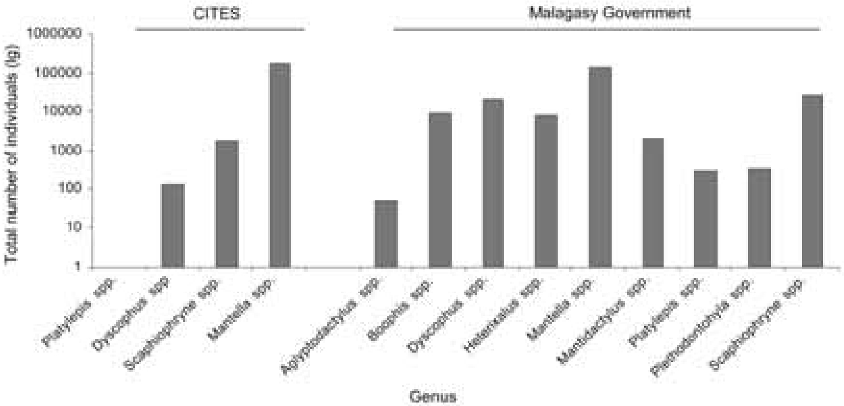

Fig. 4. The total numbers recorded for each genus traded in both the CITES listed species (Source: UNEP-WCMC database) between 1994 and 2006 and Ministére des Eaux et Forét (Malagasy government data) between and 2000 and 2006 for amphibian species exported from Madagascar (Source: Rabesihanaka, 2006).

were recorded trading in amphibians (Tab. III). Using the revenue values generated from the amphibian trade, intermediaries should receive approximately US $95,000 from the exporters and should pass approximately US $22,000 on to the collectors, based on average values and the Ministére des Eaux et Forét total figure.

Sources and levels of revenues within villages

All three villages gave the wet (December until February) and dry seasons as the same (Fig. 5). However, they recorded very different activities throughout the year and seasons (Fig. 5), with Anjajavy and Ambohidrapasy concentrated on fishing activities. The break from fishing activities recorded in July is due to the trade winds (called Varatraza), which makes going to sea dangerous. Dried fish were exported to Mahajunga and sold at markets there and were the main source of income for these two villages. Prices for dried fish sold in Mahajunga ranged from FMG 7,500 kg^{-1} for large fish (called Ankoa), FMG 4,000 kg^{-1} for medium sized fish (called Kikoa) and FMG 250,000 kg^{-1} for shark fins (called Ankio). Products purchased in Mahajunga were rice for planting, candles, oil and essentially salt. However, during the wet season, peoples from these two villages farmed small patches of land for subsistence crops.

Alternatively, Ansangabe recorded activities that had a much greater level of interaction with the surrounding forests. Ansangabe recorded activities based on the production and selling of harvested crops and timber felled from the forests (Fig. 5). The products in which commerce were practiced were crudely divided into agriculture and forest sourced (Tab. IV). Palisander, a hardwood

Exporters	Number of Individuals								
	Permits issued	Cham's	Phel's	Amphib's	Tort's	Mammal	Aves	Other taxa	Total number
1	32	991	1600	9800	45				12436
2	49	3127	3842	2423	405	33	530		10360
3	2			1100					1100
4	3			240	120		200		560
5	40	3464	2280	2450	28	10		780	9012
6	7	150	100	6160					6410
7	11	1445	2335	3555		10			7345
8	4			2340					2340
9	1			110					110
10	11			7250			240		7490
11	12	1518	1945	85				100	3648
12	1						500		500
13	1			150					150
14	30	3592	3005						6597
15	5				800		1150		1950
16	1			120					120
17	2						820		820
18	1				200				200
19	2	50	26	160					236
20	1					4			4
21	3				400				400
22	6			1345	40		700		2085
23	2						570		570
24	1					6			6
25	2	60		700					760
26	1			80					80
27	1			1000					1000
	232	14397	15133	39068	2038	63	4710	880	76289

Tab. III. The numbers of individuals within each taxon of trade reported by each exporter to the Ministére des Eaux et Forét as detailed on invoices for the austral summer 2001/02. Permits issued refer to CITES permits.

tree species, was a highly desirable commodity mostly exported to Mahajunga, but also used in construction. Other timber included small sized mangrove species, again used in construction, and alternatively large tree species used in construction and as dug-out canoes (pirogues). Farming and non-timber forest product (NTFP) extraction recorded large investments of time. Subsistence needs were removed from the harvested crops, while the excess, listed in Tab. IV, were sold in Mahajunga. Both hill and valley rice were recorded, however, valley rice is limited due to a lack of suitable ground for growing the crop. A form of swidden agriculture (called tavy) was practiced with hill rice, manioc and maize planted on the cleared forest areas (Fig. 6). NTFP collected from the forest included honey, mangos, bananas and coconuts (Tab. IV). Ansagabe recorded revenue generation of approximately US $10.06 per capita, with a total revenue of nearly US $721.00 generated from activities categorized as having a high impact on forests (shaded boxes, Tab. IV).

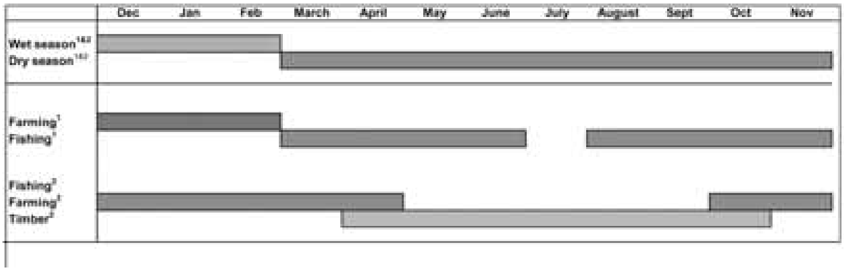

Fig. 5. Yearly timetable of the commercial and subsistence activities performed by the three North-west Madagascar villages throughout the year and seasons as they reported them. Codes are as follows: 1 = Anjajavy and Ambohidrapasy, 2 = Ansangabe; hatched boxes are where commercial and subsistence activities were recorded, plain boxes were subsistence activities only.

Economic models

High impact activities generated revenue totaling nearly US $721.00 (Tab. IV). This value was used as the target value for which revenue substitution was required. A clarification should be made between the harvester's revenue versus costs (Eq. 1), and considering that costs include 'opportunity costs' as well as direct costs, in economic terms (Perman et al., 1999).

Harvester's revenues – *Harvester's costs* = profitable income Eq. 1

Where *harvester revenue* is income generated from the amphibian trade, while *harvester costs* equate to revenue generated from high impact activities practiced at Ansangabe. Inputting known figures into equation 1 gives the following:

Harvester's revenues – US $721.00 = profitable income Eq. 2

Thus revenue from the amphibian trade needs to generate greater than the target value of US $721.00. The amphibian trade was calculated as generating a total of between US $590,000 (over 6 years) and US $906,750 (over 12 years), giving an average revenue per year of between US $98,334 and US $75,563. However, only just over 3% of this yearly value was passed on to the collector, resulting in between US $2,950 and US $2,267 reaching the collectors. Thus equation 2 can be re-written as follows:

US $2267 – US $721.00 = profit of US $1546 Eq. 3

An alternative model (Eq. 4) offers a different approach with the same financial target and using data on the unit price and harvesting levels in the calculations.

Activity	Price unit^{-1}	Volume	Total
Valley rice (A)	UK £00.28 kg^{-1}	1500 kg	UK £420.00
Hill rice (A)	UK £00.28 kg^{-1}	500 kg	UK £140.00
Maize (A)	UK £00.02 cob^{-1}	800	UK £16.00
Maize (A)	UK £00.35 kg^{-1}	500 kg	UK £175.00
Manioc (A)	UK £00.20 kg^{-1}	500 kg	UK £100.00
Bananas (F)	UK £00.25 tamgozany^{-1}	800	UK £200.00
Coconuts (F)	UK £00.10 coconut^{-1}	800	UK £80.00
Honey (F)	UK £00.50 litre^{-1}	50 litre	UK £25.00
Honey (F)	UK £01.50 litre rum^{-1}	100 litre	UK £150.00
Mangos (F)	UK £00.02 each	500	UK £10.00
Palisander (F)	UK £2.00 tree^{-1}	20	UK £40
Other timber (F)	UK £0.50 tree^{-1}	40	UK £20
Transport (F)	UK £0.38 shipment^{-1}	6	UK £2.28
		Total =	**UK £1378.28 (US $2012)**

Tab. IV. The units of trade, prices and levels of commerce practiced by the village of Ansagabe, north-western Madagascar. Code signifies A = agriculture sourced, F = forest sourced. Shaded boxes indicate high impact activities.

$$H * p = revenue \qquad \text{Eq. 4}$$

Where H = harvest and p = price unit^{-1}; data used were the target revenue, again, US $721.00 and the collectors average US $00.10 per amphibian (Rabemananjara et al., in press). Data exist for the financial target (*revenue*) and price per amphibian (p) only, thus equation 4 was re-arranged with data on the left and the number of individual amphibians to be harvested (H) on the right (Eq. 5):

$$revenue \;/\; p = H \qquad \text{Eq. 5}$$

$$\text{US \$721.00} \;/\; \text{US \$00.10} = 7210 \text{ individuals} \qquad \text{Eq. 6}$$

To facilitate an income shift, at current collector income levels, a total of 7210 individual amphibians need to be harvested from the wild (Eq. 6). However, the financial target only equals that generated by high impact activities; therefore, this needs to be increased to generate a greater incentive

Fig. 6. Recently burnt and cleared forest (called tavy) just outside the village of Ansangabe, North-west Madagascar to make way for new areas for hill rice production

for the collectors. There is also a need to reduce the number of individuals harvested to minimize any negative impacts on the population. For example, equation 7 raises the target value to US \$800.00 and increases, arbitrarily, the price per unit to US \$00.35 in order to facilitate a reduction in the number of amphibians extracted:

US \$800 / US \$00.35 = 2285 individuals Eq. 7

At least 10 amphibian species were recorded in North-west Madagascar by Glaw & Vences (1994; Tab. V). Therefore, the 2285 individuals required for harvesting could be spread across these ten species (Tab. V), potentially reducing the extraction rates to just over 200 individuals from each species.

	Genus	Species
1	*Boophis*	*tephraeomystax*
2	*Blommersia*	*wittei*
3	*Mantidactylus*	*ulcerosus*
4	*Mantidactylus*	*betsileanus*
5	*Mantella*	*betsileo*
6	*Ptychadena*	*mascareniensis*
7	*Laliostoma*	*labrosum*
8	*Hoplobatrachus*	*tigerinus*
9	*Scaphiophryne*	*calcarata*
10	*Dyscophus*	*Insularis*

Tab. V. Ten amphibian species recorded in the North-west Madagascar as cited by Glaw & Vences (1994).

DISCUSSION

Comments made by an anonymous reviewer, correctly, reminded the author's to state from the outset that the potential benefits from harvesting wild species is only one of many conservation tools available to conservationists. Also, this is only available when management structures and options are taken with a view to conservation and local peoples needs ahead of commercial interests. Issues that need to be addressed prior to any proposed harvesting project were provided in the IUCN's amphibian conservation action plan (Lau et al., 2007). Such projects should not be considered in isolation but rather in conjunction with alternative conservation methods.

Species management

CITES data presented here show over 20,000 more amphibians reported in the trade compared with data collated only six months earlier (Lau et al., 2007), highlighting the importance of providing the date when data were collated as stressed in Carpenter (2003). CITES data show the number of amphibians exported from Madagascar to be increasing, since 1994, destined for the international pet trade. However, Ministére des Eaux et Forét data shows a dramatic decline in numbers after 2003. Both data sets report declines in 2002, which coincides with a period of political unrest. However, CITES data increases after 2002 while the Ministére des Eaux et Forét continues to decline, even to levels lower than those reported for just CITES listed species. This variation between dataset trends is concerning, as the Ministére des Eaux et Forét represents up to 48 amphibian species in any one year while CITES data currently represents a maximum of 17 species. Therefore, Ministére des Eaux et Forét would be expected to be greater than the corresponding CITES data. Also, there appears to be the high degree of substitutability between amphibian species, specifically *Mantella*, traded from Madagascar, which makes control through formal legislative procedures difficult (Perman et al., 1999). Both concerns suggest that governance management authorities would benefit from training and capacity building on reporting and management processes.

At the species level, both data sets report *Mantella aurantiaca* and *M. madagascariensis* to be the most heavily traded species. However, *M. aurantiaca* has not been recorded in the trade since 2003 (Tab. I) by CITES and 2002 (Tab. II) by the Ministére des Eaux et Forét. Similarly, the species recorded 34% (CITES – Tab. I) and 9% (Ministére des Eaux et Forét – Tab. II) of the total number traded respectively, but both percentages reported were below previously reported levels of nearly 50% (Rabemananjara et al., in press). This supports the idea that trade in this species has now ceased. However, it is concerning that the CITES Management Authority on Madagascar still records trade in unknown amphibian species, a problem also observed in the trade of chameleons (Carpenter, 2003; Carpenter et al., 2004, 2005), which undermines confidence in figures reported for trade. Certainly *Mantella* is the genus that contributes most to the trade and thus concerns raised by Andreone et al. (2005) and Rabemananjara et al. (in press) were supported here. Specifically, levels of trade indicate concerns should be raised for *M. madagascariensis*, *M. viridis*, *M. pulchra*, *M. betsileo*, *M. laevigata* and *Dyscophus guineti*.

Trade structures

The structure of the amphibian trade network were similar to those reported for the chameleon trade (Carpenter et al., 2005), with local village people conducting the collecting. Considering the distribution of species reported in the trade, collectors were certainly located across Madagascar near suitable habitats. This suggests there is the potential for villagers to assume ownership and collection rights over local amphibian populations, an important factor in attempts to seek a sustainable trade (Perman et al., 1999; Carpenter, 2003). The revenues generated from the trade reported here, also suggest there is a potential income of approximately US $22,000 to collectors. Comparing the revenue generated from the trade with that reported of US $39 per household (Shyamsundar & Kramer, 1997), suggests that a much greater income is potentially available to collectors from the amphibian trade. However, activities and incomes of local people need further understanding before any project seeks to shift, or supplement, the existing source of incomes.

Intermediaries were also reported in Carpenter et al. (2005) and Rabemananjara et al. (in press) as ‘go-betweens’ for the exporters, collecting animals from villagers and returning them to exporters based in the capital. Intermediaries were dedicated to the wildlife trade for their income, and received approximately US $95,000 solely from the trade in amphibians. When other taxon are also considered (such as in Tab. IV) there appears to be a very lucrative income for intermediaries, hence their apparent faithfulness to exporters.

Bio-economic models

This study was the first attempt to combine amphibian species data with economic data into bio-economic models with reference specifically to Madagascar. Whilst currently at a basic stage, it did permit investigation in to the viability of the trade, from a financial aspect, as an alternative income source. The level of income calculated in equation 3 suggests a sizeable profit would be gained if villagers were to shift their source of income to the amphibian trade. However, the harvester revenue value used in the equation is the total, per year revenue generated for all participating collectors on Madagascar. Not all amphibians come from this one region of Madagascar but were actually widely located across the island. Therefore, calculations in equations 1 to 3 need further refinement regarding the data entered, requiring site specific data regarding the harvester revenue input value, etc.

Equations 4 to 6 calculate the number of amphibians needing to be extracted to match current income levels, while equation 7 shows that by manipulating the input values could favour conservation outcomes. However, these figures were based on a single species, but ten amphibian species have been recorded in this region of Madagascar. This would suggest that the level of extraction required to meet the current income level could be just over 200 individuals per species. Potentially, this reduces the rate of extraction by a magnitude and thus reduces the negative harvesting impacts that higher numbers may have had on the local amphibian populations.

Both forms of bio-economic models require much greater development and more specific, site level data, which currently do not exist. However, this study forms the basis from which to develop the theory and models further, with the aim, ultimately, of providing site level calculations that can be used by conservationists for developing long term sustainable projects for best conservation benefits.

RÉSUMÉ

Les amphibiens malgaches comme ressource de la vie sauvage et leurs potentiels comme outil de conservation: espèces et nombres exportés, revenu générationnel et modèle bioéconomique pour en étudier les avantages de conservation.

Madagascar est un haut lieu de la biodiversité avec de nombreuses inquiétudes quant à sa conservation. Il y a un niveau inconnu de commerce des ressources de la vie sauvage (amphibiens), qui a la capacité d'être un instrument de conservation quand il est développé en synergie avec des considérations sociales. Les données Du PNUE-WCMC CITES et du gouvernement malgache ont été revues pour identifier les espèces, le nombre et les tendances de ce commerce. Ces données ont été combinées avec les données des villages en temps qu'activités et rentrées, selon des modèles bioéconomiques qui en étudient les avantages de conservation. La *Mantella* était en forte demande commerciale, suivie par la *Scaphiophryne* et la *Dyscophus.* Spécifiquement, des inquiétudes portent sur six espèces d'amphibiens, bien que le commerce de *Mantella aurantiaca* semble avoir cessé. La structure du commerce est un système d'arbre à trois branches qui génère des revenus relativement importants pour les exportateurs et les intermédiaires, mais avec des revenus limités pour ceux qui les collectent. Anjajavi et Ambohidrapasi étaient des villages de pêche, bien que les villageois de Ansangabe pratiquaient l'agriculture et collectaient des produits forestiers. Ansangabe a enregistré des impacts négatifs sur la forêt environnante. Le revenu moyen de Ansangabe (US $10.06), était plus bas que ce qui était reporté dans l'étude préalable. Riz, manioc, et maïs étaient les principales cultures qui nécessitaient de nettoyer la forêt avec un fort impact. Les informations recueillies sur les entrées de la population locale et les exportations des amphibiens ont été combinées en deux modèles bioéconomiques, avec un objectif financier de 720.20 $ US positionné dans la catégorie des entrées liées à la vie sauvage. Des modèles de basés sur des espèces simples ont indiqué que plus de 2000 amphibiens devaient être collectés pour atteindre leurs objectifs financiers, ce qui a potentiellement d'importants impacts sur les populations. Cependant, collecter parmi 10 espèces localisées dans la région permet d'atteindre ces objectifs de revenu avec des impacts réduits sur les populations. Il existe le capacité pour le commerce de la faune sauvage pour aider à la conservation, spécialement en dehors des zones protégées, mais la gestion de chaque type de commerce nécessite une supervision attentive, spécialement avec une attention particulière aux niveaux de développement durable de la collecte.

Mots clés: Amphibiens, Collecte à développement durable, Madagascar, Modèles bioéconomiques, Récolte de la faune sauvage, Ressources biologiques.

Angus I. Carpenter
School of Environmental Sciences
University of East Anglia, Norwich, Norfolk, UK
Email chameleon.project@uea.ac.uk

Onja Robson
Département de Biologia Animale
Université d'Antananarivo
BP 906, Antananarivo 101, Madagascar

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Rainer Dolch[1]

Sustainable natural resource management. The case of the Analamazaotra Forest Station, Andasibe, Madagascar

ABSTRACT

Local people are often excluded from the decisions regarding the sustainable use of their natural resources. In most cases, management transfer of natural resources in Madagascar fails because communities are not able to generate income in an environmentally friendly way. Managed by the local NGO Mitsinjo, the Analamazazaotra Forest Station is one of the rare examples of efficient management of natural resources thanks to a multidimensional approach, focusing on the promotion of ecotourism, local handcraft production, sustainable agriculture, etc. The amphibians play an important role in the sustainable management of this site, extraordinarily rich in species of frog that attract researchers and naturalists alike. The amphibians are being featured by local craftsmen and thus contribute to the generation of income. Income generation and environmental sensitization should be incorporated in the ACSAM Initiative by the creation of a centre for the conservation of the region's threatened species.

Key words: Amphibians, Analamazoatra, Sustainable use.

INTRODUCTION

Madagascar's biodiversity, its faunal and floral peculiarities, the uniqueness of almost every living thing on this island, are proverbial. Unfortunately, the enormous threats to one of the earth's hottest biodiversity hotspots (Myers et al., 2000) are as well.

Luckily, Madagascar has long been aware of its uniqueness. It has been among the leaders of conservation in Africa, passing one of the first environmental action plans on the continent. At the World Parks Congress in Durban, South Africa, in September 2003, the President of the Republic, Marc Ravalomanana, announced to triple Madagascar's protected area by 2008, bringing it to 60,000 square kilometres, roughly 10% of the total surface area (e.g., Norris, 2006).

[1] Association Mitsinjo, Andasibe.

Commonly known as the "Durban Vision", it is, of course, much more difficult to enact than to announce it. Until present, conservation has often been hampered by a largely top-down approach. Traditionally, national parks and protected areas in Madagascar are managed by ANGAP, a rather ponderous semi-governmental organization. Local populations are usually excluded from management decisions. Even well-meant microprojects financed by a portion of entry fees to the national parks do not significantly contribute to the improvement of livelihoods of the local populations living in the vicinity of protected areas (e.g., Dolch, 2003).

According to the "Durban Vision", and in order to avoid further disconnecting biodiversity conservation and sustainable development, Madagascar's new protected areas system (SAPM) will therefore involve a variety of different management bodies that take the needs of the local populations into account.

Natural resources management transfer

There is no doubt that involvement of local populations in conservation and management of natural resources is absolutely essential for the overall conservation strategy to succeed. Therefore, two national laws, commonly known as GELOSE and GCF, constitute the framework for the transfer of natural resource management to local populations in Madagascar. Local populations conclude a contract with the Ministry of the Environment, Water and Forests in which the modalities of the management transfer of natural resources – forests, wetlands, and prairies – are fixed.

Unfortunately, many of the natural resources management transfers fail because big NGOs have been over-ambitious to implement them, without properly training local populations in management issues beforehand. Even worse, there is often no monitoring or follow-up once the contract has been signed. Many local communities that are managing natural resources in Madagascar rely on timber as the primary source of income. Given the weak management capacities, the poverty of local communities and the lack of monitoring, community forestry is hardly sustainable. Other sources of income will therefore have to be developed in order to equally satisfy the needs of both the local population and biodiversity.

Analamazaotra Forest Station - History

Andasibe – still often referred to as Périnet by its old French name – is one of the most visited villages in Madagascar thanks to its natural riches of its national park (Andasibe-Mantadia) and the surrounding forests and wetlands (Dolch, 2003; Fig. 1). Founded in 1902, the Analamazaotra Forest Station in Andasibe is one of the oldest managed forests in Madagascar that includes natural rainforest, secondary vegetation and timber plantations (e.g., Louvel, 1909). Studies on endemic fauna and flora were followed by local introductions of exotic species and Analamazaotra long served as an experimental station. After its eastern part was set aside as a special reserve for *Indri indri* in 1970 (now a part of Andasibe-Mantadia National Park), management of the western part was assured by what was then the Direction des Eaux et Forêts. Lack of staff and financial problems led to a stark decrease in surveillance efforts. In the late 1990s and early 2000s, the natural forest of Analamazaotra was being illegally logged at an alarming rate, charcoal production from native timber led to several forest fires that added to the destruction (see Dolch, 2003).

Analamazaotra Forest Station – local community management

As a result, management of the Analamazaotra Forest Station was finally transferred to several villagers from Andasibe that had founded an association called MITSINJO – which literally means "caring for the future". Being a truly local and grassroots initiative, MITSINJO has evolved out of a community project and was founded as an association in 1999. It is currently run by 36 villagers from Andasibe. The association's goal is to integrate biodiversity conservation with rural development in order to improve living standards and generating sustainable income for the rural poor.

Having steadily grown over the years, the association now is an important partner for both development and conservation organizations as well as the private sector. MITSINJO is even participating in several projects of national and international importance such as the implementation of the management plan for the Ramsar site of Torotorofotsy and a pilot project for the restoration of forest corridors between remaining habitat fragments and tied to issues of carbon sequestration regulated by the Kyoto Protocol (Delay, 2006; Holloway, 2000). The association's approach goes hand in hand with the "Madagascar Action Plan" (MAP) that forms the framework for the country's sustainable development. Clearly, collaboration with other local communities and building their capacity still is the biggest asset. Collaboration involves several farmers' groups and covers about 400 individual households.

Analamazaotra Forest Station – biodiversity

Analamazaotra has a very diverse flora and fauna, including a locally endemic palm (*Ravenea louvelii*) that does not occur anywhere else. At least 12 species of lemur thrive in this forest. The indri (*Indri indri*) surely is the most spectacular; Goodman's Mouse Lemur (*Microcebus lehilahytsara*) is the most recent discovery (Kappeler et al., 2005) and could only be described after being captured by the association's members. Amphibian species richness is one of the highest in the world, with the Andasibe region being home to more than a hundred species of frogs. These include very charismatic ones such as *Mantella baroni* and *Scaphiophryne marmorata* as well as inconspicuous but nevertheless interesting species such as *Stumpffia tetradactyla* (Glaw & Vences, 1994).

Making management of natural resources by local communities work

The Analamazaotra Forest Station is one rare example of an effective management of natural resources by a local community in Madagascar. As stated above, management transfer of natural resources often fails due to insufficient or one-dimensional sources of income that are largely based on the (very often not-so-sustainable) extraction of timber. In a more-dimensional approach that focuses on the promotion of ecotourism, local handicraft, sustainable agriculture and the wise use of non-timber forest resources (fruit, medicinal plants), MITSINJO is able to not only generate enough money for keeping the association going, but also for financing activities that benefit the people living in Analamazaotra's vicinity and subsequently lead to a reduction of the pressure on the natural resources of the whole area.

Ecotourism and its benefits

The main attractions for nature tourism in the Analamazaotra Forest Station include lemur watching, herpetology, botany, tree nurseries, canopy climbing, canoe rides and nocturnal hikes in the forest. The latter are especially interesting for frogwatchers (as are the association's treks to the Torotorofotsy Ramsar site for *Mantella aurantiaca*). As a result of the promotion of ecotourism, 35 jobs have been created (guides and other staff). Local bee-keepers and craftspeople are encouraged to sell their honey and handicraft to tourists via the association. MITSINJO not only pays a local tax that contributes to Andasibe's development projects but uses the ecotourism revenues to finance its own development activities that are benefiting approximately 400 households in the region.

Development activities

In an all-embracing approach to sustainable development, health, agriculture, and environmental education are dealt with at the same time. Health activities include awareness raising campaigns on hygiene, malaria and reproductive health (HIV/AIDS, family planning) as well as the distribution of water purification kits, mosquito nets and condoms. MITSINJO also provides a variety of agricultural trainings to improve yields, diversify produce and assist in marketing. Materials and seeds are distributed and the farmers' management capacities built. Environmental education is done in collaboration with local schools, local radio stations and volunteers. It includes the maintenance of tree nurseries and the reproduction of threatened plant species as well as participation of the local population in forest restoration and biodiversity monitoring.

Amphibians' role in sustainable management

Madagascar is home to lemurs and tenrecs, endemic bird families such as vangas and ground rollers and an enormous diversity of reptiles. However, it is the amphibians that are the most species rich vertebrates of Madagascar. Currently 238 species of Malagasy amphibians are known (Glaw & Vences, 2007), making Madagascar the 12th richest country in the world for amphibians (Moore & Mendelson III, 2007). Even for Malagasy standards, Andasibe is immensely rich in amphibians and a true frog hotspot.

Amphibians face the classical threats to Madagascar's biodiversity that include deforestation due to slash-and-burn agriculture and uncontrolled logging (e.g., Vallan et al., 2004). They are additionally threatened by the pet trade and by the chytrid fungus *Batrachochytrium denrobatidis* which is not yet known from Madagascar but – given its pathology and the almost always lethal consequences of chytridiomycosis – is the main reason for global amphibian decline (Weldon et al., 2008).

Amphibians play a prominent role in MITSINJO's approach to sustainable management. Particularly, they attract both researchers and ecotourists. Since they are often portrayed in local handicraft, amphibians contribute to local incomes. They could also do so after a thorough evaluation of the potential for the sustainable use of amphibian populations for the pet trade.

Two main projects have resulted from the attention that is given to amphibians at the Analamazaotra Forest Station: (1) In a collaborative effort with partners from the universities of Braunschweig (Germany) and Antananarivo (Madagascar), MITSINJO has been comprehensively contributing to the translation of the 3rd edition of the "Fieldguide to the Amphibians and Reptiles of Madagascar" into Malagasy; (2) Plans for an amphibian breeding station have progressed and the association is collaborating with renowned frog breeder Hellmut Kurrer (Kurrer, 2006). An essential component of the "Sahona Gasy Action Plan", captive breeding at the Analamazaotra Forest Station will focus on the establishment of breeding programs for endangered frog species with respect to current or future threats such as chytridiomycosis. This captive breeding initiative will be launched under the coordination of the Amphibian Specialist Group to assure correct standards of captive breeding hygiene that are absolutely important with respect to conservation objectives. Species will be chosen accordingly, with respect to conservation status and ecology. Only a few species (Tab. I) will be bred in the beginning to avoid risks of disease occasionally occurring in places with too many species and individuals held. The breeding station will also house research infrastructure that could be used be herpetologists and other scientists alike. Furthermore, the breeding station is projected to have a significant positive impact on environmental awareness among villagers. Lastly, it will likely become an additional attraction for nature loving tourists and thus an invaluable source of additional income of the local population.

Species	**Justification**
Mantella aurantiaca	CR, restricted range, bulk of populations in the area
Mantella cowani	CR, single-site endemic, threatened by both habitat destruction and over-harvesting
Mantella crocea	En, pet trade, colour variants, bulk of populations in the area
Mantella milotympanum	CR, restricted range, bulk of populations in the area

Tab. I. Amphibian species selected for captive breeding at Analamazaotra Forest Station.

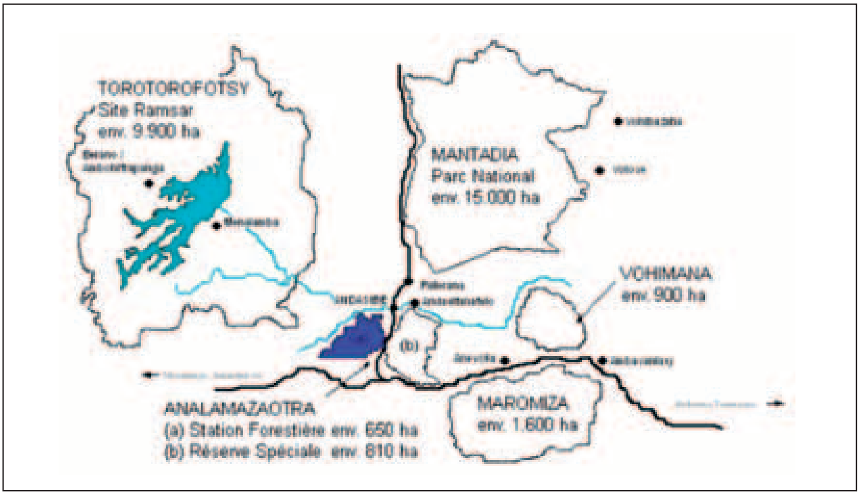

Fig. 1. Analamazaotra Forest Station and surroundings

CONCLUSION

The Malagasy culture makes intensive use of proverbs that combine a very rich oral tradition and the wisdom of a people. Since this paper is the outcome of a talk given at a workshop elaborating a conservation strategy for the amphibians of Madagascar, I like to conclude by stressing: *horakoraka foana no an'ny sahona, fa ny tsiboboka ihany no tompon'ny rano* (The frogs make the noise, but the tadpoles are the masters of the water). In this example, the frogs stand for the big conservation and development organisations. The tadpoles stand for the local communities. Without the latter, sustainable development that benefits both people and biodiversity will not be achieved.

RÉSUMÉ

La gestion durable des ressources naturelles – le cas de la station forestière d'Analamazaotra à Andasibe, Madagascar.

Les populations locales sont souvent exclues des décisions vis-à-vis la gestion durable de leurs ressources naturelles. Dans la plupart des cas, les transferts de gestion des ressources naturelles à Madagascar sont des échecs car les communautés n'arrivent pas à générer des revenus d'une façon favorable à l'environnement. Gérée par la communauté de base revenue l'ONG MITSINJO, la station forestière d'Analamazazaotra est un des rares exemples d'une gestion efficace des ressources naturelles grâce à une approche multidimensionnelle qui focalise sur la promotion de l'écotourisme, l'artisanat local, l'agriculture durable, etc. Les amphibiens jouent un rôle important dans la gestion durable du site car il est extraordinairement riche en batraciens qui attirent chercheurs et touristes en même temps. Les amphibiens sont aussi portraits dans l'artisanat local et contribuent donc à la génération de revenus. La génération des revenus et la sensibilisation environnementale seraient intégrées dans la Stratégie pour la Conservation des Amphibiens de Madagascar en mettant en place une station d'élevage en captivité pour quelques espèces les plus menacées de la région.

Mots clés: Amphibiens, Analamazoatra, Utilisation soutenable.

Rainer Dolch
Association Mitsinjo
Andasibe 514, Madagascar
Email mitsinjo@hotmail.com

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 385-396

Zo Lalaina RAKOTOBE[1], Luciano ANDRIAMARO[1], Rollande FINOANA[1],
David H. KNOX[2], Harison RABARISON[1], Harison H. RANDRIANASOLO[1]

Key Biodiversity Areas as a tool for identifying priority amphibian conservation sites in Madagascar

ABSTRACT

To ensure efficient protection of Malagasy biodiversity, Key Biodiversity Areas (KBAs) are being used as a tool to support the identification of the new protected areas called "Système des Aires Protegées de Madagascar" (SAPM) for Madagascar. KBAs are identified based on the presence of globally threatened species according to the IUCN Red List of Threatened Species, restricted range, congregatory, and bio-regionally restricted species. To date, 164 KBAs have been identified covering 8 taxa in Madagascar and 43 out of 164 are KBAs for amphibian. The highest priority subsets of KBAs are the Alliance for Zero Extinction (AZE) sites, which hold the last remaining population of a Critically Endangered (CR) or an Endangered (EN) species. For amphibians, there are currently nine AZE sites covering twelve amphibians in Madagascar. Five of these sites are already protected; an additional four sites will receive protection under the new protected area network.

Key words: Amphibian, Alliance for Zero Extinction, Key Biodiversity Areas, Madagascar, Protected Areas.

INTRODUCTION

With increasing threats to biodiversity, conservation practitioners require sophisticated tools to support decision making and to better focus conservation action, prioritizing important sites for biodiversity conservation is hence a crucial activity (Mittermeier et al., 2004). Such conservation planning needs excellent knowledge on species distributions and their habitat preferences and above all must be undertaken in a data-driven, transparent fashion. International organizations have been working on identifying global priority

[1] Conservation International, Madagascar.
[2] Conservation International, South Africa.

areas for conservation following the framework of irreplaceability and vulnerability, widely used in conservation planning (Margules & Pressey, 2000), notably the 'Biodiversity Hotspots' of Conservation International (Myers et al., 2000). Biodiversity hotspots are defined as important regions for conservation and characterized by high irreplaceability regions containing more than 1500 endemic plants and high vulnerability, regions having lost 70% of their natural habitat (Myers et al., 2000).

Considering the limited funding available for conservation action and that it is impossible to conserve species one by one, prioritization of key sites is necessary. (Brooks et al., 2007). The conservation of important sites as protected areas or other safeguard mechanisms is often the most efficient strategy in the conservation manager's toolbox for securing biodiversity (Bruner et al., 2001). Here, we propose the identification of Key Biodiversity Areas, as a mechanism for identifying the most important sites for amphibian biodiversity. It is a starting point to identify important amphibian areas but herpetologists should refine it according to the results of their findings in amphibian habitats, threats, and taxonomy.

The protection of Key Biodiversity Areas criteria will contribute to the implementation of the "Vision Sahona Gasy" or the amphibian conservation strategy for Madagascar. Additionally, these sites will also be incorporated in the Durban Vision, the government's commitment to increase of the protected area network from 1.7million hectares to 6 million hectares before 2008.

METHODS

Criteria for key biodiversity areas

KBAs build upon the success of BirdLife International's Important Bird Areas approach by identifying and ultimately protecting globally significant sites for biodiversity conservation (Eken et al., 2004). The goal of the identification of KBAs is to develop universal standards for selecting sites of global significance for biodiversity conservation through the application of quantitative criteria. (Eken et al., 2004).

The KBA criteria are based on the framework of irreplaceability and vulnerability widely used in systematic conservation planning (Margules & Pressey, 2000). KBAs are identified based on the presence of the following species at a site: 1) globally threatened according to the IUCN Red List of Threatened Species™, (Endangered (EN), Critically Endangered (CR), and Vulnerable species) 2) restricted-range species, 3) congregations of species that concentrate at particular sites during some stage of their life cycle, and 4) biome-restricted species assemblages. One criterion concerns vulnerability, the presence of globally threatened species, while the remaining three concern different elements of irreplaceability.

The datasets used in identifying Madagascar KBAs is composed by 538 threatened species (CR, EN, and VU) on the IUCN Red List 2006 and come from the most recent scientific information such as species distribution and conservation status from the relevant global species assessments, Global Mammal Assessment (GMA), Global Amphibian Assessment (GAA), Global Marine Species Assessment (GMSA) and additional data from universities, other research institutions and field biologists. Based on the new publication of Frost in 2006, we used the new taxonomy names for some globally threatened species (Tab. II).

Alliance for Zero Extinction sites are defined based on the following criteria: 1) Endangerment: An AZE site must contain at least one Endangered (EN) or Critically Endangered (CR) species, as listed on the IUCN Red List, 2) Irreplaceability: An AZE site should only be designated if it is the sole area where an EN or CR species occurs, or contains the overwhelming proportion of the known resident population of the EN or CR species for at least one life history segment (e.g., breeding or wintering), and 3) Discreteness: The area must have a definable boundary within which the character of habitats, biological communities, and/or management issues have more in common with each other than they do with those in adjacent areas (Ricketts et al., 2006). Data from the Alliance for Zero Extinction website and from other scientific publications are analyzed and updated taxonomically.

RESULTS

Since 2004, Conservation International's Madagascar Program and partners have been identifying KBAs. The best available data has been used to inform this process. Based on the 538 threatened species on the IUCN Red List 2006, we identified 164 KBAs covering eight taxonomic groups. Of these, 50 (30.5%) are official protected areas while 114 KBAs still require management and governance structures to safeguard these sites (Fig. 1). Alliance for Zero Extinction sites represent the highest priority subset of KBAs, these sites contain the last remaining populations of Critically Endangered or Endangered species (Ricketts et al., 2006). Among the 164 KBAs, 16 Alliance for Zero Extinction sites and nine of these are officially protected (Tab. I). There are currently nine AZE sites covering thirteen amphibians species in Madagascar. Five of them are already protected; an additional four sites will be afforded official protection status under the new Madagascar protected area system (SAPM).

Among the 164 KBAs, 43 are triggered by amphibians (Tab. II). For this analysis, we used amphibian data covering nine Critically Endangered species, 22 Endangered species, and 31 Vulnerable species. The nine CR species are distributed across nine KBAs (Fig. 2): Ambohitantely Special Reserve, Ankaratra Massif, Antoetra, Fierenana, Ibity the future reserve, Isalo National Park, Itremo the future reserve, Manombo Special Reserve, Montagne des Français, and the Torotorofotsy Wetlands. Of these nine sites, only three are officially protected KBAs. Overall, 19 out of 43 amphibian KBAs are officially protected and nine out of 43 are in the process of receiving official. The remaining 15 Amphibian KBAs are outside the officially and temporary protected areas and protected needs to be

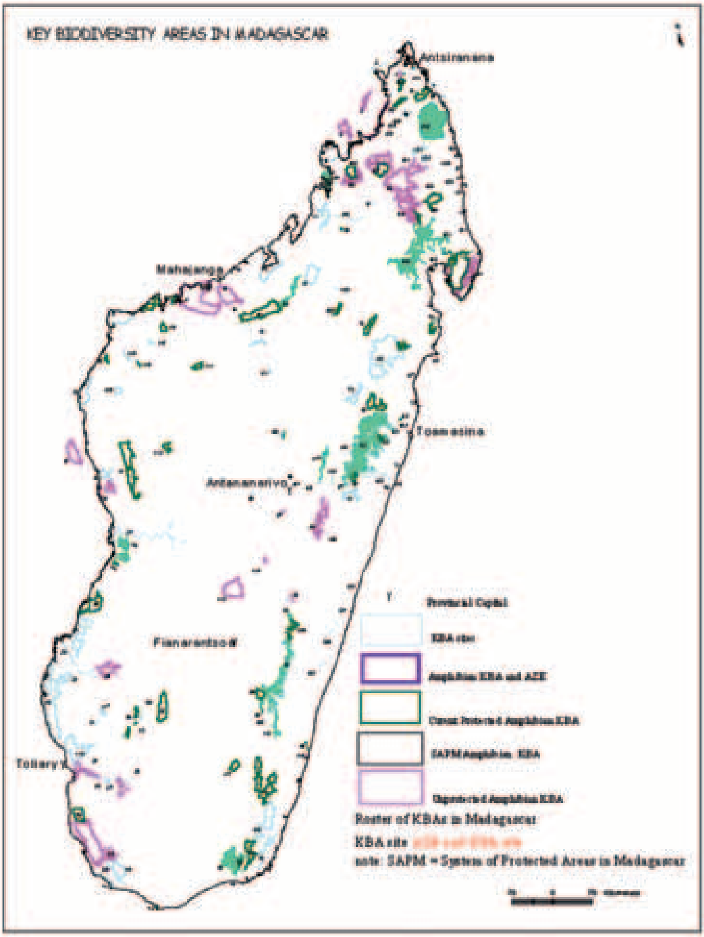

Fig. 1. Map of all Key Biodiversity Areas and Alliance for Zero Extinction sites in Madagascar.

afforded to these sites. Among the 15 unprotected Amphibian KBAs, Torotorofotsy wetland, Itremo, Ankaratra Manjakatompo, and Antoetra are the highest priority sites to be protected under the Durban Vision. These sites contain three critically endangered species *Mantella aurantiaca*, *Mantella cowani*, and *Mantidactylus pauliani*, that are not protected elsewhere in Madagascar (Vences et al., 2002; Andreone & Randrianirina, 2003). Another unprotected site, Nosy Be and satellite islands, where the habitat of two Vulnerable amphibian species *Rhombophryne testudo* and Stumpffia pygmaea, form the next tier of priority sites to be protected (Andreone et al., 2003. Glaw & Vences, 2002).

Sites	Protection status	Globally Threatened Species
Ambohitantely SR	Protected Area	*Stumpffia helenae* *
Ampitambe Forest		*Eliurus penicillatus*
Andohahela NP	Protected Area	*Spinomantis microtis**
Andringitra NP	Protected Area	*Mantidactylus madecassus*
Ankarafantsika SNR / Ampijoroa FS	Protected Area	*Macrotarsomus ingens* *Microcebus ravelobensis*
Ankaratra Massif	Temporary protection pending gazettement	*Boophis williamsi* * *Mantidactylus pauliani* *
Anosy Mountains	Temporary protection pending gazettement	*Anodonthyla rouxae* *
Baie de Baly NP	Protected Area	*Astrochelys yniphora*
Daraina	Temporary protection pending gazettement	*Propithecus tattersalli*
Fierenana	Temporary protection pending gazettement	*Scaphiophryne boribory**
Isalo NP	Protected Area	*Mantella expectata** *Scaphiophryne gottlebei* * *Gephyromantes corvus**
Alaotra Lake	Temporary protection pending gazettement	*Aythya innotata* *Tachybaptus rufolavatus*
Menabe Forest	Temporary protection pending gazettement	*Aglyptodactylus laticeps* * *Hypogeomys antimena* *Pyxis planicauda*
Montagne d'Ambre SR and NP	Protected Area	*Monticola erythronotus*
Tsaratanana SNR	Protected Area	*Platypelis alticola* * *Plethodonhyla guerntherpetersi* *
Tsimanampetsotsa SNR	Protected Area	*Galidictis grandidieri*

Tab. I. Globally threatened species according to the Madagascar Alliance for Zero Extinction and their occurrence in relevant sites. Data obtained from Andreone (1992), Andreone et al. (2005), Glaw & Vences (1994), Vences et al. (2002), Anonymous. (2001 CAMP Report), Ricketts et al. (2006), Glaw & Vences, 2007 (in Press). and website www.zeroextinction.org. Amphibian taxa are marked with an asterisk. FS = Forestry Station, NP = National Park; SR= Special Reserve, SNR = Strict Nature Reserve.

Although KBAs criteria fit well in identifying important bird areas and for other taxonomic groups, it is difficult to apply the congregatory and biome-restricted criteria to amphibians given limited knowledge. However, we identified important areas for amphibians using the threatened species criterion given the alarming habitat destruction, and the urgent need for increasing protected areas in Madagascar.

DISCUSSION

Using the best available amphibian data, a preliminary set of important amphibian areas are defined from this process. Having information on the number, the location and the conservation status of amphibian Key Biodiversity Areas and AZE sites in Madagascar is vital to the successful implementation of the Sahonagasy Action Plan. The goal of this action plan is to protect the unique amphibian fauna of Madagascar. However, this information of KBAs for amphibian must be refined and updated regularly as a new data becomes

Amphibian Key Biodiversity Areas	Threatened Amphibians within KBAs	RLCategory
Ambohitantely SR	*Mantella crocea*	EN
	Stumpffia helenae	CR
Andohahela NP - Parcel I	*Anodonthyla montana*	VU
	Anodonthyla rouxae	EN
	Boehmantis microtympanum	EN
	Boophis haematopus	VU
	Madecassophryne truebae	EN
	Spinomantis bertini	VU
	Spinomantis brunae	EN
	Spinomantis elegans	VU
	Spinomantis guibei	EN
	Spinomantis microtis	EN
Andringitra NP	*Anodonthyla montana*	VU
	Mantidactylus madecassus	EN
	Plethodontohyla coronata	VU
	Spinomantis bertini	VU
Andringitra Pic d'Ivohibe Future SAPM	*Plethodontohyla coronata*	VU
	Spinomantis bertini	VU
	Spinomantis elegans	VU
Andringitra Ranomafana Future SAPM	*Mantidactylus madecassus*	EN
	Spinomantis elegans	VU
Angavokely Forest Station	*Plethodontohyla tuberata*	VU
Anjanaharibe Sud-Marojejy future SAPM	*Gephyromantis klemmeri*	VU
	Gephyromantis rivicola	VU
	Gephyromantis schilfi	VU
	Gephyromantis striatus	VU
	Platypelis mavomavo	EN
	Platypelis tetra	EN
	Platypelis tsaratananaensis	VU
Anjanaharibe-South SR	*Gephyromantis klemmeri*	VU
	Platypelis mavomavo	EN
	Platypelis tetra	EN
	Platypelis tsaratananaensis	VU
	Plethodontohyla serratopalpebrosa	VU
	Rhombophryne coronata	VU
Ankaratra Massif	*Boophis williamsi*	CR
	Mantidactylus pauliani	CR
	Plethodontohyla tuberata	VU
Anosy Mountains	*Anodonthyla rouxae*	EN
	Boehmantis microtympanum	EN
	Madecassophryne truebae	EN
	Spinomantis bertini	EN
	Spinomantis elegans	VU
	Spinomantis guibei	EN
	Spinomantis microtis	EN
	Plethodontohyla tuberata	VU
Antoetra	*Mantella cowani*	CR
Bemaraha Tsingy NP and SNR	*Gephyromantis corvus*	EN
Betampona SNR	*Boophis blommersae*	VU
	Gephyromantis klemmeri	VU
	Gephyromantis rivicola	VU
	Gephyromantis tandroka	VU
	Rhombophryne coudreaui	VU

Fierenana	*Mantella crocea*	EN
	Mantella milotympanum	CR
	Mantella pulchra	VU
	Scaphiophryne boribory	EN
Ibity Future SAPM		
	Boophis williamsi	CR
Isalo NP	*Gephyromantis corvus*	EN
	Mantella expectata	CR
	Scaphiophryne gottlebei	CR
Itremo Future SAPM	*Mantella cowani*	CR
Kalambatritra SR	*Spinomantis guibei*	EN
Kirindy-South Forest-Complex	*Aglyptodactylus laticeps*	EN
Mananara-North NP	*Mantella pulchra*	VU
Manongarivo Future SAPM	*Gephyromantis ambohitra*	VU
	Platypelis milloti	EN
	Spinomantis massorum	VU
Manongarivo SR	*Boophis andreonei*	VU
	Gephyromantis ambohitra	VU
	Platypelis milloti	EN
	Spinomantis massorum	VU
Mantadia NP and Analamazaotra SR	*Mantella crocea*	EN
	Rhombophryne coronata	VU
	Scaphiophryne marmorata	VU
Manombo	*Mantella viridis*	CR
Marojejy NP	*Gephyromantis klemmeri*	VU
	Gephyromantis rivicola	VU
	Gephyromantis salegy	VU
	Gephyromantis schilfi	VU
	Gephyromantis silvanus	EN
	Gephyromantis striatus	VU
	Gephyromantis tandroka	VU
	Platypelis tetra	EN
	Plethodontohyla coudreaui	VU
	Plethodontohyla serratopalpebrosa	VU
	Rhombophryne coudreaui	VU
	Spinomantis elegans	VU
Marotandrano	*Scaphiophryne boribory*	EN
Masoala	*Gephyromantis klemmeri*	VU
	Gephyromantis salegy	VU
	Gephyromantis striatus	VU
	Platypelis mavomavo	EN
	Platypelis tetra	EN
	Rhombophryne coudreaui	VU
Menabe Forest-Complex	*Aglyptodactylus laticeps*	EN
Midongy-South NP	*Boehmantis microtympanum*	EN
Montagne d"Ambre Future SAPM	*Boophis blommersae*	VU
Montagne d'Ambre NP and SR	*Boophis blommersae*	VU
	Gephyromantis ambohitra	VU
	Gephyromantis horridus	EN
Montagne des Francais Future SAPM	*Mantella viridis*	CR
Nosy Be and satellite islands	*Boophis jaegeri*	VU
	Gephyromantis horridus	EN
	Platypelis milloti	EN

Nosy Mangabe SR	*Gephyromantis silvanus*	EN
	Gephyromantis webbi	EN
Ranomafana NP	*Mantella bernhardi*	EN
	Mantella madagascariensis	VU
	Plethodontohyla brevipes	EN
	Spinomantis elegans	VU
Ranomafana North Future SAPM	*Mantella bernhardi*	EN
	Mantella madagascariensis	VU
	Plethodontohyla brevipes	EN
	Spinomantis elegans	VU
Sahamalaza Bay Wetlands SAPM	*Boophis jaegeri*	VU
Torotorofotsy wetlands	*Mantella aurantiaca*	CR
	Mantella crocea	EN
Tsaratanana Future SAPM	*Gephyromantis horridus*	EN
	Gephyromantis massorum	VU
	Platypelis alticola	EN
	Platypelis milloti	EN
	Platypelis tsaratananaensis	VU
	Plethodontohyla guentherpetersi	EN
	Plethodontohyla serratopalpebrosa	VU
Tsaratanana SNR and adjacent areas	*Boophis andreonei*	VU
	Boophis blommersae	VU
	Gephyromantis horridus	EN
	Platypelis alticola	EN
	Platypelis milloti	EN
	Platypelis tsaratananaensis	VU
	Plethodontohyla guentherpetersi	EN
	Plethodontohyla serratopalpebrosa	VU
	Plethodontohyla tuberata	VU
	Spinomantis massorum	VU
Tsaratanana-Marojejy Future SAPM	*Gephyromantis ambohitra*	VU
	Gephyromantis horridus	EN
	Gephyromantis tandroka	VU
	Platypelis alticola	EN
	Platypelis tsaratananaensis	VU
	Plethodontohyla guentherpetersi	EN
	Plethodontohyla serratopalpebrosa	VU
	Spinomantis massorum	VU
Tsitongambarika Classified Forest	*Madecassophryne truebae*	EN
Zahamena-Ankeniheny SAPM	*Mantella crocea*	EN
	Rhombophryne coronata	VU
	Scaphiophryne marmorata	VU
	Spinomantis phantasticus	VU

Tab. II. Key Biodiversity Areas for Amphibians. Data obtained from Andreone (1992), Andreone et al. (2005), Andreone et al. (2006), Glaw & Vences (1994), Vences et al. (2002), Anonymous. (2001 CAMP Report), Ricketts et al. (2006), and Glaw & Vences (2007). FS = Forestry Station, NP = National Park; SR= Special Reserve, SNR = Strict Nature Reserve.

available. At this time, *Mantella* distribution in Madagascar is reviewed by M. Vences and his team; results are in press and will be used to update this Amphibian Key Biodiversity Areas. Of critical importance are the sites Torotorofotsy wetland (Andreone et al., 2005), Itremo, Antoetra, and Ankaratra Manjakatompo (Vences et al., 2002; Andreone & Randrianirina, 2003) which are the highest priority for conservation of amphibian KBAs. Information from this process would be useful to the establishment and the implementation of the management plans of existing and planned protected areas that cover amphibian KBAs. It is critical that the "Vision Sahona Gasy" advocates for the urgent protection of these KBAs in order to ensure that Malagasy amphibian biodiversity is conserved.

RÉSUMÉ

Les Key Biodiversity Areas comme un instrument pour l'identification des sites prioritaires pour la conservation des amphibiens à Madagascar.

Dans cet article les Key Biodiversity Areas (KBAs) ont été utilisées pour assurer une protection efficace de la biodiversité de Madagascar, en tant que comme instrument qui supporte l'identification des nouvelles aires protégées de Madagascar. Les KBA ont été localisées en se basant sur la présence d'espèces menacées globalement d'apres la Liste Rouge des Espèces Menacées de l'UICN, une aire de distribution limitée et les espèces limitées a niveau bio-régional. Jusqu'à aujourd'hui 164 KBA ont été désignées à Madagascar sur la base de 8 taxons, dont 43 sur la base de la présence d'amphibiens. Le sous-ensemble des KBA de majeure priorité est l' Alliance for Zero Extinction (AZE), qui comprends les populations à danger critique (Critically Endangered; CR) ou en danger (Endangered; EN). Pour les amphibiens il y a 9 lieux de l'AZE qui couvrent douze amphibiens de Madagascar. Sept parmi ces lieux sont déjà protégés, bien que autres quatre vont recevoir une protection dans le cadre des nouvelles aires protégées.

Mots clés: Aires protegées, Amphibiens, Alliance for Zero Extinction, Key Biodiversity Areas, Madagascar.

Zo Lalaina Rakotobe, Luciano Andriamaro, Rollande Finoana
Harison Rabarison, Harison H. Randrianasolo
Madagascar Center for Biodiversity Conservation
Conservation International
BP 5178, Antananarivo (101), Madagascar
Email zrakotobe@conservation.org

David H. Knox
Conservation International
Centre for Biodiversity Conservation
Kirstenbosch Botanical Gardens
Private Bag X7, Claremont 7735, South Africa
Email d.knox@conservation.org

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 397-410

David R. VIEITES[1,2 *], Sandra NIETO-ROMÁN[2,3], Miguel VENCES[4]

Towards understanding the spatial pattern of amphibian diversity in Madagascar

ABSTRACT

We summarize the current state of the exploration of the spatial pattern of the amphibian diversity in Madagascar based on a comprehensive database of specimen and locality data records for Malagasy amphibians, containing 2154 unique records. Data were gathered from museum voucher specimens, literature and from recent field work, and geo-referenced when possible. The recent increase in species descriptions and phylogenetic work challenged the validity of a considerable amount of species records, especially in cases where cryptic species are being discovered. Many of the records from literature or museums could not be precisely assigned to species in the light of novel taxonomic knowledge, and thus had to be discarded. Our analysis shows that for many species we have fewer than ten reliable records, with 130 species having only one or two records. Sampling effort has been traditionally biased towards protected areas, their surroundings and sites along major roads. We analyzed the potential effects of including unverified data on modeling species distribution of Malagasy amphibians, and we identify target areas for exploration to complete our knowledge of the biogeography of these organisms.

Key words: Amphibians, Distribution modelling, Locality records, Madagascar, Maxent.

INTRODUCTION

Madagascar harbors a large number of amphibian species, and is considered one of the hotspots for amphibian global diversity (Stuart et al., 2004). However, little is known about most of those species (Glaw & Vences, 1994). To develop an effective conservation strategy for the amphibians of Madagascar it is necessary to inventory all species (Vallan, 2000; Andreone et

[1] Museum of Vertebrate Zoology, Berkeley.
[2] Department of Integrative Biology, Berkeley.
[2] Departamento de Biología y Ecología Animal. Vigo.
[2] Technical University of Braunschweig.
* Corresponding author; web: vieites.berkeley.edu

al., 2005), solve their taxonomy, and define their distribution ranges. These three goals are linked, and work to achieve them is currently in progress. Inventories and rapid assessments have been carried out in many regions, mainly focused on protected areas (e.g., Andreone et al., 2000, 2001, 2003; Andreone & Randriamahazo, 1997; Nussbaum et al., 1999; Rakotomalala, 2002; Raselimanana et al., 2000; Raxworthy et al., 1996, 1998; Vences et al., 2002). The efforts to clarify the phylogenetic relationships of Malagasy amphibians, and the rate of discovery of new amphibian species in Madagascar, have never been as high as during the last decade (Glaw & Vences, 2006; Köhler et al., 2005; Vences et al., 2003), which is changing our current view on Madagascar's amphibian diversity and biogeography. Although many of the newly discovered species are genetically, bio-acoustically and morphologically different, many are difficult to distinguish by morphology from sibling species (Glaw et al., 2001; Köhler et al., 2005), their discovery questioning the validity of some species identifications in inventories and rapid assessments. The outcome is that the knowledge on the ranges of most species is changing rapidly, usually because of their splitting into several species. Together with true new discoveries of endemic taxa of restricted ranges (Glaw et al., 2006), these data claim for a revision of our assumptions on the spatial distribution of Madagascar's amphibian diversity (i.e. Andreone et al., 2005; Lees et al., 1999).

Clarifying the spatial distribution of the amphibian fauna in Madagascar is critical to understand the patterns of richness and endemism in space, and to define priority areas for conservation. Here, we analyze the current knowledge on the spatial distribution of Malagasy amphibians, explore the potential effects of the new discoveries in assessing potential distributions of species, and identify priority target regions for future field surveys.

MATERIAL AND METHODS

We assembled a comprehensive locality database for all the amphibian and reptile species of Madagascar. Locality data were gathered from different sources, including voucher specimen data from museum collections, own GPS readings from fieldwork, and literature. Almost all available literature was reviewed (see Vences et al., in press in this volume) and locality data, when available, were incorporated into the database. Many of the localities reported in the literature, or from old museum records, were too vague to be properly geo-referenced. For every geo-referenced locality we incorporated an uncertainty value following Chapman and Wieczorek (2006), allowing us to filter imprecise localities for GIS modeling analyses. These kinds of data are suitable to develop potential distribution models and biodiversity estimates for this fauna. Although dozens of records from different specimens, years or researchers, may be available for a species at a particular location, we considered them as duplicates for the purposes of this paper, only one species record per locality being considered.

In order to assess the potential effect of taxonomic uncertainty on predicting

Malagasy amphibian species' distributions, we performed a test with one of the commonest species in eastern rainforests. *Boophis luteus* is a medium-sized green arboreal frog that is found in primary and secondary rainforests across the central and southern part of the island (Glaw & Vences, 1994). The occurrence of *B. luteus* in northern parts of the island, like the Marojejy region, has not been confirmed although the species had been previously reported there (e.g., Blommers-Schlösser & Blanc, 1991). Several species were recently recognized from the *B. luteus* group (Andreone, 1993, 1996; Andreone et al., 1995; Glaw & Thiesmeier, 1993; Glaw & Vences, 2002). Recent genetic and bioacoustic analyses allowed us to confirm the presence of *B. luteus* in some localities and discriminate among other species of this group. As a result, some of the previous literature and museum records assigned to this species are now taxonomically unclear, because a reliable distinction of preserved specimens is impossible. Hence, we merged them under the name of "undetermined *Boophis luteus* complex". To test the effect of the inclusion of those records on predicting the potential distribution of the species, we performed two separate analyses with and without these uncertain locality records.

We used nineteen climatic variables from the WorldClim database version 1.4 (Hijmans et al., 2005), with potential evapotranspiration and percentage of forest cover in 2000, as predictors for the environmental niche models. The Worldclim dataset was created by interpolation of observed world weather station data, using a thin-plate smoothing spline and longitude, latitude and elevation as independent variables (Hutchinson, 1995), being the current version 1.4 more accurate than previous ones in some regions, because of the inclusion of more weather stations. The climatic variables employed in the models were annual mean temperature, mean diurnal temperature range, isothermality (monthly/annual temperature range), temperature seasonality (standard deviation across months), maximum temperature of warmest month, minimum temperature of coldest month, temperature annual range, mean temperature of wettest, driest, warmest and coldest quarters, annual precipitation, precipitation of wettest and driest months, precipitation seasonality (coefficient of variation), and precipitation of wettest, driest, warmest and coldest quarters.

From all the environmental niche modeling methods currently available, we chose Maxent (version 2.3, Phillips et al., 2006), as it outperformed others in a recent cross-comparison analysis (Elith et al., 2006), and with small sample size datasets (Hernández et al., 2006). Maxent finds the distribution of maximum entropy subject to constraints imposed both by the observed distribution of the species, and the environmental conditions across the defined study area, and estimates the likelihood of a species being present. It computes a probability distribution across the defined study area, for which it requires presence and background absence data. As background pseudo-absence data, we randomly selected 10000 data points across Madagascar. Real absence data is not yet available for Madagascar, as detectability of many tropical amphibian species is very low. We run Maxent using 75% of the data for testing and 25% for training, with default values except the regularization multiplier value which was set to 0.25. The output predicted distributions are in cumulative format, in which the output value at a grid cell is the sum of the probabilities of all grid cells with no higher probability than the grid cell, times 100 (Phillips et al., 2006). Grid cell values can vary from zero (not suitable) to 100 (highly suitable). In order to evaluate the performance of the model, we calculated the area under the Receiver Operating Characteristic curve (AUC), which measures the ability of the model to discriminate between sites were the species is present versus sites were is absent (Hanley & McNeil, 1982). It ranges from 0 to 1, being AUC scores above 0.7 considered good model performance (Fielding & Bell, 1997).

RESULTS

Our database includes 452 spatially geo-referenced localities with 2154 unique valid amphibian records adequate for distribution modeling analyses. Most of these records were gathered from fieldwork developed during the last decade by MV, DRV and F. Glaw. About 700 additional unique records were discarded, being not suitable for such kind of analyses, because of the lack of precise geographic coordinates, or due to taxonomic uncertainty.

Figure 1 shows the spatial distribution of localities, and the number of species recorded in each locality. The geo-referenced localities with amphibian data associated were distributed all across the island, mainly in the eastern rainforests (Fig. 1). However, most of them were within National Parks, other protected areas, their surroundings or close to the roads connecting them with major towns. The most densely sampled areas were the protected areas of Mantadia-Analamazaotra, Ranomafana, Andringitra, Andohalela, Nosy-Be, Montagne d'Ambre and their surroundings. Many of the localities sampled are close to the roads that connect Antananarivo with Andasibe, Antananarivo with Fianarantsoa-Ranomafana, or Fianarantsoa with Toliara, where almost every locality is by the road. Large areas of natural habitat remain to be explored, mainly between national parks in eastern Madagascar. These include a large portion of rainforest between Mantadia-Analamazaotra and Masoala, from where very few localities with records exist, and 11 small reserves across the island for which no confirmed amphibian records have been published.

The number of species recorded per locality was higher in reserves than in other areas. In 87% of the localities, fewer than ten species were recorded. In some areas, many of the localities were very close to each other but not all species occurring in the general area were recorded from each of these localities, resulting in relatively low numbers of species per locality. The mean number of species per locality was 4.6 ± 5.7 (mean ± SD). The total number of valid records per species is shown in figure 2. The mean number of locality records per species was 6.5 ± 8.7 (mean ± SD), and only 16.7% of species had more than 10 locality records. More than half of the species had fewer than 5 records (55.4%), most of the unique records corresponding to recently described species.

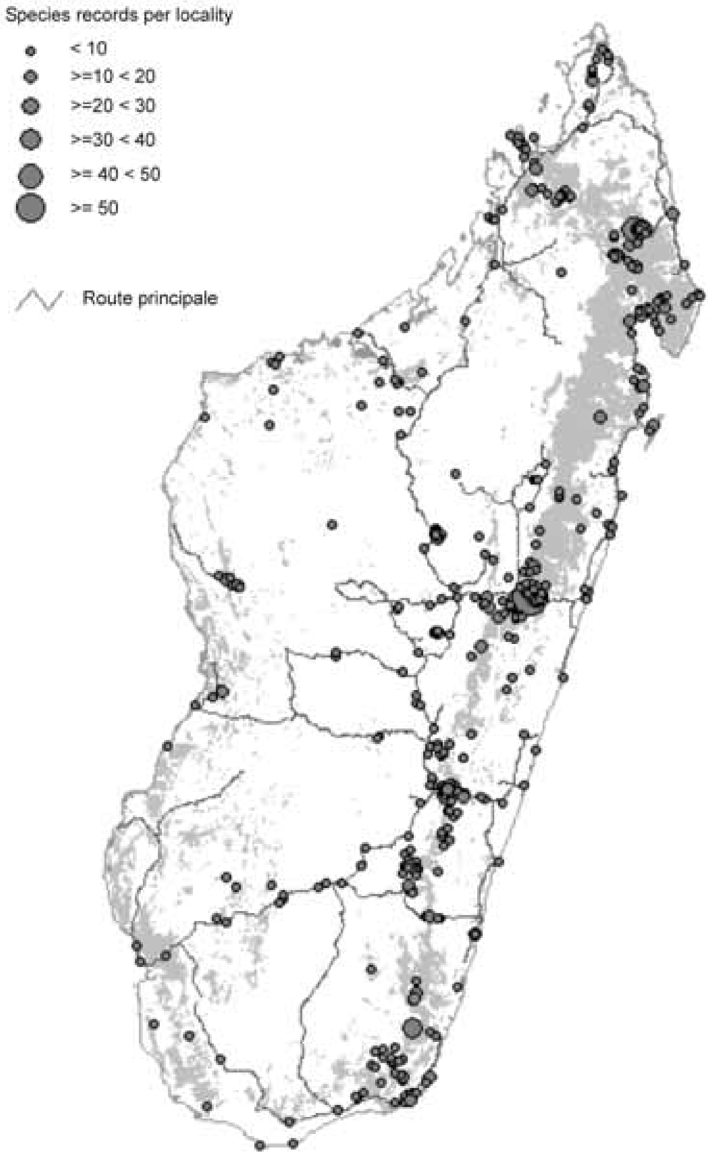

Fig. 1. Plot of the number of individual and non-duplicated geo-referenced species records per locality in our database. Circle size is proportional to the number of records. Grey represents remaining rainforest where most of amphibian diversity occurs. Major roads (Routes principales) are depicted.

The potential distribution models for *Boophis luteus* and for the *B. luteus* species complex are depicted in figure 3. The AUC values for 25% testing data were very high in both cases (0.864 and 0.932 respectively), suggesting the models performed well to predict the distributions. When only confirmed records were used to predict the distribution of *B. luteus* (Fig. 2 C), the model suggested the most suitable areas for the species are in the eastern rainforests south of Zahamena and some central areas. Isalo is predicted, although with low suitability. Some over-prediction occurred in areas like Marojejy or Masoala but not further north and with low suitability values. When all confirmed and non-confirmed data were included (Fig. 2 D), the species is still predicted in the same areas, but the range extending further north and suggesting a continuous distribution from Andohahela to Marojejy, and also in Montagne d'Ambre. The distribution range obtained from the Global Amphibian Assessment (Fig. 2 B, IUCN, 2006) is a coarse representation of the species range, with less detail and a ca. 200 km extension further north compared with the model. This extension corresponds to two localities in which the species has been cited but for which we have no data to confirm the records (Fig. 2 A).

DISCUSSION

Taxonomy in progress and identification verifiability

Over 240 species of amphibians have been formally described in Madagascar so far, about one third of them during the last decade (Köhler et al., 2005). However, from molecular, bioacoustic and morphological data, our database currently contains about 126 additional species more that need formal description. This suggests an increment of 54% respect to the current number, a higher increase than during the last decade, and there are many additional taxa that probably have to be added to this list. These new discoveries enlighten the patterns of amphibian richness and endemism on the island. This previously unrecognized diversity challenges our ability to properly identify these taxa in the field. Identifications based on morphology or colorations are unreliable (as we further discuss in another chapter in this volume). Molecular techniques have proven to be of much help in identifying Malagasy amphibian species and seem to be more successful than any other approach (Thomas et al., 2005, Vences et al., 2005). However, there is no doubt that a combination of methods is needed to ascertain the identification of amphibians in Madagascar. Fieldwork, specimen vouchers, call recordings and tissues for DNA sequencing analyses are vital for filling the gaps in species taxonomy and identification, because many more species are expected to be discovered from poorly surveyed areas.

Current efforts are in progress to clarify the taxonomy of Malagasy amphibians, while we are learning more about the distribution of these species on the island. New species descriptions, large unexplored areas, and low number of records per species is a common situation in tropical areas, which

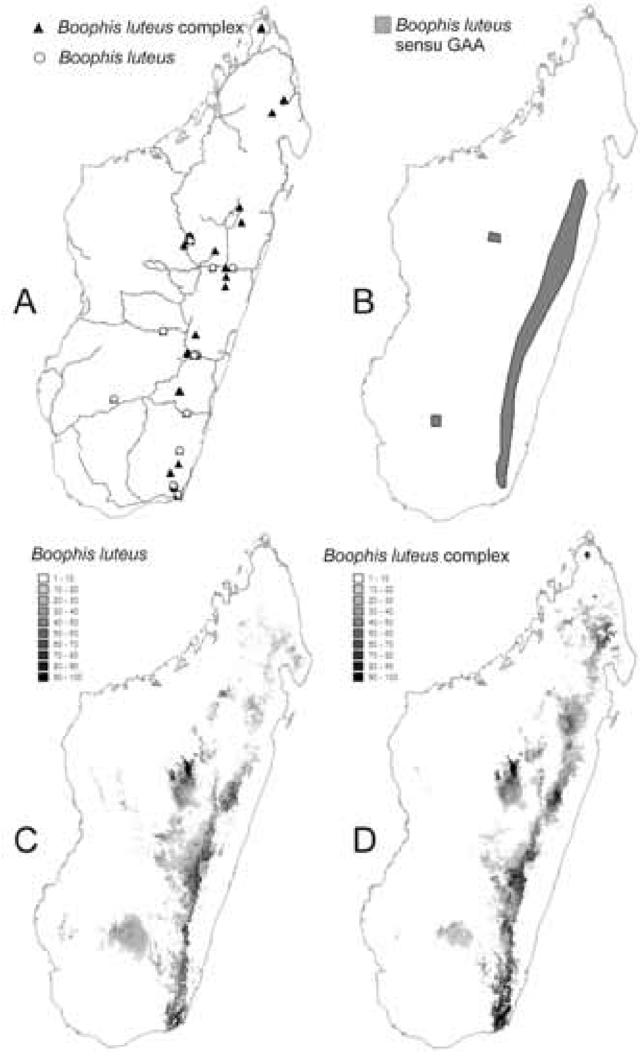

Fig. 2. Locality records and distribution models for *Boophis luteus*. (A) White circles represent the confirmed records for this species in Madagascar, while black triangles represent unconfirmed records previously assigned to the species. (B) Distribution of *B. luteus* according to the Global Amphibian Assessment based on expert opinion. (C) Potential distribution model for *B. luteus* using confirmed records only. Suitability values per grid cell go from cero (not suitable, light grey) to 100 (very suitable, black) (D) Potential distribution model for *B. luteus* complex including confirmed and unconfirmed records.

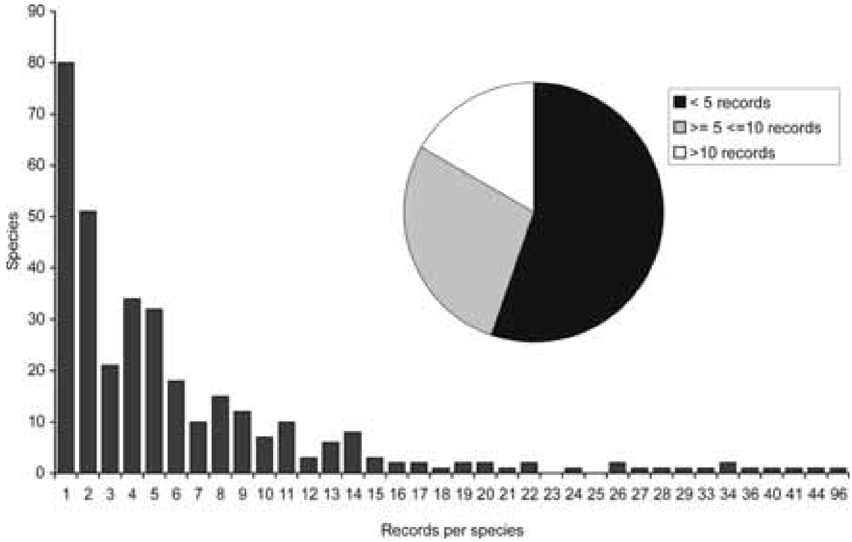

Fig. 3. Histogram showing the number of reliable locality records per species of Malagasy amphibians compiled in our database.

difficult species' distribution modeling and conservation planning. Different kinds of distribution data (i.e. point locality, geographic ranges), usually have associated commission and omission errors (Rondini et al., 2006), which can influence conservation planning. As we have shown in the case of a common species like *Boophis luteus*, any attempt to model species distributions using non-validated records can lead to seriously wrong predictions and needs to be strictly avoided. If problems are already detected with common and well-known species, we expect considerable difficulties for the more poorly known species.

Current pattern of amphibian diversity

The geographic pattern of amphibian diversity in Madagascar is poorly understood. Few biodiversity analyses have been done to analyze the spatial pattern of Malagasy amphibian diversity based on previous data (Lees, 1996; Lees et al., 1999; Andreone et al., 2005). New discoveries and sampling effort can bias these analyses, as some areas, like Mantadia or Ranomafana National Parks, received much more attention than others, which resulted in a higher number of species recorded per locality (Fig. 3). Modeling the distribution of the species may be a way to circumvent the problems caused by the biased distribution of sampling efforts across the island.

For many species we do not have enough information to directly assess their distribution ranges, hence to perform accurate biodiversity, hotspot or endemism analyses. The number of records per species is low, mainly due to two reasons. First, many areas have been extensively sampled, while others still need to be surveyed. Large areas in the East, North and West parts of the island likely hold high species diversity which requires confirmation through sampling. Exploration of these areas will lead to the discovery of new species and to range expansions for many species, but in many cases access to these areas is not easy.

Second, the new taxonomic developments are showing that what we thought to be one species often is in fact a complex of several species. Hence, all the previous records for that species have to be re-evaluated and distributed among the "new" taxa. In some cases this is possible but in others not, resulting in a high number of records that can be assigned to species groups but not precisely to any species. As a consequence it is not possible to model several species due to limited records after taxonomic revisions. Ten records is usually considered a low number to perform distribution modeling, and five would be an absolute minimum (Hernández et al., 2006), giving suitability estimates that will be helpful to locate areas environmentally similar to those where the species is actually present, but may be not representing the real distribution of the species. Less than five records are available for more than half of the species of Malagasy amphibians, and about 30% of the species have between 5 and 10 records, making the modeling of the distribution of these species difficult without more data. One approach that can be followed in such cases is to model clades defined through molecular phylogenies, instead of species units.

Inventories are needed in new areas to complete the distribution range of many species, and increase the number of records per species, which would allow for more accurate modeling analyses. However, models based on limited records are still useful as they often overpredict species occurrences leading us to priority sites for conducting surveys for those species (Raxworthy et al., 2003).

Target regions for future inventory work.

A preliminary test of models for species with more than 5 records, with a detailed analysis of the distribution of localities from figure 1 and remnant natural habitats, suggested several target regions which merit further surveys in the near future. From North to South they would be the remaining habitat corridors between Tsaratanana and Ankarana, and Tsaratanana and Marojejy, which have been poorly explored and likely sustain contact zones between biogeographic regions. The Masoala peninsula has only been partially explored thus far, and from collaborative molecular work with F. Andreone it is clear now that many of the taxa from this area are undescribed new species. Between roughly Marojejy and Mantadia there are ca. 500 km of rainforest which have been poorly explored, with only few records from Zahamena and Ambatovaky in the middle and no published records thus far from the large new Makira Reserve. This area could hold a huge diversity of species and multiple potential geographic range expansions of southern and northern species need to be confirmed there. The corridors Mantadía-Ranomafana and Ranomafana-Andringitra need further exploration because few confirmed records are available from the areas in between these biodiversity hotspots. In the South, Andohahela has been extensively sampled, but the area from Midongy du Sud to Andringitra needs further work, and the whole Anosy and Vohimena chains urgently need to be inventoried using also bioaocustic and molecular methods. Huge range extensions have been discovered by sampling low elevation localities in the east coast, and more work is needed to assess the diversity of species present in low elevations also outside primary habitats. In the West, species distribution modeling suggests range extensions for many species between Ankarafantsika and Manongarivo. Although the diversity of amphibian species in the West will be lower than in the eastern rainforests, many of the western species are locally endemic to highly threatened forest fragments.

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RÉSUMÉ

Vers la compréhension des patterns spatiaux de la diversité pour les amphibiens de Madagascar.

Nous résumons le statut curent de l'exploration des patterns spatiaux pour la diversité des amphibiens à Madagascar, en se basant sur une base de données complet des spécimens et des localités de collecte, avec 2154 records uniques. Les données ont eté récoltés pour les spécimens de musée, de la littérature et le travail de terrain récent, et géoréferencés quand possible. L'augmentation récente dans le taux de description d'espèces et de travaux phylogénétiques ont mis en doute une bonne quantité de données de présence des espèces, puisque plusieurs espèces cryptique ont été décrites. Beaucoup parmi les données bibliographique ou muséologiques peuvent pas être assignés aux espèces sur la base de la nouvelle connaissance taxinomiques, et pourtant on du être éliminés. Notre analyse montre que pour plusieurs taxons nous avons moins de dix données fiables, avec 130 espèces avec moins de 2 données. L'effort d'échantillonnage a été traditionnellement orienté vers les aires protégées ou leurs entours, ou sur des sites a coté des routes principales. Nous avons pourtant analysé les effets potentiels de considérer des données non-vérifiés pour modéliser la distribution des espèces, avec l'identification de aires-cible pour compléter notre connaissance de la biogéographie de ces organismes.

Mots clés: Amphibiens, Données de localité, Madagascar, Maxent, Modélisation de la distribution.

David R. Vieites
Museum of Vertebrate Zoology, 3101 Valley Life Sciences Building.
Department of Integrative Biology
3060 Valley Life Sciences Building
University of California
Berkeley, CA 94720-3160, USA
Email vieites@berkeley.edu

Sandra Nieto-Román
Departamento de Biología y Ecología Animal
Campus Lagoas Marcosende
Universidad de Vigo. 36200. Vigo, Spain

Miguel Vences
Zoological Institute, Technical University of Braunschweig, Spielmannstr 8, 38106 Braunschweig, Germany

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 411-418

Denis Vallan[1], Olivier Behra[2]

Les petites parcelles de forêt: haute diversité spécifique, faible protection. Que leur réserve l'avenir?

ABSTRACT

Small forest remnants: High diversity low protection. What's about their future?

Beside habitat loss for many amphibians and other animal species the fragmentation of its habitat is one of the biggest threats. In Madagascar there are many cases in which small remnants harbour either a high amphibian diversity or amphibian species that are highly endangered. Several of these small habitats don't benefit from a special legal protection regulation. What are the strategies we could apply to allow the concerned species a long-term survival in situ? The range of strategies is broad, each implying a set of consequences. The case of the region of Vohimana containing the better known forest of An'Ala will be discussed. This forest is among the sites with the highest amphibian diversity in Madagascar. It lies between the "Réserve Spécial" of Analmazaotra, the Mantadia national park and the "Forêt Classée" of Maromiza (Vohidrazana). Surrounded by more or less protected forests the 600 ha sized forest of An'Ala has only since 2002 the efforts of protection of the NGO Man And The Environment. The future of this remnant depends whether it could be connected to other forests and valorised respectively protected. Which path should be treaded to reach the goal to conserve amphibian and other species?

Key words: Conservation, Exploitation, Fragmentation, Habitat loss, Local people, Madagascar, Slash and burn, Tourism, Valorization, Vohimana.

INTRODUCTION

La diversité faunistique et floristique de Madagascar est exceptionnelle et unique au monde (Myers et al., 2000). Longtemps ce fait était perçu surtout par des scientifiques et naturaliste. Dans les dernières années des personnes au delà des cette minorité ce sont rendu compte que le patrimoine naturel

[1] Natur-Museum Luzern.
[2] Man And The Environment Madagascar, Antananarivo.

de Madagascar est un capital important et qu'il faut vivre de ces intérêts plutôt que de l'entamer.

Malheureusement depuis la colonisation et surtout pendant les dernières décennies son environnement a sérieusement été touché par l'homme (Durbin et al., 2003): défrichement des forêts et feu de brousse pour la création de pâturages pour les zébus et l'aménagement des rizières, coupes de bois pour la production de charbon et de bois de construction. De plus des plantes et des animaux sont collectés d'une façon incontrôlée depuis longtemps (observation personnelles, Behra, 1991). Ce sont des activités qui sont souvent indispensables pour permettre aux riverains des forêts de vivre. Mais cette surexploitation des ressources naturelles va avoir des conséquences néfastes non seulement pour la nature mais aussi pour les hommes.

Les politiciens conscients de la valeur économique de l'environnement ont primo promulgué des décrets, arrêtés et lois pour diminuer l'exploitation forestière et deusio en 2003, le président de la république Marc Ravalomanana a annoncé au "World Parks Congres", à Durban en Afrique du sud, son engagement de tripler la surface des aires protégées de Madagascar d'ici 2008 (Norris, 2006).

Des lois et des résolutions sont des bons signes mais le plus important est de développer des stratégies qui permettent aux hommes de prospérer en exploitant le capital naturel d'une façon durable. Rappelons nous en effet qu'Andrianpoinimerina au 18 ème sciècle avait déjà condamner la culture sur brûlis et que le premier code malgache qui interdisait légalement cette culture date de 1881 sous Ranavalo II "on ne peut défricher la forêt par le feu dans le but d'y établir des champs de riz, de maïs ou toute autre culture; les parties antérieurement défrichées et brûlées seules peuvent être cultivées; si des personnes opèrent de nouveaux défrichements par le feu ou étendent ceux déjà existants, elles seront mises aux fers pendant cinq ans" (Mauro & Raholiarisoa, 2000).

Les populations locales n'exploitent pas de grande surface de forêts. Très généralement ils aménagent les cultures d'une façon traditionnelle. De cette façon les forêts ne disparaissent pas complètement laissant des fragmentations forestières. Mais à long terme ces îlots vont disparaître avec leurs richesses naturelles.

Dans cette article on va montrer au moyen de l'exemple du Projet de "Vohimana" à l'est de Madagascar, les problématiques et l'importance des fragments forestiers et donner des solutions comment on peut les protéger en les valorisant.

La problématique des fragments de forêt

En général les fragments forestiers sont beaucoup plus en danger que les grandes surfaces (Vallan, 2000a) mais ils ne sont pas touchés par les mêmes problèmes. Ces problématiques sont respectivement:

- Souvent le fragment forestier ne présente pas le même avantage de protection légale que les grandes forêts qui font partie du réseau des aires protégées de Madagascar,
- Il est rare de pouvoir intégrer le fragment dans un aménagement bien géré d'une région,

- Généralement, il n y a pas des grandes espèces attractives (fréquemment "umbrella species"), du au fait que les grand espèces souvent exigent des territoires de grande taille (observation personnelles),

- Peu de diversité par rapport aux grandes forêts (Vallan, 2000a),

- Les animaux habitant les fragments forestier isolés sont plus touché par une dégénération génétique que les animaux habitant des grandes forêts continues (Hitchings & Beebee, 1998),

- Les fragments de forêts sont très exposés et sensibles à cause de l'"edge effect".

Par contre ces fragments peuvent avoir des rôles très importants dans le reboisement. Ils agissent comme pierre d'étape dans les cas où on relie des forêts par des corridors reboisés. En plus Certains fragments peuvent abriter des espèces rares avec une distribution très réduite (Vallan, 2000b) ou une diversité exceptionnelle (Vallan, 2002).

Les moyens de protection d'une forêt

Pendant les siècles passés on protégeait les sites d'une certaine importance, biologique ou touristique en les déclarants aires protégées, souvent sans impliquer la population locale qui dépendait directement ou indirectement des ressources naturelles. Il parait pourtant important, que le projet de conservation d'un site soit géré avec les populations locales, et il est fondamental qu'elles tirent profit directement de la préservation de leur environnement.

Du a une forte croissance de la population malgache, les ressources naturelles comme les terrains, les bois et aussi les ressources agricoles deviennent de plus en plus rares. Des pratiques traditionnelles telle la culture sur brûlis – une méthode pertinente en cas d'une densité humaine faible – deviennent de plus en plus dangereuse lorsque la population augment. Seules les coupes de bois sélectives peuvent être acceptées. Si les coupes – et en général l'exploitation des ressources – dépassent un certain volume, les ressources disparaissent (Fig. 1), et ce n'est pas juste l'existence de la nature qui est en danger mais les potentialités de développement. Des alternatives doivent être trouvées pour générer les revenus tout en protégeant les ressources. Il y a plusieurs moyens techniques pour résoudre ce problème même si leur mis en œuvre restes souvent embryonnaires dans les projets.

Nous montrons par la suite de ce manuscrit, qu'il existe des moyens pour valoriser un petit fragment de forêt et quelles sont leurs valeurs pour les populations locales et pour la conservation, à l'aide de l'exemple du Projet "Vohimana".

Projet "Vohimana": rapide historique

Entre 1995 et 1997, D. Vallan a conduit une recherche sur l'influence des hommes sur la diversité des anoures dans la région d'Andasibe (Vallan, 2002). Un des sites étudié, connu sous le nom d'An'ala, se trouve a six kilomètres à l'est de Andasibe (Fig. 2). La forêt a une superficie d'environ 6 km^2. On a recensé 57 espèces d'amphibiens. Ce nombre est très élevé étant donné que

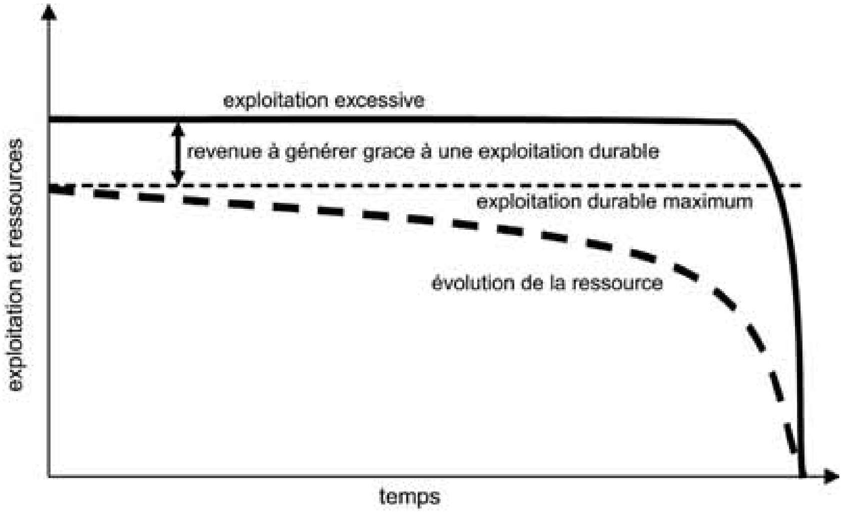

Fig. 1. Une exploitation excessive mène à une perte des ressources. Une exploitation durable par contre générer moins de revenus avec l'avantage de pouvoir exploiter les ressources plus longtemps. Pour qu'on puisse établir un system d'exploitation durable il faut généré des revenus qui compense la perte du a une exploitation inférieure (durable).

dans tout Madagascar (587.000 km^2) il y plus de 230 espèces reconnues à ce jour (Glaw & Vences, 2007) et dans tout l'Europe Centrale (920.000 km^2) on ne connaît pas plus de 24 espèces (Nöllert & Nöllert, 1992).

Une visite, en 1999, a montré que la forêt d'An'Ala (Vohimana) était de plus en plus exploitée. (Vallan, 2000 c). Olivier Behra, le fondateur de l'ONG "L'Homme et l'Environnement" a remarqué cette situation et a réalisé que le site n'avait pas seulement une grande valeur herpétologique, mais aussi un potentiel humain à valoriser. Il s'est également rendu compte que si la zone avait une faible importance par les gestionnaires de l'environnement à cause de sa petitesse, elle pourrait jouer un rôle très important comme pierre d'étape dans la futur reconstitution d'un corridor forestier entre la forêt de Maromiza (qui fait parti de la forêt classée de Vohidrazana) au sud et le parc national de Mantadia au nord. C'était trois bonnes raisons pour établir un Projet de conservation. Mis en place en 2002, ce projet a permis la mise en place de beaucoup d'activités.

La région prise en considération pour développer le projet dépasse la forêt d'An'Ala. Elle a une surface de 2000 hectares incluant les zones de cultures et de végétations secondaires (Fig. 2). L'analyse rapide de la situation des défrichements de la zone a montrée que si rien n'était fait, il n'aurait plus de forêt naturelle dans la région de Vohimana en 2019 (Tab. I).

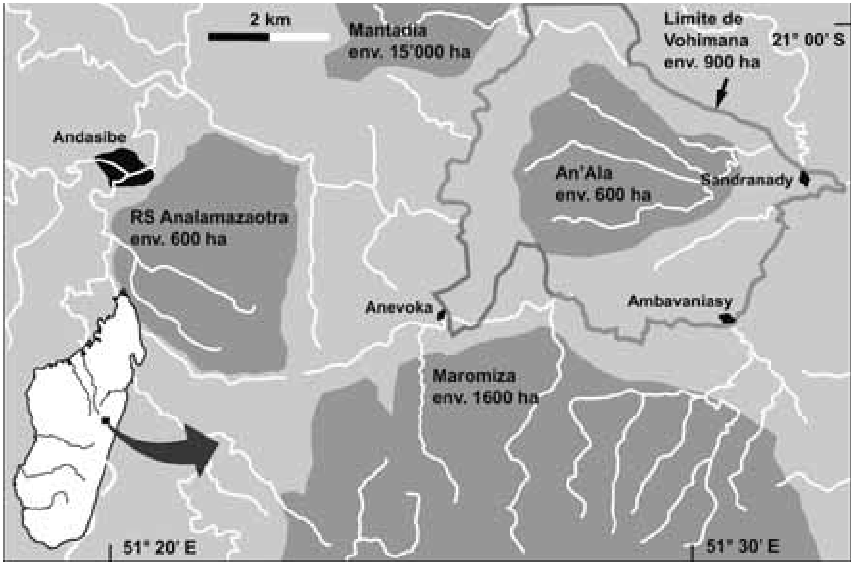

Fig. 2. Localisation de la région de Vohimana. Noir: villages; gris fonce: forêt naturelles; gris claire: végétation secondaire, reboisement de *Eucalyptus* ou culture.

ANNEE	POPULATION	SURFACE DEFRICHE CUMULE (TAVY)
2002	1250	72 hectares
2010	1583	464 hectares
2019	2066	836 hectares

Tab. I. Prospective de développement de la population et du défrichement dans la région de Vohimana.

Conservation et exploitation ne doivent pas être des contradictions

Quelles sont les buts du Projet Vohimana? Comme mentionner plus haut le projet de Vohimana doit permettre de préserver la biodiversité tout en assurant aux populations locales les revenus indispensables. Le but final du projet étant aussi de montrer des orientations à prendre pour préserver des zones d'importances biologiques majeures hors aires protégées. Les mesures contraignantes pour les populations à prendre sont l'arrêt de la production du riz par la culture sur brulis (tavy) en zone forestière et d'arrêter les coupes de bois autochtones non contrôlées. Il fallait donc montrer et propager des alternatives à ces pratiques.

Pour que ces nouvelle pratiques puissent s'établir elles doivent donner au moins autant de revenus que la production du riz (tavy) et que les coupes de bois autochtones dans la forêt (Fig. 1). Il a été ainsi nécessaire d'approcher le projet par une compréhension des flux économiques possibles, aussi bien locaux, régionaux qu'internationaux. Les mesures adoptées sont la production de fruits et d'épices pour le marcher local mais aussi la production d'huiles essentielles pour le marché international. Ces activités permettent de générer des revenus d'une façon durable. L'originalité du projet consiste aussi à étudier les possibilités concrètes de production d'huile essentielles et de plantes médicinales à partir de plantes locales. Ceci permet en effet de montrer directement les liens entre les revenus et la biodiversité. Le processus de mise sur le marché international des produits naturels nouveaux produit durablement est complexe mais il a été possible d'avoir des réalisations concrètes avec déjà quatre firmes internationales achetant des nouveaux produits de plantes locales.

Une infrastructure a été établie pour accueillir un tourisme simple et orienté à la nature. La mise en place de l'infrastructure et le service aux touristes génère aussi du travail puisqu'elle a été conçue en gestion avec du personnel local. Outre les activités "hôtelières", des guides locaux ont été également formés pour accompagner les visiteurs lors des excursions. Tout comme pour les plantes locales, ceci créé des revenus et montre la valeur de la forêt.

Le projet d'établir un corridor entre la Reserve Spéciale de Analamazaotra, le Parc National de Mantadia, Maromiza-Vohidrazana et Vohimana a vu le jour et plusieurs dizaines de milliers d'arbres autochtones sont produits maintenant en pépinière pour démarrer du reboisement. Ce travail est financé par différentes institutions et par l'état. Il peut-être particulièrement important dans une phase de démarrage des activités de développement de plantations productives qui prennent plusieurs années puisqu'il offre une autre possibilité de générer immédiatement des revenus en donnant du travail aux populations locales.

Tout projet doit être accompagné scientifiquement. Si plusieurs scientifiques ont travaillé dans le projet afin de suivre et de donner des nouveaux "inputs" au projet, un système d'accueil d'étudiant permet aussi de collecter des données à moindre coût. Le système d'hébergement local mis en place génère aussi des revenus au niveau des populations.

Le projet en chiffre

En renonçant à la culture traditionnelle le "tavy", une partie des revenus des populations locales va être perdue et on comprend qu'on ne pourrait pas avoir leur adhésion à un projet de conservation sans pallier à cette perte. Les alternatives mentionnées en haut bouchent le trou financier produit par les changements subis. Mais il faut du temps avant que le projet soit bien fonctionnel et rentable. Dans une première étape la perte financière doit être amortie par des financements externes (ONGs et/ou l'état). Des analyses montrent qu'avec le temps les revenus générés par les activités de production pérennes en terme environnemental dépassent les revenus initiaux. En renonçant au Tavy la population de la région avait une perte estimée à 89 millions de FMG en 2002 (Gourdon & Demulder, 2005) Avec la production alternative de fruit et d'épices et avec la production d'huiles essentielles les revenus annuels devront augmenter de 125 millions de FMG) en 2010. Le tourisme et la recherche devront générer encore plus d'argent.

Perspectives

Toutes les stratégies proposées en haut ne sont pas nouvelles. La production de fruit et légumes apporte plus de revenus que le "tavy" est bien connue (Rasoavarimana, 1997). La production d'huile essentielle peut être écologique si elle est faite d'une façon responsable. Il est évident que le tourisme peut apporter un certain bien-être s'il est bien géré.

L'important dans tout le processus doit être l'intégration des problématiques des habitants de la région. Ils sont touchés par la dégradation environnementale mais ils doivent avoir une prospérité économique rapide étant donné leur état de pauvreté. La finalité du projet c'est que sont eux qui peuvent soutenir le projet et rendre la conservation viable à long terme. Il faut aussi des apports techniques. Mais les populations doivent être impliquées dans les décisions. C'est le seul garant de faire comprendre leurs engagements qui sont indispensables en faveur de la préservation des habitats. Les organisations telle que "L'Homme et l'Environnement" sont des catalyseurs, le moteur sera la population locale. A long terme c'est cette approche "bottom-up" qui fonctionnera. Le projet de Vohimana, comme celui de "Mitsinjo" à Andasibe (Dolch, 2007), montre que le fonctionnement d'ensembles "Homme et Nature" est possible. Il montre aussi que des initiatives individuelles se reposant sur des partenariats privés et publiques peuvent être la clé de la préservation d'habitats particulièrement riches en herpethofaune hors aires protégées. Il faut maintenant que biologistes et conversationnistes soient des promoteurs de ces modes d'interventions pour la préservation durable de l'herpétofaune.

RÉSUMÉ

Au delà de la destruction des habitats pour les amphibiens et les autres espèces animales, la fragmentation de ces habitats est une des premières menace majeure. Il y a à Madagascar de nombreux cas ou de petits blocs forestier résiduels abritent soient une diversité importante d'une diversité importante d'amphibiens ou des espèces d'amphibiens hautement menacées. Plusieurs de ces petits habitats ne bénéficient pas de protection légale. Qu'elles sont les stratégies que nous pourrions adopter pour permettre aux espèces en question de survivre à long terme in situ? L'éventail des stratégies exprimées est large, chacune entrainant un lot de conséquences. Le cas de la région de Vohimana (abritant la mieux connue forêt d'An'Ala est discuté. Cette forêt fait parmi des sites avec la plus haute diversité d'amphibiens à Madagascar. Il se situe entre la Réserve Spéciale d'Analamazotra, le parc National de Mantadia et la Forêt classée de Maromiza (Vohidrazana). Entourée donc par des forêts plus ou moins protégées les 600 hectares de surface d'An'Ala n'ont que depuis 2002 fait l'objet d'effort de protection par l'ONG L'Homme et l'Environnement. Le futur de ce bloc forestier résiduel dépend de la possibilité de le reconnecter aux autres forêts et de sa valorisation dans un cadre de protection. Quels sont les orientations que nous devons choisir pour atteindre les objectifs de conservation des amphibiens et des autres espèces?

Mot clé: conservation, perte de l’habitat, fragmentation, Madagascar, Vohimana, culture sur brûlis, exploitation, tourisme, valorisation, population locale.

Denis VALLAN
Natur-Museum Luzern
Kasernenplatz 6
6003 Luzern, Suisse
Email Denis.Vallan@lu.ch

Olivier BEHRA
Man And The Environment Madagascar
Lot II V 102b Ampandrana
101 Antananarivo, Madagascar
Email obdirect@mate.mg

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A Conservation Strategy for the Amphibians of Madagascar	Monografie del Museo Regionale di Scienze Naturali di Torino, XLV (2008): pp. 419-438

Franco ANDREONE[1], Neil A. COX[2], Frank GLAW[3], Jörn KÖHLER[4],
Nirhy H. C. RABIBISOA[5], Herilala RANDRIAMAHAZO[6], Harison RANDRIANASOLO[5],
Christopher J. RAXWORTHY[7], Simon N. STUART[2],
Denis VALLAN[8], Miguel VENCES[9]

Update of the Global Amphibian Assessment for Madagascar in light of species discoveries, nomenclature changes, and new field information

ABSTRACT

We updated the Global Amphibian Assessment for Malagasy amphibians, including considerations on the species described or resurrected between 2005-2007, and newly available information on other taxa. The revised assessment allowed us to include 66 threatened species: 6 Critically Endangered, 31 Endangered, and 29 Vulnerable. Three species formerly assessed as Critically Endangered (*Mantella expectata, M. viridis,* and *Scaphiophryne gottlebei*) are downlisted to Endangered, since they are more widespread than formerly presumed. Other recently described species have been assessed as threatened: seven are categorised as Endangered (*Boophis tampoka, Gephyromantis azzurrae, G. runewsweeki, Mantidactylus noralottae, Tsingymantis antitra, Cophyla berara,* and *Plethodontohyla fonetana*), and a single species (*Boophis sambirano*) categorised as Vulnerable. The little known and enigmatic *Mantella manery,* formerly assessed as Data Deficient, has been recently found on the Tsaratanana Massif. In view of this enlarged distribution and ongoing degradation of the habitats where it lives, it has been re-assessed as Vulnerable.

Key words: Amphibians, Conservation, Global Amphibian Assessment, Madagascar, New assessment.

[1] Museo Regionale di Scienze Naturali, Torino.
[2] Center for Applied Biodiversity Science, Washington.
[3] Zoologische Staatssammlung München.
[4] Hessisches Landesmuseum Darmstadt.
[5] Conservation International, Antananarivo.
[6] Wildlife Conservation Society, Antananarivo.
[7] American Museum of Natural History, New York.
[8] Natur-Museum Luzern.
[9] Technical University of Braunschweig.

INTRODUCTION

The Global Amphibian Assessment (http://www.globalamphibians.org/; Stuart et al., 2004) has proved to be a crucial tool in identifying and defining the conservation priorities for most of the world's amphibians. This global survey, undertaken with a large participation of the worldwide community of herpetologists, led to the compilation of an important fallout, the Amphibian Conservation Action Plan (Gascon et al., 2007), a keystone document towards advancing global and regional efforts for amphibian conservation.

Passing from a global to a more local scale, we here deal with the assessment of the highly diverse amphibians from Madagascar. In this country, an assessment of the global conservation status for the 220 species known from Madagascar in 2004, using the IUCN Red List Categories and Criteria, identified 9 Critically Endangered (CR) species, 21 Endangered (EN) species and 25 Vulnerable (VU) species (Andreone et al., 2005 a).

Furthermore, most of the amphibian conservation projects recently conducted in Madagascar were influenced by the ideas, suggestions and perspectives reported in Andreone et al. (2005 a). These include, for example, the contributions and conservation actions on the threatened *Mantella cowani* (Andreone & Randrianirina, 2003; Chiari et al., 2005; Rabemananjara et al., 2007 a), *M. milotympanum* (Randrianirina, 2005; Vieites et al., 2005), *M. aurantiaca* (Bora et al., 2008), *M. bernhardi* (Rabemananjara et al., 2005; Vieites et al., 2006), *M. viridis, M. expectata,* and *Scaphiophryne gottlebei* (Andreone et al., 2005 b, c; Mercurio & Andreone, 2006). We may also affirm that the ACSAM (A Conservation Strategy for the Amphibians of Madagascar) initiative itself and the present volume took origin from the GAA initiative (Andreone et al., 2004; Moore, 2007).

We here present the facsimile reprint of the GAA paper in its integral form (Andreone et al., 2005 a). In fact, we believe that this important contribution is worth to be available to all those interested in the conservation of Malagasy amphibians. At the same time, we also wish to associate a relevant update on the species discovered and described since 2005, in light of new distribution and field information. In fact, several new species have been described, but the conservation status for only a few of them have so far been assessed. Furthermore, the important taxonomic work carried out by several of the contributors to the present volume led to the revalidation of some taxa that were not yet assessed.

The current paper is intended to provide the new categorisation of the current amphibian fauna. Moreover, for the species included in the Critically Endangered category we provide a summary of the advancement of the knowledge status. It is also worth stating the declaration by the Malagasy President Marc Ravalomanana to triple the existing coverage of the island 's protected network in the application of the so-called "Durban Vision " (Norris, 2006; Andreone & Randriamahazo, 2008). Therefore, we also update the species' occurrence within the new system of protected areas.

MATERIAL AND METHODS

The analysed species

The species presented and assessed in this contribution are those formally described by 31st December 2007. We explicitly excluded from our analysis other species not yet described at that time, although it is evident that many unknown and informally described species are already known, as shown from the overview of the most recent field guide by Glaw & Vences (2007 b).

In total, we reviewed 238 species (Andreone et al., 2008). The updated list of the threatened species (included in the IUCN categories CR, EN, VU), associated to nomenclatural changes, is provided in Tab. I. Fifteen species (8 mantellids and 7 microhylids) were described from 2005 to the 31st December 2007. They are here listed with considerations on their conservation status and categorization assessment. Then, five mantellid species were resurrected from synonymy, and thus deserve conservation categorisation. Several other species are now better known in terms of distribution, ecology and conservation biology. This leads to some updates and changes in their status as follows. Finally, for some of the Critically Endangered species more data have been accumulated.

Taxonomy and nomenclature

We followed the recent taxonomic contributions by Glaw & Vences (2006) and Frost et al. (2006), integrated within the most recent opinions (e.g., Glaw & Vences, 2007 b). In terms of distribution we took into consideration all the data provided by Andreone et al. (2005 a) and subsequently provided either under the GAA website or on the IUCN red-list website (http://www.iucnredlist.org/). For some of the nine Critically Endangered species defined by Andreone et al. (2005 a) we added information and distribution changes summarised by Glaw & Vences (2007 b), integrated by unpublished data.

Assessment of the conservation status

The analysis of the conservation status was carried out on the basis of a revised distribution and updated knowledge since 2005. After this, we provided further contributions and comments. In general there was full consensus among the authors about the conservation status of most species, but in a few cases the classification represents a majority agreement. This is mainly due to the fact that the distribution knowledge is often fragmentary and the perception of threats affecting the different species is heterogeneous. We provide the rationale for each classification in the following chapters.

Used abbreviations

Abbreviations used in this paper are as follows: GAA, Global Amphibian Assessment; ACSAM, A Conservation Strategy for the Amphibians of Madagascar; CR, Critically Endangered (species); EN, Endangered (species); VU, Vulnerable (species); NT, Near Threatened (species); LC, Least Concern (species); DD, Data Deficient (species); AOO, Area of Occupancy (of a species); EOO, Extent of Occurrence (of a species).

SPECIES	FORMER DENOMINATION	FAMILY
CRITICALLY ENDANGERED		
Boophis williamsi		Mantellidae
Mantella aurantiaca		Mantellidae
Mantella cowani		Mantellidae
Mantella milotympanum		Mantellidae
Mantidactylus pauliani		Mantellidae
Stumpffia helenae		Microhylidae
ENDANGERED		
Aglyptodactylus laticeps		Mantellidae
Boehmantis microtympanum	*Mantidactylus microtympanum*	Mantellidae
Boophis tampoka		Mantellidae
Gephyromantis azzurrae		Mantellidae
Gephyromantis corvus	*Mantidactylus corvus*	Mantellidae
Gephyromantis horridus	*Mantidactylus horridus*	Mantellidae
Gephyromantis runewsweeki		Mantellidae
Gephyromantis silvanus	*Mantidactylus silvanus*	Mantellidae
Gephyromantis webbi	*Mantidactylus webbi*	Mantellidae
Mantella bernhardi		Mantellidae
Mantella crocea		Mantellidae
Mantella expectata * [CR]		Mantellidae
Mantella viridis * [CR]		Mantellidae
Mantidactylus madecassus		Mantellidae
Mantidactylus noralottae		Mantellidae
Spinomantis brunae	*Mantidactylus brunae*	Mantellidae
Spinomantis guibei	*Mantidactylus guibei*	Mantellidae
Spinomantis microtis	*Mantidactylus microtis*	Mantellidae
Tsingymantis antitra		Mantellidae
Anodonthyla rouxae		Microhylidae
Cophyla berara		Microhylidae
Madecassophryne truebae		Microhylidae
Platypelis alticola		Microhylidae
Platypelis mavomavo		Microhylidae
Platypelis milloti		Microhylidae
Platypelis tetra		Microhylidae
Plethodontohyla brevipes		Microhylidae
Plethodontohyla fonetana		Microhylidae
Plethodontohyla guentherpetersi		Microhylidae
Scaphiophryne boribory		Microhylidae
*Scaphiophryne gottlebei** [CR]		Microhylidae
VULNERABLE		
Boophis andreonei		Mantellidae
Boophis blommersae		Mantellidae
Boophis haematopus		Mantellidae
Boophis jaegeri		Mantellidae
Boophis sambirano		Mantellidae
Gephyromantis ambohitra	*Mantidactylus ambohitra*	Mantellidae
Gephyromantis klemmeri	*Mantidactylus klemmeri*	Mantellidae
Gephyromantis rivicola	*Mantidactylus rivicola*	Mantellidae
Gephyromantis salegy	*Mantidactylus salegy*	Mantellidae
Gephyromantis schilfi	*Mantidactylus schilfi*	Mantellidae
Gephyromantis striatus	*Mantidactylus striatus*	Mantellidae
Gephyromantis tandroka	*Mantidactylus tandroka*	Mantellidae
Mantella haraldmeieri		Mantellidae
Mantella madagascariensis		Mantellidae

RED LIST CRITERION	PET TRADE	CITES APPENDIX	PROTECTED AREAS
B1ab(iii)+2ab(iii)			*
B2ab(iii, v)	+	II	*
A2acd + B2ab(iii)	+	II	*
B2ab(iii)	+	II	*
B2ab(iii)			*
B2ab(iii)			+
B1ab(iii)			+
B2ab(iii)			+
B2ab(iii)			+
B2ab(iii)			+
B2ab(iii)			+
B1ab(iii)			+
B2ab(iii)			*
B1ab(iii) + 2ab(iii)			+
B1ab(iii) + 2ab(iii)			+
B2ab(iii, v)	+	II	+
B1ab(iii, v) + 2ab(iii, v)	+	II	+
B2ab(iii, v)	+	II	+
B2ab(iii)	+	II	*
B1ab(iii) + 2ab(iii)			+
B2ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B2ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii, v)	+		
B2ab(iii, v)	+	II	+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)			+
D2			+
B1ab(iii)			+
B1ab(iii)			+
B1ab(iii)	+	II	+
B1ab(iii)	+	II	+

Mantella haraldmeieri		Mantellidae
Mantella madagascariensis		Mantellidae
Mantella manery * [DD]		Mantellidae
Mantella pulchra		Mantellidae
Mantidactylus delormei #		Mantellidae
Spinomantis elegans	*Mantidactylus elegans*	Mantellidae
Spinomantis massorum	*Mantidactylus massorum*	Mantellidae
Anodonthyla montana		Microhylidae
Platypelis tsaratananaensis		Microhylidae
Plethodontohyla tuberata		Microhylidae
Rhombophryne coronata	*Plethodontohyla coronata*	Microhylidae
Rhombophryne coudreaui	*Plethodontohyla coudreaui*	Microhylidae
Rhombophryne serratopalpebrosa	*Plethodontohyla serratopalpebrosa*	Microhylidae
Rhombophryne testudo		Microhylidae
Scaphiophryne menabensis		Microhylidae
Scaphiophryne marmorata		Microhylidae
Stumpffia pygmaea		Microhylidae

Tab. I. Threatened Malagasy amphibians included in IUCN Red List Categories Critically Endangered, Endangered and Vulnerable), with information on Red List Criteria (explained in IUCN (2007), occurrence in the pet trade, listing on the Appendices of CITES, and their occurrence in protected areas (* = in newly created protected areas). New species described since 2005 are

RESULTS

Recently described species

Boophis axelmeyeri is currently known from the massifs of Tsaratanana, Manongarivo, and Marojejy (Vences et al., 2005 a, b; Glaw & Vences, 2007; Andreone et al., in press). Further observations (F. Andreone, unpublished) suggest its likely presence at Anjanaharibe-Sud, Ambolokopatrika-Betaolana ridge, and Masoala (Andreone et al., 2000). Thus, *Boophis axelmeyeri* is here listed as VU because its EOO is less than 20,000 km^2, it is known from fewer than ten locations, and there is continuing decline in the extent and quality of its habitat in northern Madagascar.

Boophis tampoka. This green *Boophis* was unexpectedly found at Tsingy de Bemaraha, a protected area in western Madagascar (Köhler et al., 2007). We consider it as a Bemaraha endemic and infer that its potential distribution includes only forest habitat along streams of this area. The potential threats are due to ongoing habitat degradation, largely through general deforestation, overgrazing of vegetation by cattle, and water pollution Similarly to other species restricted to arid areas we ascribe it to the EN category because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations, and there is continuing decline in the extent and quality of its habitat.

Gephyromantis azzurrae is known only from the arid Isalo Massif (Mercurio & Andreone, 2007). We infer that its potential distribution includes forest habitats along streams of the Isalo area, within and outside the protected area boundaries (Mercurio et al., 2008). In its original description it was tentatively categorised as

B1ab(iii)	+	II	+
B1ab(iii)	+	II	+
B1ab(iii)			+
B1ab(iii)	+	II	+
B1ab(iii)			+
B1ab(iii) + 2ab(iii)			+
B1ab(iii) + 2ab(iii)			+
D2			+
B1ab(iii)			+
B1ab(iii)			+
B2ab(iii)			
B1ab(iii)			+
B1ab(iii)			+
D2			+
B2ab(iii)			+
B1ab(iii)	+		+
D2			+

reported in bold; # revalidated species; species marked with asterisk (*) are those whose categorization has been changed since the paper by Andreone et al. (2005 a). Their former assessment is reported between square parentheses.

CR, but on further review, we here list it as EN because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations, and there is continuing decline in the extent and quality of its habitats.

Gephyromantis runewsweeki. It is known only from Ranomafana (Vences & de la Riva, 2007). The authors originally categorized this species as NT. However, despite its characteristic calls it has only been recorded from the type locality and a second site where it is apparently very rare. For this reason, we recategorise it as EN because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations, and there is probably a continuing decline in the extent and quality of much of its habitat.

Guibemantis timidus was not assessed in terms of conservation status by the describers (Vences & Glaw, 2005 b). Its distribution is sufficiently large and the species is apparently able to adapt to rather degraded habitats (F. Andreone, unpublished). It occurs in at least two protected area (Manombo Special Reserve: M. Vences, unpublished; Betampona Strict Nature Reserve: F. Andreone and G. Rosa, unpublished). Therefore, it is listed as LC since it is locally abundant, tolerant of a high degree of habitat disturbance, and not believed to be declining.

Mantidactylus noralottae was described from a single Isalo locality (Mercurio & Andreone, 2007). We infer that its potential distribution includes the whole Isalo area, within and outside the protected area boundaries (Mercurio et al., 2008). Similarly to *Gephyromantis azzurrae* it was originally assessed as CR, but we here list it as EN because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations, and there is continuing decline in the extent and quality of its habitat.

Tsingymantis antitra. This peculiar species was recently found in the Ankarana area (NW Madagascar), and it represents a very ancient relict lineage (Glaw et al., 2006; Kurabayashi et al., 2008). It was categorised as EN. We here confirm this assessment, since its EOO is less than 5,000 km^2, all individuals are in fewer than five locations (currently it is known from two sites), and there is continuing decline in the extent and quality of its habitat".

Anodonthyla hutchisoni. This species is apparently restricted to the Masoala Peninsula, NE Madagascar (Fenolio et al., 2007). There, it is known from five localities, although it is likely that it is more widespread. The authors categorised the species as DD, due to the fact that it could be potentially present at other sites of Masoala. We confirm this assessment since there is still very little known about its distribution. If it will be confirmed at other Masoala sites it is likely that it should be categorised as LC.

Anodonthyla moramora, known from Ranomafana area (E Madagascar), was declared as potentially NT (Glaw & Vences, 2005). We here categorise the species as DD, since there is still very little known about its status and ecological requirements.

Cophyla berara is known only from the Sahamalaza Peninsula, NW Madagascar (Vences et al., 2005 a). Although surveys at other north-western sites did not yield any further findings (Andreone et al., in press) we here list *C. berara* as EN because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations (actually only a single locality is currently known), and there is continuing decline in the extent and quality of its forest habitat.

Paradoxophyla tiarano. Andreone et al. (2006) found this species at a single site of Masoala, NE Madagascar. For this they categorised it as DD. We confirm this listing since it has only recently been described, and there is still very little known about its distribution, status and ecological requirements.

Plethodontohyla fonetana. Described from the Bendrao Forest in the Tsingy de Bemaraha National Park (W Madagascar), it is currently one of the few cophyline microhylids occurring in the arid west (Glaw et al., 2007; Andreone & Randrianirina, 2008). The authors categorised the conservation status as DD. We here list it as EN because its EOO is less than 5,000 km^2, all individuals are in fewer than five locations (actually only one locality is currently known), and there is continuing decline in the extent and quality of its forest habitat in the Tsingy de Bemaraha, especially by zebu grazing.

Plethodontohyla guentheri. This species is currently known only from Marojejy (NE Madagascar) and has been categorized as DD (Glaw & Vences, 2007 a). Although its presence has been confirmed at Anjanaharibe-Sud (F. Andreone, unpublished), we confirm its listing as DD since there is still very little known about its distribution, status and ecological requirements.

Scaphiophryne menabensis is known mainly from the Menabe area, W Madagascar (Glos et al., 2005), although it was reported from Tsingy de Bemaraha, Isalo and other apparently isolated western areas (Glaw & Vences, 2007 b; Mercurio et al., 2008). We therefore assess it as VU, since its AOO is very small (< 2,000 km^2) and its habitat is in decline.

Revalidated species

Mantella ebenaui. This species was recently differentiated from *M. betsileo,* of which it represents the northern relative (Rabemananjara et al., 2007b; Glaw & Vences, 2007). It is listed as LC in view of its wide distribution, adaptation to a broad range of habitats, presumed large population, and because it is unlikely to be declining fast enough to qualify for listing in a more threatened category.

Mantidactylus bellyi. Formerly considered conspecific with *Mantidactylus curtus* (Glaw & Vences, 2006). Listed as LC because it has a likely wide distribution in N Madagascar (e.g., Ankarana, Montagne d'Ambre, and Montagne des Français), it is apparently rather tolerant of habitat degradation, has presumably large populations, and because it is unlikely to be declining fast enough to qualify for listing in a more threatened category.

Mantidactylus bourgati. Formerly included within *Mantidactylus curtus* (Glaw & Vences, 2006). Only known from the Andringitra Massif (SE Madagascar). Listed as DD since it has only recently been revalidated, and there is still very little known about its status and ecological requirements.

Mantidactylus cowanii. Until recently included within *Mantidactylus lugubris* (Glaw & Vences, 2006), it is apparently exclusive of the high plateau (e.g., Ambohitantely, Antoetra, and Mantadia). Listed as NT since although it is relatively widely distributed, it lives along fast-flowing stretches of streams and waterfalls only, and its AOO is probably not much larger than 2,000 km^2, and the extent and quality of its habitat is declining, thus making the species close to qualifying for VU.

Mantidactylus delormei. Previously included within *Mantidactylus brevipalmatus* (Glaw & Vences, 2006). Only known from the Andringitra Massif and the Maharira Forest (SE Madagascar). Anyhow, it is probably not so rare in highland forests between Andringitra and Ranomafana. Listed as VU, in view of its EOO of less than 20,000 km^2, with all individuals in fewer than ten locations, and a continuing decline in the extent and quality of its habitat.

Species with revised conservation status

Mantella expectata. Until recently, this mantella was known from only a few localities of the Isalo Massif (S Madagascar), and considered to be subject to heavy collection for pet-trade. Then its EOO was estimated to be less than 100 km^2, with all individuals considered to be in a single location, and with a continuing decline in the extent and quality of its habitat. For these reasons it was classified as CR (Andreone et al., 2005 a). Subsequently, through recent survey work (Mercurio et al., 2008; Crottini et al., submitted), *M. expectata* has been found in many other Isalo sites, from the southernmost border to the north of the massif. The final distribution area is now recognised as being much wider than 100 km^2. Recent genetic work undertaken by Rabemananjara et al. (2007b) also indicates that populations from Tsingy de Bemaraha and from other western sites should possibly be considered to be a distinct species. In view of these findings, we follow Mercurio et al. (2008) and consider as *M. expectata* s.str.

only the Isalo populations, in large part characterised by males with blue legs. For all these reasons we here reclassify *M. expectata* in the EN category, as it has an EOO of >5,000 km^2 and populations are likely fragmented.

Mantella manery. This species was known from only a few individuals found at a low altitude forest of the Marojejy Massif, NE Madagascar (Glaw & Vences, 2007 b). For this reason it was classified as DD. More recently the species was also located at Tsaratanana (NW Madagascar) (N.H.C. Rabibisoa and C.J. Raxworthy, unpublished). In view of this new information, we recategorise it as VU because its EOO is less than 20,000 km^2, only two populations are known and there is continuing decline in the extent and quality of its assumed habitat in northern Madagascar.

Mantella viridis. This mantella from N Madagascar was formerly classified as CR due to its restricted distribution and intense collecting activity (Andreone et al., 2005 a). Surveys undertaken by V. Mercurio in 2004-2005 (Mercurio & Andreone, 2008), F. Glaw and J. Köhler (2007, unpublished) and others (Metcalf et al., 2007) have shown that the species has an EOO that is much larger than 100 km^2. In addition, genetic work done by Rabemananjara et al. (2007b) showed that populations from Ankarana are also rather close to those from Montagne des Français and Antongombato, thus indicating a much wider distribution of this species. *Mantella viridis* is here recategorised as EN because its EOO is less than 5,000 km^2, it is severely fragmented, and there is continuing decline in the extent and quality of its habitat.

Scaphiophryne gottlebei. This endemic frog of the Isalo Massif (S Madagascar) was also formerly categorised as CR (Mercurio et al., 2008; Crottini et al., submitted), due to narrow distribution and threats due to collecting activity. Similarly to *M. expectata,* the number of locations for *S. gottlebei* is now recognised to be higher than believed. It is here classified as EN, since its EOO is less than 5,000 km^2, all individuals are in fewer than five locations, and there is continuing decline in the extent and quality of its habitat around Isalo. It is possibly subject to over-collecting for the pet trade leading to a decline in the number of mature individuals. Further investigations of this possible threat are necessary.

New data on the critically endangered species

Mantella aurantiaca. Recent reports of this frog in E Madagascar clearly indicate that the golden mantella is more widespread than formerly believed. New population discoveries of *M. aurantiaca* are being compiled to provide a more complete assessment of the AOO of these species (Bora et al., 2008). A conservation survey of *M. aurantiaca* in 2008 by the NGO Madagasikara Voakajy allowed to confirm over 20 populations of this species and identified a cluster of sites in the forests south of Moramanga (R. K. B. Jenkins, pers. comm.). These forests are currently unprotected and are under severe pressure but should be considered priority sites for the conservation of *M. aurantiaca.*

Mantella cowani. The harlequin mantella is known from only a few sites from the high plateau, central Madagascar (Andreone & Randrianirina, 2003;

Chiari et al., 2005). Listed by Andreone et al. (2005 a) as CR because its AOO was considered less than 10 km^2, its distribution was severely fragmented, the extent of its habitat was declining; and also because of a drastic population decline, estimated to be more than 80% over the last three generations, inferred from observed shrinkage in distribution and declines in the number of mature individuals, anecdotal information on habitat destruction and/or degradation, and from levels of exploitation inferred from the numbers of animals in international trade. Although some data on the species' occurrence were provided by Andreone et al. (2007), and new sites have been recently found at Itremo (C. J. Randrianantoandro, unpublished), this results in no change to its threat categorisation.

Mantella milotympanum. Individuals with the typical red colouration come from Fierenana (E Madagascar), while populations intermediate with *M. crocea* are known from several other sites, e.g., Andriabe and Sakavoakina, thus showing that there is not a reliable method to distinguish these colour morphs as separate species. Seen these difficulties in terms of identification, and substantial genetical identity with *M. crocea*¸ it is likely that in the future the conservation status of *M. milotympanum* will be reconsidered. Some studies have been conducted on the species abundance and distribution at Fierenana (Randrianirina, 2005; Vieites et al., 2005; Bora et al., 2008).

Boophis williamsi. So far, very little is known about the distribution and ecological requirements of this species. It is apparently restricted to a few altitude streams of the Ankaratra Massif (central-eastern Madagascar). Urgent actions are therefore needed to protect the species' stream habitats and to unveil its habitat requirements.

Mantidactylus pauliani. This montane frog is also known only from the Ankaratra Massif. Conservation activities, in particular the protection of important stream habitats, are urgently needed.

Stumpffia helenae. This small terrestrial frog species remains known only from Ambohitantely Special Reserve (central Madagascar). Surveys at other potential localities on the high plateau have yet to reveal any additional populations.

DISCUSSION

A new assessment for the amphibians of Madagascar

Taking into account the current total of 238 species (at May 2008), the number of threatened species (CR + EN + VU) sums up to 66, thus representing the 27.7% of the whole Malagasy amphibian fauna. This is only slightly different from the 25% given by Andreone et al. (2005 a) for a total number of 220 species.

Since the publication of the GAA paper in 2005, specifically addressed studies have been carried out on some threatened species, such as *Mantella cowani, M. expectata, M. viridis, M. aurantiaca, M. milotympanum* and

Scaphiophryne gottlebei (Andreone & Randrianirina, 2003; Chiari et al., 2005; Bora et al., 2008; Mercurio et al., 2008).

One important fallout of these studies is that three of the formerly CR species have been downgraded to EN, *Mantella expectata, M. viridis* and *Scaphiophryne gottlebei.* As stressed the rationale for these changes is mainly based on the fact that they have a distribution larger than formerly believed. This means that, although threats were not removed, a better comprehension of their distribution was necessary to realistically assess their conservation category. Moreover, they also have a rapid generation period and comparatively short life span (F.M. Guarino and F. Andreone, unpublished). For this reason both *M. expectata* and *M. viridis* are likely species that could better support the take off for the pet-trade under carefully managed and monitored programs to be defined according to the Action Plan addressed to the amphibians of Madagascar (see also Rabemananjara et al., 2008).

Scaphiophryne gottlebei appears more ecologically specialised than *M. expectata* and *M. viridis,* since it lives within the more stable canyon habitats, and tadpoles develop in deep pools within canyons (Mercurio & Andreone, 2006; Mercurio et al., 2008). Due to its chromatic attractiveness it is currently exported for the pet-trade. Surprisingly enough, up to now no data is published on the captive breeding. A reproduction event in captivity occurred in London Zoo, but tadpoles did not complete their development (R. D. Gibson, unpublished). Due to this difficulty in obtaining captive breeding success, we recommend that it is maintained with a rather low number of allowed export animals per year (1000).

The downlisting of these three species is based on new data on distribution and life-history and a different interpretation of the impact of pet-trade. The effect of pet-trade on the conservation status of many species currently considered as threatened is indeed still controversial, and up to now little data are available for Madagascar (Andreone et al., 2005 b). We recommend investigating this aspect in the future.

Several other species from relatively arid environments are now included within the EN category: *Gephyromantis corvus, Mantidactylus noralottae, Tsingymantis antitra, Plethodontohyla fonetana* and *Boophis tampoka.* All these species share a similar situation in terms of distribution and threats. A special attention should be paid in the future on the species from the western and arid sites, since they are in general less known than species from rainforests and since threats are more difficult to assess.

The need for further studies on threatened species

Seen the current knowledge further field studies should be carried out on the CR species. We recommend studying the distribution of *Mantella cowani* and to develop management plans for its main habitats. The realisation of a protected area destined to *M. cowani* and/or to other amphibians is crucial, especially when not yet included in the protected area network (Rabemananjara et al., 2008 b).

A special attention is to be paid to three species that actually are poorly known: *Boophis williamsi, Mantidactylus pauliani* and *Stumpffia helenae.* These CR species are indeed to be studied, since almost nothing is known for their distribution and life history traits. The former two species are among the few Malagasy amphibians which do not occur in any existing protected area (although the sites where they live are scheduled to become future protected areas). Again, very few data are available on distribution and ecological requirements of *Stumpffia helenae*. For this, we strongly advocate collecting basic data on their distribution and biology (e. g. activity, sex ratio, egg number and longevity) that will become useful to establish conservation priorities and to estimate extinction probabilities.

Mantella aurantiaca and *M. milotympanum* should also better studied in terms of recovering capacity after collecting for the pet-trade. The effect of pet-trade on the conservation status of these frogs is currently little known: this aspect is worth to be urgently analysed to warrant the definition of quotas of exportable individuals based on scientific data collected in the wild (Carpenter et al., 2008).

Because new CR and EN species have been added to the GAA list, it is evident that studies and surveys should be promoted on them. Anyhow, a further important issue regards the need to carry out research on the DD species. For most of these species the information is really limited and this obscures their real conservation status. We advocate that, in parallel to research conducted on threatened species a special attention is paid to little-known species and funds should be made available to collect new field data so that their conservation status might be better understood..

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RÉSUMÉ

Mise-au-jour du Global Amphibian Assessment pour Madagascar sur la base des récentes découvertes d'espèces, des changements nomenclaturels et sur les informations d'histoire naturelle.

Nous avons mis au jour le Global Amphibian Assessment, en tenant conte des découvertes de nouvelles espèces à partir du 2005, avec informations sur la distribution et sur leur abondance. La nouvelle catégorisation comprends 6 espèces Menacées critiquement (CR), 31 espèces Menacées (EN), et 29 espèces Vulnérables (VU). Trois espèces considérées en précédence comme Menaces critiquement (*Mantella expectata, M. viridis, Scaphiophryne gottlebei*) sont maintenant re-catégorisées comme Menacées. Cette variation est due au fait que elles vivent dans une aire plus vaste que celle auparavant reconnue. Des autres espèces décrites recemment ont eté classées comme Menacées (*Boophis tampoka, Gephyromantis azzurrae, G. runewsweeki, Mantidactylus noralottae, Tsingymantis antitra, Cophyla berara* et *Plethodontohyla fonetana*), et une comme Vulnerable (*Boophis sambirano*). Un'espèce très enigmatique, *Mantella manery, en* precedence classes comme Données insuffisantes, a eté recemment trouvée sur le Massif du Tsaratanana Massif. Sur la base de cette distribution enlargie, il a eté classée comme Vulnerable.

Mots clés: Amphibiens, Conservation, Global Amphibian Assessment, Madagascar, Nouvelle catégorisation.

Franco Andreone
Museo Regionale di Scienze Naturali
Via G. Giolitti, 36, I-10123 Torino, Italy
Email franco.andreone@regione.piemonte.it

Neil A. Cox
Simon N. Stuart
IUCN/SSC CI/CABS Biodiversity Assessment Unit
2011 Crystal Drive, Suite 500,
Arlington, VA 22202, USA
Email n.cox@conservation.org
s.stuart@conservation.org

Frank Glaw
Zoologische Staatssammlung München
Münchhausenstr. 21, D-81247 München, Germany
Email Frank.Glaw@zsm.mwn.de

Jörn Köhler
Abteilung Naturgeschichte - Zoologie
Hessisches Landesmuseum Darmstadt
Friedensplatz 1, D-64283 Darmstadt, Germany
Email j.koehler@hlmd.de

Nirhy H. C. Rabibisoa
Harison Randrianasolo
Conservation International
6 Rue Razafindratandra, Antananarivo 101, Madagascar
Email nrabibisoa@conservation.org
hrandrianasolo@conservation.org

Herilala Randriamahazo
Wildlife Conservation Society Madagascar
Villa Ifanomezantsoa, Lot Face II A 78 D Soavimbahoaka
Antananarivo 101, Madagascar
Email herilala@wcsmad.org

Christopher J. Raxworthy
American Museum of Natural History
Central Park West at 79th Street, New York, New York 10024-5192, USA
Email rax@amnh.org

Denis Vallan
Natur-Museum Luzern
Kasernenplatz 6, CH-6003 Luzern, Switzerland
Email Denis.Vallan@lu.ch

Miguel Vences
Zoological Institute, Technical University of Braunschweig
Spielmannstr. 8, D-38106 Braunschweig, Germany
Email: m.vences@tu-bs.de

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ADDENDUM

Together with the current contribution we here report the facsimile reprint of the original Global Amphibian Assessment for Madagascar, published in 2005. This must be intended as a "special service" for the readers of the ACSAM book, due to the fact that this paper is an important step in the knowledge of the amphibians of Madagascar and their conservation.

Species Review of Amphibian Extinction Risks in Madagascar: Conclusions from the Global Amphibian Assessment

FRANCO ANDREONE,* JOHN E. CADLE,† NEIL COX,‡ FRANK GLAW,§ RONALD A. NUSSBAUM,** CHRISTOPHER J. RAXWORTHY,†† SIMON N. STUART,‡ DENIS VALLAN,‡‡ AND MIGUEL VENCES§§

*Museo Regionale di Scienze Naturali, Via G. Giolitti, 36, I-10123 Torino, Italy, email f.andreone@libero.it
†Department of Herpetology, Chicago Zoological Society, 3300 Golf Road, Brookfield, IL 60513, U.S.A.
‡IUCN/SSC-CI/CABS Biodiversity Assessment Initiative, c/o Center for Applied Biodiversity Science, Conservation International, 1919 M Street NW, Suite 600, Washington, D.C. 20036, U.S.A.
§Zoologische Staatssammlung, Münchhausenstrasse 21, D-81247 München, Germany
**Division of Reptiles and Amphibians, Museum of Zoology, University of Michigan, Ann Arbor, MI 48109-1079, U.S.A.
††Department of Herpetology, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024-5192, U.S.A.
‡‡Universität Bern, Zoologisches Institut, Baltzerstrasse 6, CH-3012 Bern, and Natur-Museum Luzern, Kasernenplatz 6, CH-6003 Luzern, Switzerland
§§Institute of Biodiversity and Ecosystem Dynamics, Zoological Museum, Mauritskade 61, 1092 AD Amsterdam, The Netherlands

Abstract: *We assessed the extinction risks of Malagasy amphibians by evaluating their distribution, occurrence in protected areas, population trends, habitat quality, and prevalence in commercial trade. We estimated and mapped the distribution of each of the 220 described Malagasy species and applied, for the first time, the IUCN Red List categories and criteria to all species described at the time of the assessment. Nine species were categorized as critically endangered, 21 as endangered, and 25 as vulnerable. The most threatened species occur on the High Plateau and/or have been subjected to overcollection for the pet trade, but restricted extent of occurrence and ongoing habitat destruction were identified as the most important factors influencing extinction threats. The two areas with the majority of threatened species were the northern Tsaratanana-Marojejy-Masoala highlands and the southeastern Anosy Mountains. The current system of protected areas includes 82% of the threatened amphibian species. Of the critically endangered species, 6 did not occur in any protected area. For conservation of these species we recommend the creation of a reserve for the species of the* Mantella aurantiaca *group, the inclusion of two* Scaphiophryne *species in the Convention on the International Trade in Endangered Species Appendix II, and the suspension of commercial collecting for* Mantella cowani*. Field surveys during the last 15 years reveal no pervasive extinction of Malagasy amphibians resulting from disease or other agents, as has been reported in some other areas of the world.*

Key Words: IUCN, species risk categorization, species status assessment

Revisión del Riesgo de Extinción de Anfibios en Madagascar: Conclusiones de Evaluación Global de Anfibios

Resumen: *Evaluamos los riesgos de extinción de anfibios malgaches mediante el análisis de su distribución, ocurrencia en áreas protegidas, tendencias poblacionales, calidad del hábitat y prevalencia en el comercio. Estimamos y mapeamos la distribución de cada una de las 220 especies descritas para Madagascar y aplicamos, por primera vez, las categorías y criterios de la Lista Roja de IUCN a todas las especies descritas al momento*

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de la evaluación. Nueve especies fueron clasificadas en peligro crítico, 21 como amenazadas y 25 como vulnerables. Las especies más amenazadas ocurren en High Plateau y/o han sido sujetas a sobreexplotación para el comercio de mascotas, pero identificamos a la extensión restringida de ocurrencia y a la destrucción del hábitat como los factores que más influyen sobre las amenazas de extinción. Las mesetas de Tsaratanana-Marojejy-Masoala en el norte y las Montañas Anosy en el sureste fueron las dos áreas con la mayoría de especies amenazadas. El actual sistema de áreas protegidas incluye a 82% de las especies de anfibios amenazadas. De las especies en peligro crítico, 6 no ocurrieron en ninguna área protegida. Para la conservación de estas especies recomendamos la creación de una reserva para especies del grupo de Mantella aurantiaca*, la inclusión de dos especies de* Scaphiophryne *en el Apéndice II de la Convención Internacional para el Comercio de Especies en Peligro y la suspensión de la colecta comercial de* Mantella cowani*. Los estudios de campo llevados a cabo en los últimos 15 años no muestran la extinción generalizada de anfibios malgaches debido a enfermedades u otros agentes, como se ha registrado en algunas otras partes del mundo.*

Palabras Clave: clasificación del riesgo de especies, evaluación del estatus de especies, IUCN

Introduction

The diversity and endemism of Malagasy amphibians have been highlighted in recent decades (Blommers-Schlösser & Blanc 1991; Stuart et al. 2004), illustrating the importance of this vertebrate group to understanding evolutionary processes and in identifying conservation priorities. High rates of deforestation and general habitat degradation are among the most immediate threats to Madagascar's biota and landscapes, and it is important to review the current conservation status of endemic species and speciose groups such as amphibians, which are sensitive to environmental change (Vallan 2002, 2003).

There are four families of frogs in Madagascar: Mantellidae, Microhylidae, Ranidae, and Hyperoliidae (Glaw & Vences 2003). Mantellidae is the most speciose group and is endemic to Madagascar and the Comoro Islands. It includes the genera *Mantidactylus* (90 species), *Mantella* (15 species), *Boophis* (50 species), *Aglyptodactylus* (3 species), and *Laliostoma* (1 species). *Mantidactylus* and *Mantella* show peculiar features related to reproduction, such as essential absence of amplexus (mating embrace) and nuptial pads, eggs laid outside water, and presence (in most species) of femoral glands. Species of *Mantella* (Vences et al. 1999) are brightly colored and show accumulation of alkaloids in the skin (Daly et al. 1996). *Boophis* species are arboreal frogs that lay eggs in water (Blommers-Schlösser 1979). *Aglyptodactylus* and *Laliostoma* are terrestrial and breed in temporary ponds (Vences & Glaw 2001). Ranids include the opportunistic and widely distributed *Ptychadena mascareniensis*, present also in the Mascarene Islands and Seychelles, and *Hoplobatrachus tigerinus*, introduced to Madagascar from southern Asia (Kosuch et al. 2001). Microhylids are represented by 10 genera (and approximately 50 species) with diverse life histories (Blommers-Schlösser & Blanc 1991): *Dyscophus*, *Paradoxophyla*, *Scaphiophryne*, *Cophyla*, *Platypelis*, *Anodonthyla*, *Plethodontohyla*, *Madecassophryne*, *Rhombophryne*, and *Stumpffia*. Finally, the only Malagasy hyperoliids are in the endemic genus *Heterixalus* (11 species), which inhabits grasslands and forest edges (Vences et al. 2003).

The different life-history traits of these amphibians are mirrored by their differential ecological sensitivity and conservation needs (Andreone & Luiselli 2003). Most of the Malagasy frogs inhabit the eastern rainforest, an ecosystem that allowed the rapid diversification of some frog groups such as *Boophis* (Vences et al. 2002*b*), *Mantidactylus* (Andreone 2003), and cophyline microhylids (Andreone et al. 2005). The original eastern rainforest block is now severely fragmented because of deforestation in recent times (Green & Sussman 1990), and it continues to be subject to heavy anthropogenic pressure (Vallan 2000*b*). As a rule, forest fragmentation has led to an impoverishment of the native amphibian fauna, although in some cases this loss of amphibian species richness is not immediately evident (Vallan et al. 2004) because species have differing sensitivities to habitat alterations (Andreone 1994). Overharvesting for the pet trade is an additional threat to the long-term survival of a number of Malagasy amphibians. Thousands of colorful frogs (e.g., *Mantella*, *Scaphiophryne*, *Dyscophus* species) are exported each year to Europe, North America, or Japan, where they can fetch high prices (Behra & Raxworthy 1991). The effects of trade on natural populations are still poorly studied, and we did not consider the effects of collecting on the long-term survival of these populations (Raxworthy & Nussbaum 2000; Andreone & Luiselli 2003; Rabemanjara et al. 2005).

Current conservation strategies in Madagascar include identifying priority areas for threatened species or overall species diversity and including these areas in nature reserves (Ganzhorn et al. 1997; ANGAP 2001). The presence of a rich amphibian fauna or of threatened amphibian species was only rarely considered in the establishment of new protected areas because other, more "visible" taxa (e.g., lemurs, birds) were often considered a priority. Most Malagasy amphibian species occur in one or more protected areas. Some species, however, known as "gap species," do not occur in protected areas and are of particular concern (Rodrigues et al. 2004).

As part of the Global Amphibian Assessment (GAA, Stuart et al. 2004), we evaluated the conservation status of all described amphibians from Madagascar, based on the IUCN Red List Categories and Criteria (IUCN 2001). We summarize the results of the GAA workshop, provide updated information on species distributions, and discuss how life-history traits and other factors influence conservation assessment of amphibians. We also provide updated or new red listings for all amphibian species and highlight general patterns gleaned from our assessment.

Methods

Conservation Priorities Investigation

During the GAA workshop of 2003 we evaluated 220 amphibian species (described or in press as of December 2003) based on published data and our own unpublished information on species distributions and systematics (Tables 1 & 2). We followed IUCN categorization rules (reported in IUCN [2001]) in which species are classified as critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), data deficient (DD), or least concern (LC).

To establish the threat category for each species, one of us (R.A.N.) conducted a preliminary screening of the available information regarding the distribution and threats of each species. Based on his findings, he drew a distribution map for the species and entered data on the distribution, abundance, population trends, ecology, habitat preferences, threats, utilization, conservation measures, and red-list status into the GAA database, following data standards outlined in IUCN (2001). The rest of us reviewed the data sheets compiled by R.A.N., and then at the GAA Madagascar workshop added further information and data. At the workshop we reached agreement on the data associated with each species. (The GAA data for Madagascar are publicly available from www.globalamphibian.org.) We then determined the appropriate IUCN category for each species based on these data, not on expert opinion. Localities mentioned in the text are shown in Fig. 1.

Statistical Procedures and Graphical Analysis

Spatial analyses of the species' distribution maps were performed with ESRI ArcView 3.2a Spatial Analyst extension (ESRI 2000) to determine the areas with the highest diversities of amphibian species and those areas with a high diversity of species in IUCN threatened categories. The individual digitized, multipolygon-based distribution maps were assembled to create a single shapefile that contained the distribution information for all Malagasy species. This shapefile was then dissolved against the species name record included in the associated attribute table, creating a single distribution polygon for each species. We then used a script to create a grid (with cell size of 0.1°) from each polygon. We overlaid these grids and calculated the value for the number of species present within each cell. We then created two species-richness maps for all species, and a combined map of species density for the three (CR + EN + VU) highest IUCN threat categories.

Results

Species Summary

There were 55 species in threatened categories, corresponding to 25% of the Malagasy amphibians (Tables 1 & 2). Of these, 13 species are collected and exported in pet trade and 11 are listed in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix II (www.cites.org/eng/appendices.shtml). Two species classified as threatened and involved in trade but not listed in CITES are *Scaphiophryne boribory* and *S. marmorata.* The remaining species were not categorized in the three highest threat categories, although some of them were classified as NT. These include two species that are sometimes in trade (*Mantella laevigata* and *Scaphiophryne madagascariensis*) and one species that is the only Malagasy amphibian currently listed in CITES Appendix I, the tomato frog (*Dyscophus antongili*). Species assigned to the DD category included poorly known species.

Critically Endangered Species

We categorized nine species as CR: *Boophis williamsi*, *Mantella aurantiaca*, *M. cowani*, *M. expectata*, *M. milotympanum*, *M. viridis*, *Mantidactylus pauliani*, *Scaphiophryne gottlebei,* and *Stumpffia helenae* (Fig. 2).

We listed *Boophis williamsi* as CR based on its extent of occurrence (EOO) of < 100 km^2 and its area of occupancy (AOO) of < 10 km^2. Since its description in 1974 the only known population of this species is a single unprotected site in the Ankaratra Massif at 2100 m of elevation (Vences et al. 2002*b*). The extent and quality of habitat in this area continue to decline. *B. williamsi* may have lived originally in montane rainforest, but it is now restricted to high-elevation grasslands with relict montane forest. It breeds in fast-flowing mountain streams and inhabits nearby degraded areas. This habitat is annually burned and is subject to extensive overgrazing and cultivation (potato fields). The species appears to be very rare and was only occasionally encountered.

Mantella aurantiaca was categorized CR based on its AOO of < 10 km^2. Its distribution is now severely fragmented. Although localized, the population density of *M.*

Table 1. Status[a] of globally threatened Madagascan amphibians.

Species	*Family*	*Red-list criterium[b]*	*Occurrence in pet trade*	*CITES appendix[c]*	*Occurrence in protected areas*
Critically endangered (CR)					
Boophis williamsi	Mantellidae	B1ab(iii)+2ab(iii)			
Mantella aurantiaca	Mantellidae	B2ab(iii, v)	+	II	
Mantella cowani	Mantellidae	A2acd + B2ab(iii)	+	II	
Mantella expectata	Mantellidae	B2ab(iii, v)	+	II	+
Mantella milotympanum	Mantellidae	B2ab(iii)	+	II	
Mantella viridis	Mantellidae	B2ab(iii)	+	II	
Mantidactylus pauliani	Mantellidae	B2ab(iii)			
Scaphiophryne gottlebei	Microhylidae	B2ab(iii, v)	+	II	+
Stumpffia helenae	Microhylidae	B2ab(iii)			+
Endangered (EN)					
Aglyptodactylus laticeps	Mantellidae	B1ab(iii)			+
Mantella bernhardi	Mantellidae	B2ab(iii, v)	+	II	+
Mantella crocea	Mantellidae	B1ab(iii, v) + 2ab(iii, v)	+	II	+
Mantidactylus brunae	Mantellidae	B1ab(iii)			+
Mantidactylus corvus	Mantellidae	B2ab(iii)			+
Mantidactylus guibei	Mantellidae	B1ab(iii)			+
Mantidactylus horridus	Mantellidae	B1ab(iii)			+
Mantidactylus madecassus	Mantellidae	B1ab(iii) + 2ab(iii)			+
Mantidactylus microtis	Mantellidae	B1ab(iii)			+
Mantidactylus microtympanum	Mantellidae	B2ab(iii)			+
Mantidactylus silvanus	Mantellidae	B1ab(iii) + 2ab(iii)			+
Mantidactylus webbi	Mantellidae	B1ab(iii) + 2ab(iii)			+
Anodonthyla rouxae	Microhylidae	B1ab(iii)			
Madecassophryne truebae	Microhylidae	B1ab(iii)			+
Platypelis alticola	Microhylidae	B1ab(iii)			+
Platypelis mavomavo	Microhylidae	B1ab(iii)			+
Platypelis milloti	Microhylidae	B1ab(iii)			+
Platypelis tetra	Microhylidae	B1ab(iii)			+
Plethodontohyla brevipes	Microhylidae	B1ab(iii)			+
Plethodontohyla guentherpetersi	Microhylidae	B1ab(iii)			+
Scaphiophryne boribory	Microhylidae	B1ab(iii, v)	+		
Vulnerable (VU)					
Boophis andreonei	Mantellidae	B1ab(iii)			+
Boophis blommersae	Mantellidae	B1ab(iii)			+
Boophis haematopus	Mantellidae	B1ab(iii)			+
Boophis jaegeri	Mantellidae	B1ab(iii)			+
Mantella haraldmeieri	Mantellidae	B1ab(iii)	+	II	+
Mantella madagascariensis	Mantellidae	B1ab(iii)	+	II	+
Mantella pulchra	Mantellidae	B1ab(iii)	+	II	+
Mantidactylus ambohitra	Mantellidae	B1ab(iii)			+
Mantidactylus elegans	Mantellidae	B1ab(iii) + 2ab(iii)			+
Mantidactylus klemmeri	Mantellidae	B1ab(iii)			+
Mantidactylus massorum	Mantellidae	B1ab(iii) + 2ab(iii)			+
Mantidactylus rivicola	Mantellidae	B1ab(iii)			+
Mantidactylus salegy	Mantellidae	B1ab(iii)			+
Mantidactylus schilfi	Mantellidae	D2			+
Mantidactylus striatus	Mantellidae	B1ab(iii)			+
Mantidactylus tandroka	Mantellidae	B1ab(iii)			+
Anodonthyla montana	Microhylidae	D2			+
Platypelis tsaratananaensis	Microhylidae	B1ab(iii)			+
Plethodontohyla coronata	Microhylidae	B2ab(iii)			
Plethodontohyla coudreaui	Microhylidae	B1ab(iii)			+
Plethodontohyla serratopalpebrosa	Microhylidae	B1ab(iii)			+
Plethodontohyla tuberata	Microhylidae	B1ab(iii)			+
Rhombophryne testudo	Microhylidae	D2			+
Scaphiophryne marmorata	Microhylidae	B1ab(iii)	+		+
Stumpffia pygmaea	Microhylidae	D2			+

[a] *Status based on IUCN (2001) criteria.*
[b] *Criteria coding defined in IUCN (2001) (also available from http://www.redlist.org/info/categories_criteria2001.html#critical).*
[c] *CITES, Convention of International Trade of Endangered Species of Wild Fauna and Flora.*

Table 2. Malagasy frog species classified as near threatened, least concern, and data deficient.

Family—subfamily	*Near threatened*	*Least concern*	*Data deficient*
Hyperoliidae	*Heterixalus carbonei, H. rutenbergi*	*Heterixalus alboguttatus,[a] H. andrakata, H. betsileo,[a] H. boettgeri, H. luteostriatus [a] H. madagascariensis,[a] H. punctatus, H. tricolor,[a] H. variabilis*	
Mantellidae—Boophinae	*Boophis majori, B. occidentalis, B. rhodoscelis, B. rufioculis*	*Boophis albilabris,[a] B. albipunctatus, B. ankaratra, B. boehmei, B. bottae, B. doulioti, B. erythrodactylus, B. goudotii, B. guibei, B. idae, B. lichenoides, B. luteus, B. madagascariensis, B. marojezensis, B. microtympanum,[a] B. miniatus, B. opisthodon, B. pauliani, B. picturatus, B. pyrrhus, B. rappiodes, B. reticulatus, B. tasymena, B. tephraeomystax, B. viridis, B. vittatus*	*Boophis andohahela, B. anjanaharibeensis, B. brachychir, B. burgeri, B. elenae, B. englaenderi, B. feonnyala, B. hillenii, B. laurenti, B. liami, B. mandraka, B. periegetes, B. schuboeae, B. septentrionalis, B. sibilans, B. solomaso, B. xerophilus*
Mantellidae—Laliostominae		*Aglyptodactylus madagascariensis, A. securifer, Laliostoma labrosum*	
Mantellidae—Mantellinae	*Mantella laevigata,[a] Mantidactylus bertini, M. blanci, M. decaryi, M. leucocephalus, M. leucomaculatus, M. plicifer, M. spiniferus*	*Mantella baroni,[a] M. betsileo,[a] M. nigricans,[a] Mantidactylus aerumnalis, M. aglavei, M. alutus, M. ambreensis, M. argenteus, M. asper, M. betsileanus, M. bicalcaratus, M. biporus, M. blommersae, M. boulengeri, M. brevipalmatus, M. charlotteae, M. curtus, M. depressiceps, M. domerguei, M. femoralis, M. fimbriatus, M. flavobrunneus, M. grandidieri, M. grandisonae, M. granulatus, M. guttulatus, M. kely, M. liber, M. lugubris, M. luteus, M. majori, M. malagasius, M. melanopleura, M. mocquardi, M. moseri, M. opiparis, M. peraccae, M. phantasticus, M. pseudoasper, M. pulcher, M. redimitus, M. sculpturatus, M. tornieri, M. ulcerosus, M. ventrimaculatus. M. wittei, M. zipperi*	*Mantella manery, Mantidactylus albofrenatus, M. albolineatus, M. ambohimitombi, M. cornutus, M. eiselti, M. enki, M. kathrinae, M. madinika, M. punctatus, M. sarotra, M. thelenae, M. tricinctus, M. tschenki, M. zavona, M. zolitschka*
Ranidae—Raninae		*Hoplobatrachus tigerinus,[c] Ptychadena mascareniensis*	
Microhylidae—Dyscophinae	*Dyscophus antongili[b]*	*Dyscophus guineti,[a] D. insularis[a]*	
Microhylidae—Scaphiophryninae	*Scaphiophryne madagascariensis[a]*	*Paradoxophyla palmata, Scaphiophryne brevis, S. calcarata, S. spinosa[a]*	
Microhylidae—Cophylinae		*Anodonthyla boulengeri, Cophyla phyllodactyla, Platypelis barbouri, P. grandis, P. tuberifera, Plethodontohyla alluaudi, P. bipunctata, P. inguinalis, P. laevipes, P. mihanika, P. notosticta, P. ocellata, Stumpffia gimmeli*	*Anodonthyla nigrigularis, Platypelis cowanii, P. occultans, P. pollicaris, Plethodontohyla minuta, Stumpffia grandis, S. psologlossa, S. roseifemoralis, S. tetradactyla, S. tridactyla*

[a] *Species in the pet trade.*
[b] *Species included in CITES Appendix I.*
[c] *Species included in CITES Appendix II and introduced from southeast Asia.*

aurantiaca can be high within just a few hectares. This species lives in damp swamp forests usually associated with *Pandanus* screw pines (Vences et al. 1999). The extent of its forest habitat is declining, and overharvesting for trade may have reduced some of the existing populations. *M. aurantiaca* has a narrow distribution in east-central Madagascar centered in the Torotorofotsy area and the Andranomena Forest (at 920–960 m) (Vences et al. 2004). In 2001 much of the forest bordering the Torotorofotsy areas, probably including some of the remaining habitat suitable for *Mantella*, was burned in a large forest fire (Vences et al. 2004). The area did not appear to

Figure 1. Map of Madagascar, with the localities cited in the text. Square is capital city.

be heavily affected, and 3 years later *Mantella* were still common (M.V., personal observation). This species was kept in about 35 zoological gardens and other institutions and is commonly bred in captivity (Glaw et al. 2000). A management plan to ensure a controlled and sustainable trade through the establishment of a trade quota is being developed. *M. aurantiaca* is locally extremely abundant, and the collecting of specimens for the pet trade has not had a visible effect on populations.

We categorized *Mantella cowani* as CR based on its AOO of < 10 km^2. A drastic population decline occurred recently, as deduced from a dramatic reduction in its distribution and in the number of mature adults (Andreone & Randrianirina 2003). The fact that this decline followed a period of increased exploitation for the international pet trade suggests that populations were overcollected, resulting in a population crash. Although its complete distribution is unknown, *M. cowani* appears to be limited to unprotected High Plateau sites of east-central Madagascar near Antoetra and Tsinjoarivo (at 1000–2000 m). It is a terrestrial frog that lives along streams in highland moors, in areas virtually without forest cover that are regularly subjected to fire. Ongoing field research (F.A., unpublished) revealed that the surviving populations are now often composed of just a few individuals, which are difficult to detect. At a single site next to Antoetra we ascertained the existence of hybrids with *M. baroni* (F. A., unpublished). A moratorium on the export of *M. cowani* was implemented in 2003.

Mantella expectata was categorized as CR based on its EOO of < 100 km^2. *M. expectata* occurs mainly in syntopy with *Scaphiophryne gottlebei*, and the same threats affect both species. Recent surveys revealed that *M. expectata* is present in several locations around the Isalo Massif (at 700–1000 m). Records from near Toliara (Busse & Böhme 1992) were probably erroneous (Vences et al. 1999). Records from Morondava region and Mandena (Glaw & Vences 1994) are unreliable because no voucher specimens or recent field surveys document the species in these areas. At Isalo, *M. expectata* is sometimes abundant next to seasonal streams, and in wet canyons sometimes it is associated with narrow gallery forest. This species appears to be locally abundant and is actively sought for the pet trade, and during the rainy season up to several thousand specimens are collected. Sapphire mining activities and related habitat alteration in the vicinity are also possible threats.

We categorized *Mantella milotympanum* as CR because its AOO is <10 km^2, its distribution is severely fragmented, and the extent of its forest habitat in east-central Madagascar is declining. The species is known in a few unprotected locations in east-central Madagascar near Fierenana (at 900–1000 m). It is locally common in gallery forest around swamps and in seasonally flooded forest. Its habitat is receding because of subsistence agriculture, timber extraction, charcoal manufacture, livestock grazing, and fires.

Mantella viridis was categorized as CR because its AOO is <10 km^2, its distribution is fragmented, and the size and quality of its habitat continue to decline. It occurs in unprotected sites at the Montagne des Français in northern Madagascar and in the Antongombato Massif south of Antsiranana (at 50–300 m), where it is locally abundant. *M. viridis* is typical of deciduous dry forest associated with limestone landscape, usually occurring near temporary brooks and streams. Recent observations confirmed its presence in degraded habitats with good vegetational cover, which provides higher humidity and shade than adjacent nonvegetated areas. Because forest loss frequently leads to permanent drying of smaller streams, however, reduction of natural habitats of this species is a serious concern. The known localities are subject to fires, selective logging, firewood collection, and livestock grazing.

Mantidactylus pauliani was categorized as CR because its AOO is < 10 km^2, and its only known population is in a single unprotected site at about 2200 m in the Ankaratra Massif (Vences et al. 2002*a*). Like *Boophis*

Figure 2. The nine critically endangered frog species of Madagascar, two endangered species, and the CITES Appendix I listed Dyscophus antongili. *(a)* Boophis williamsi, *Ankaratra Massif (CR) (photo by M. Vences); (b)* Mantella aurantiaca, *Andranomena (CR) (photo by M. Vences); (c)* Mantella expectata, *Ilakaka (CR) (photo by F. Andreone); (d)* Mantella cowani, *Soamazaka, Antoetra (CR) (photo by F. Andreone); (e)* Mantella milotympanum, *Fierenana (CR) (photo by M. Vences); (f)* Mantella viridis, *Montagne des Français (CR) (photo by C. J. Raxworthy); (g)* Mantella bernhardi, *Tolongoina region (EN) (photo by F. Andreone); (h)* Mantidactylus pauliani, *Ankaratra Massif (CR) (photo by M. Vences); (i)* Stumpffia helenae, *Ambohitantely (CR) (photo by D. Vallan); (j)* Aglyptodactylus laticeps, *Kirindy Forest (EN) (photo by F. Glaw); (k)* Dyscophus antongili, *Maroantsetra (NT) (photo by M. Vences); (l)* Scaphiophryne gottlebei, *Ilakaka (CR) (photo by F. Andreone). Abbreviations: CR, critically endangered; EN, endangered; NT, near threatened.*

williamsi, this *Mantidactylus* is rarely encountered, and presumably lived originally in montane rainforest but is now known only along a single stream and in high-elevation grassland with relict forests. The main threats to the habitat are fire, overgrazing, and expanding potato farming. Pollution and sedimentation of the streams as a result of agriculture and mining are observed in the area.

We categorized *Scaphiophryne gottlebei* as CR because its EOO is <100 km^2. All records for this species are from a few areas within the Isalo Massif (at 700–1000 m). It

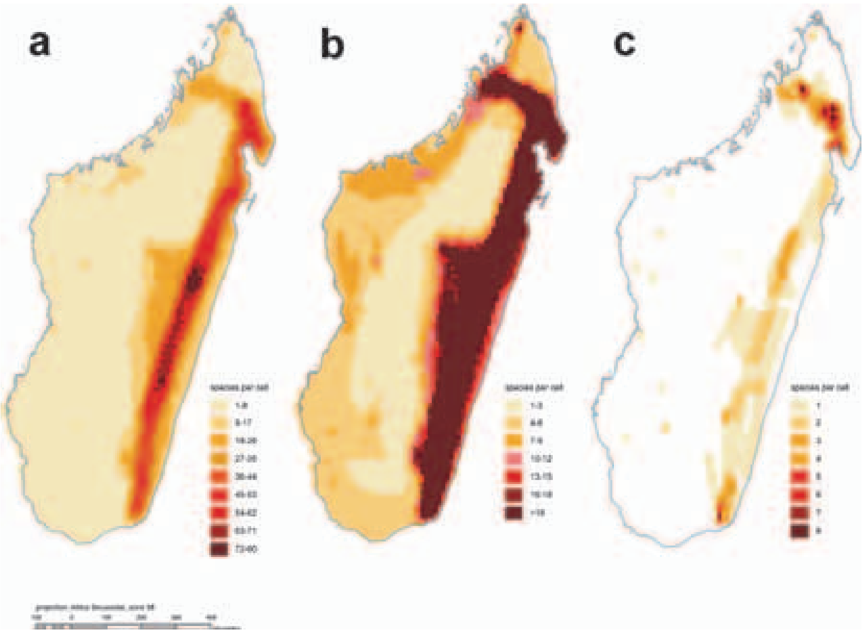

Figure 3. *Amphibian species diversity in Madagascar: (a) distribution based on overlaying the estimated distributions of all species described or in press up to December 2003; (b) distribution of total diversity with an emphasis on the species richness in the less diverse western regions (grid cells with > 18 species shaded alike to emphasize and permit greater discrimination among areas with fewer species); (c) distribution of species assigned IUCN categories of threat during the Global Amphibian Assessment workshop (critically endangered, endangered, or vulnerable).*

appears to be a localized frog, although it is abundant in the humid canyons where it usually lives. The extent and quality of its habitat continue to decline, and it is subject to overcollecting for the pet trade. Other threats are similar to those affecting *Mantella expectata,* with which it is syntopic.

Stumpffia helenae was categorized as CR because it is known only from two forest fragments at 1500 m within the Réserve Spéciale d'Ambohitantely in central Madagascar (Vallan 2000*a*). Its AOO is < 10 km^2, and the extent of its habitat is declining because of fire, wood cutting, and overgrazing. The size of the Ambohitantely forest has been shrinking since the nineteenth century (Langrand & Wilmé 1997), and between 1995 and 1997 this degradation increased. Since 2002 the situation has worsened: fires have encroached on the edges of the remaining fragments, and recently 30 ha of a parcel burned (D.V., unpublished).

Areas of Diversity and Distribution of Threatened Species

The highest-diversity areas for the amphibian fauna were in eastern and northeastern Madagascar (Fig. 3a). These regions had 64–82 species per grid cell. The arid western and southern areas associated with deciduous dry or spiny forests had still fewer frog species.

Because the species diversity in the eastern forests is much greater than in other regions, we successively evaluated the frog species with more coarse-grained species richness categories and combined all areas with more than 18 species into a single category (Fig. 3b). This approach permitted a finer discrimination among areas in western Madagascar with generally low species diversity, thus permitting identification of areas of dry forests worthy of special attention. The northwestern sector appeared more diversified than the other western areas. The areas of highest diversity in the west coincided with some protected forest fragments (e.g., Ampijoroa, Bemaraha, Kirindy, and Isalo). Patterns of species richness on the central High Plateau paralleled the general trend toward greater richness in the east and lower richness in the west (Fig. 3a, b). In fact, the eastern portion of the High Plateau was much richer in species than its remaining portion. The flora and fauna of the eastern area of the plateau are characterized by a species composition that is more similar to the eastern rainforests than regions farther west.

The overlay of the distributions of highly threatened species showed that many of them fall primarily in the northern and northeastern highlands (Fig. 3c), including the protected areas of Masoala and Marojejy-Anjanaharibe, Tsaratanana, Manongarivo, Lokobe (Nosy Be), and Montagne d'Ambre. A second concentration point of threatened species occurred in the extreme southeast, in humid forests of the Anosy and Vohimena mountains. A third group of threatened species occurred on the central massifs of Ankaratra and Andringitra. Other areas with important concentrations of threatened species are in the vicinity of Moramanga (for many species of *Mantella*) and at Isalo Massif (for *Mantella expectata* and *Scaphiophryne gottlebei*).

Discussion

Present Extinction Status of Amphibian Fauna

An interesting result of our evaluation is that, with the exception of two species (*Anodonthyla rouxae* and *Mantidactylus ambohimitombi*), the existence of all species of Malagasy frogs described since the nineteenth century was confirmed during the last 15 years in our own fieldwork. This suggests that Madagascar has so far escaped large-scale, recent amphibian extinctions such as those reported in many other areas of the world (e.g., Central America, Australia, and the United States) (Heyer et al. 1988; Alexander & Eischeid 2001; Young et al. 2001). We currently suspect our failure to confirm *Anodonthyla rouxae* (in the Anosy Mountain chain in southeastern Madagascar) and *Mantidactylus ambohimitombi* (in the High Plateau) is a consequence of insufficient field research in these regions.

Species rarefaction of Malagasy amphibians is due mainly to habitat loss. Extensive habitat degradation and forest destruction, however, have not yet caused perceivable extinctions of amphibian species. We believe the reason for this is that amphibian species are able to survive in small forest areas within comparatively small populations. Nonetheless, habitat alteration can quantitatively affect the species composition of communities over brief time scales (Andreone 1994; Vallan 2000*b*, 2002). Although we are not aware of documented species extinctions, we cannot exclude the possibility that the extensive clearing of the High Plateau may have already caused the extinction of (unknown) locally endemic species (Raxworthy & Nussbaum, 1996; Raxworthy 2003).

Protected Areas and Endangered Species

Forty-five threatened species of frogs were found in protected areas. Of the nine CR species, only three (*Stumpffia helenae*, *Scaphiophryne gottlebei*, and *Mantella expectata*) currently occur within a protected area (Réserve Spécial d'Ambohitantely and Parc National de l'Isalo), and therefore benefit from legal protection. *M. aurantiaca* occurs at a site (Torotorofotsy Marsh) that soon will become legally protected as a Ramsar site (ANGAP 2001). Of the threatened species in other categories (EN, VU; Table 1), three are not known from protected areas: *Anodonthyla rouxae*, *Plethodontohyla coronata*, and *Scaphiophryne boribory.* Their threatened status is thus worthy of special attention in defining new protected areas.

The CR species most at risk of extinction (*Mantella cowani*, *Boophis williamsi*, *Mantidactylus pauliani*, and *Stumpffia helenae*) live on the High Plateau, where much of the original habitat has been lost because of extensive slash-and-burn agricultural practices and erosion. These species survive in only a few isolated sites surrounded by landscapes hostile to amphibians (e.g., secondary savannahs and spoiled soils) that represent dispersal barriers between populations. Degradation of montane habitats in the High Plateau may also affect other species classified as endangered: *Mantidactylus guibei, M. madecassus*, *M. microtis*, *Anodonthyla rouxae*, *Platypelis alticola*, and *Plethodontohyla guentherpetersi.*

The remaining threatened species (mostly in EN and VU categories) occur in the eastern and northwestern rainforest belt at low- to mid-elevation areas ($\leq$1000 m): *Mantella bernhardi*, *Mantidactylus brunae*, *M. horridus*, *M. microtympanum*, *M. silvanus*, *M. webbi*, *Madecassophryne truebae*, *Platypelis milloti*, *Plethodontohyla brevipes*, and *Scaphiophryne boribory.* They all have restricted ranges and some are rare or localized, although sometimes locally abundant.

Data-Deficient Species and Undersampled Areas

Forty-six species (20.6% of the known amphibians) were categorized as data deficient (DD). For these species it was difficult to provide reliable conservation recommendations, except based on ecological parameters (e.g., Andreone & Luiselli 2003). The DD list includes mostly recently described species, for which geographic distributions are still poorly known, that in many cases are still restricted to a single forest site (e.g., *Boophis feonnyala*, *B. liami*, and *B. solomaso*) (Glaw et al. 2001; Vallan et al. 2003). Field research is therefore badly needed to update and clarify their status in the wild.

The DD list also includes species whose taxonomy and identifications are provisional. Many of these are, in reality, assemblages of closely related taxa, and their systematic revision will result in the descriptions of new species. The IUCN listing will therefore need to be updated once their systematic status is resolved. Many of the DD frogs are cophyline microhylids, for which the taxonomy and even the specific attribution are often dubious (Andreone et al. 2005). For example, within this group we lack sufficient systematic resolution of *Platypelis cowani*, *P. pollicaris*, *Plethodontohyla minuta*, *Stumpffia psologlossa*, and *S. tetradactyla* to provide a reliable conservation assessment. Similar problems pertain to species of *Boophis* and *Mantidactylus* (e.g., *B. brachychir* and *M. punctatus*).

Most of the research activity in Madagascar has been carried out in areas that are already known for high species diversity (e.g., Andasibe) or have good vegetational cover (e.g., Masoala, Marojejy). There are other areas that are undersampled, such as large portions of southeastern Madagascar, especially between the Andringitra Massif and the Anosy Mountains. Especially little is known of areas that are not yet legally protected. In these areas the abundance and diversity of amphibians can be rapidly assessed; therefore, amphibians here are well suited for biological assessment surveys (Andreone & Randrianirina 2000). Indeed, the analysis of amphibian diversity in some unprotected areas was the basis for their upgrading and for integrations of protected networks, such at Betaolana between Anjanaharibe-Sud and Marojejy (Andreone et al. 2000).

Another area where the pattern of amphibian diversity is almost unknown is the central High Plateau. We believe this area was originally less rich in species than the eastern rainforest escarpment. Now heavy anthropogenic pressure has resulted in an almost total deforestation of the area and caused further impoverishment, with presence of savannah-like grasslands and eroded lands. The residual small forest fragments and small vegetation belts along the streams and rivers and a few high-elevation moors are the only surviving natural habitats. These forest islands may harbor undescribed species.

Other undersampled areas for amphibians include the western deciduous forests, which are heavily logged; the dry area between Montagne d'Ambre and the Marojejy-Masoala complex in northeastern Madagascar; and the lowlands of the east coast south of Toamasina, which is largely deforested. A program of survey work in these areas is therefore urgent.

International Trade Impacts and CITES Listings

Several CR and EN species are in demand for international trade. The genus with the highest number of threatened species is *Mantella*, with 10 out of the 15 described species, followed by *Scaphiophryne*, with 3 out of 7 species. Not all species of these genera are highly sought after by the pet trade. For example, some less attractive species of *Mantella* (e.g., *M. betsileo*, *M. bernhardi*, and *M. haraldmeieri*) are only occasionally collected for commercial purposes and are mainly threatened by habitat modifications (Rabemanjara et al. 2005). Other species (e.g., *M. nigricans*, *M. baroni*, and *M. pulchra*) are more regularly seen in commercial markets but are not especially threatened at present because they have wide distributions.

A general problem concerning traded species is the lack of information about the effect of commercial collecting on the integrity of populations. Nonetheless, it is our conviction that when ecological requirements and sensitivity to habitat alteration are combined with intensive capture, the species in question become more endangered. This is the case for *Mantella cowani*, whose small distribution, concurrent habitat alteration, and collection combine to make this one of the most threatened frog species of Madagascar (Andreone & Randrianirina 2003). In other cases, such as for *Mantella aurantiaca* and *Scaphiophryne gottlebei*, populations are still large enough to sustain some well-regulated commercial collecting.

The tomato frog, *Dyscophus antongili*, is the only species of Malagasy amphibian currently listed in CITES, Appendix I (since 1987). Its inclusion implies a complete ban on trade because large quantities of this attractive species were formerly exported. Our observations in the coastal town of Maroantsetra indicate the tomato frog is moderately common, living partly burrowed in sandy soil and reproducing in sewage ditches (Glaw & Vences 1994), and that trade does not constitute a current threat. Habitat alteration and the uncertainty of its occurrence in protected areas (e.g., no reliable records within the Masoala National Park), however, pose some problems for survivorship of the largest populations. Surprisingly, except for a few notes (e.g., Pintak 1987), little is known about this species. The tomato frog was previously categorized as vulnerable by IUCN (Raxworthy & Nussbaum 2000), whereas we classified it as near threatened. The tomato frog is regularly bred in captivity (De Vosjoli & Mailloux 1990), and this may constitute an advantage with respect to other species because the trade could be supplied with captive-bred rather than wild individuals. Instead, attention should be paid to the situation regarding *D. guineti*, which has become more subject to capture as a consequence of the inclusion of *D. antongili* in Appendix I.

Proposals for Amphibian Conservation

The CR frog species could be used to catalyze amphibian conservation action in Madagascar, where a "flagship approach" may be useful. In particular, the establishment of *Mantella* sanctuaries would afford protection for *Mantella* and other amphibian species. We suggest that at least some of these areas be integrated into a protected-area network. A possible sanctuary in central-eastern Madagascar might include the Torotorofotsy wetlands and nearby areas, where *M. aurantiaca*, *M. crocea*, *M. baroni*, and *M. pulchra* occur. At least some areas here, with a high diversity of CR species, fall within areas of high overall amphibian diversity (Fig. 3). This area and the forests surrounding Andasibe are known for their high frog diversity (>100 species, F.G. and M.V., unpublished) and for high levels of biological diversity overall.

Moreover, some other areas that host threatened species are not yet included in the protected-area network. These are, for example, Fierenana, which contains typical habitat for *Scaphiophryne boribory* and *Mantella milotympanum*, and Montagne des Français, which contains typical habitat for *Mantella viridis.* General habitat conservation in these areas will aid in the protection of the CR species, and protection of a CR species (such as *M. aurantiaca* at Torotorofotsy) will help preserve a habitat that otherwise would be subject to degradation or deforestation.

Because *Mantella cowani* is present only in relict natural habitats on the High Plateau, where the overall species diversity is low, a special effort should be made to preserve high-elevation moors and heaths where the species occurs (Raxworthy & Nussbaum 1996). This could be at some sites next to Antoetra, where the species is present and where the major haplotype richness has been confirmed (Chiari et al. 2005). Banning trade in *M. cowani* and investigating whether the species could be reliably bred in captivity to generate captive stocks should be associated with efforts to get more precise data on its distribution, population abundance, and genetic isolation. This approach must be carefully managed because the species has not yet been bred successfully in captivity.

A major concern is the conservation of other plateau species such as *Boophis williamsi* and *Mantidactylus pauliani* that occur at a few unprotected sites in areas with comparatively low species diversity. We suggest that further research be conducted on these species and that known distribution areas will benefit from special attention.

A complementary conservation approach is necessary to identify unprotected areas with high amphibian diversity. Areas thus identified can then be proposed as amphibian reserves. Some of these areas are coincident with Mantadia-Analamazaotra and the Torotorofotsy wetlands and Fierenana forest. Others are around Andohahela, the more northerly Anosy-Vohimena Mountains, and the northern corridor forests that link the four reserves of Masoala, Anjanaharibe-Sud, Marojejy, and Tsaratanana.

Some of these reserves already have well-established conservation programs, and it should be possible to include long-term monitoring programs to assess potential population changes in sensitive taxa or communities. We also envision interesting prospects for using new distribution modeling approaches in Madagascar (Raxworthy et al. 2003). This would allow us, for example, to map the distributions of amphibian species currently excluded from protected areas and thus make recommendations for new protected areas that maximize unprotected amphibian inclusion.

The inclusion of some species in CITES listings may present a reliable method for monitoring and thereby protecting species in the commercial trade. With the exception of the tomato frog, most of the other traded species are in Appendix II. The only species in trade that are not included on any list and are classified as EN or VU are *Scaphiophryne boribory* and *S. marmorata.* These two species should be incorporated in CITES Appendix II because of their attractiveness and high market demand. Regulation of their exportation would allow monitoring for this and other traded and threatened species.

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