# TURTLES ON THE BRINK IN MADAGASCAR

**PROCEEDINGS OF TWO WORKSHOPS ON THE STATUS, CONSERVATION, AND BIOLOGY OF MALAGASY TORTOISES AND FRESHWATER TURTLES** 

### Edited by

CHRISTINA M. CASTELLANO, ANDERS G.J. RHODIN, MICHAEL OGLE, RUSSELL A. MITTERMEIER, HERILALA RANDRIAMAHAZO, RICK HUDSON, AND RICHARD E. LEWIS



**CHELONIAN RESEARCH MONOGRAPHS** Number 6 – October 2013

Published by Chelonian Research Foundation

in association with

IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Conservation International, Turtle Conservancy, Turtle Survival Alliance, Durrell Wildlife Conservation Trust, Turtle Conservation Fund, Utah's Hogle Zoo, and International Union for Conservation of Nature / Species Survival Commission



## **CHELONIAN RESEARCH MONOGRAPHS** Contributions in Turtle and Tortoise Research

#### Series Editor

#### ANDERS G.J. RHODIN

Chelonian Research Foundation, 168 Goodrich Street, Lunenburg, Massachusetts 01462 USA [RhodinCRF@aol.com]

**CHELONIAN RESEARCH MONOGRAPHS** (ISSN 1088-7105), founded in 1996, is an international peer-reviewed scientific publication series for monograph-length manuscripts, collected proceedings of symposia, edited compilations, and other longer turtle-related research documents. The series accepts contributions dealing with any aspects of chelonian research, with a preference for conservation or biology. Manuscripts or edited compilations dealing with conservation biology, systematic relationships, chelonian diversity, geographic distribution, natural history, ecology, reproduction, morphology and natural variation, population status, husbandry, and human exploitation or conservation management issues are of special interest. Bibliographic and other reference materials are also of interest. Submit proposals for publications directly to Anders G.J. Rhodin at the e-mail address above. Instructions for manuscript submission and detailed guidelines for authors are available at the same address. The series is published on an occasional basis by Chelonian Research Foundation and is available for purchase and/or downloading at www.chelonian.org.

#### **Published Issues in the Series**

- 1. The Galápagos Tortoises: Nomenclatural and Survival Status. 1996. By PETER C.H. PRITCHARD. 85 pp. ISBN: 0-9653540-0-8 (hardback); 0-9653540-1-6 (paperback).
- 2. Asian Turtle Trade: Proceedings of a Workshop on Conservation and Trade of Freshwater Turtles and Tortoises in Asia. 2000. Edited by Peter Paul van Dijk, Bryan L. Stuart, and Anders G.J. Rhodin. 164 pp. ISBN: 0-9653540-2-4 (hardback); 0-9653540-3-2 (paperback).
- 3. Biology and Conservation of Florida Turtles. 2006. Edited by PETER A. MEYLAN. 376 pp. ISBN: 0-9653540-4-0 (hardback); 0-9653540-5-9 (paperback).
- 4. Defining Turtle Diversity: Proceedings of a Workshop on Genetics, Ethics, and Taxonomy of Freshwater Turtles and Tortoises. 2007. Edited by H. BRADLEY SHAFFER, NANCY N. FITZSIMMONS, ARTHUR GEORGES, AND ANDERS G.J. RHODIN. 200 pp. ISBN: 0-9653540-7-5 (hardback); 0-9653540-8-3 (paperback).
- 5. Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. 2008–2012. Edited by Anders G.J. Rhodin, Peter C.H. Pritchard, Peter PAUL VAN DIJK, RAYMOND A. SAUMURE, KURT A. BUHLMANN, JOHN B. IVERSON, AND RUSSELL A. MITTERMEIER. Installments 1–5, 843 pp. to date. ISBN: 0-9653540-9-1 (looseleaf).
- 6. Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles. 2013. Edited by Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis. 184 pp. ISBN: 978-0-9910368-0-6 (hardback), 978-0-9910368-1-3 (paperback).

**CHELONIAN RESEARCH MONOGRAPHS** are available for purchase from Chelonian Research Foundation. No overall series subscription rate is available, as individual monograph issues are priced separately. Contact Chelonian Research Foundation, 168 Goodrich Street, Lunenburg, MA 01462 USA (Phone: 978-807-2902; E-mail: RhodinCRF@aol.com; Web Site: www.chelonian.org/crm) for prices, titles, and to place orders. Chelonian Research Foundation, founded in 1992, is a private, nonprofit tax-exempt organization under section 501(c)(3) of the Internal Revenue Code.

## TURTLES ON THE BRINK IN MADAGASCAR

PROCEEDINGS OF TWO WORKSHOPS ON THE STATUS, CONSERVATION, AND BIOLOGY OF MALAGASY TORTOISES AND FRESHWATER TURTLES

EDITED BY

CHRISTINA M. CASTELLANO, ANDERS G.J. RHODIN, MICHAEL OGLE, RUSSELL A. MITTERMEIER, HERILALA RANDRIAMAHAZO, RICK HUDSON, AND RICHARD E. LEWIS







## TURTLES ON THE BRINK IN MADAGASCAR

**PROCEEDINGS OF TWO WORKSHOPS ON THE STATUS, CONSERVATION, AND BIOLOGY OF MALAGASY TORTOISES AND FRESHWATER TURTLES** 

Edited by

### CHRISTINA M. CASTELLANO<sup>1</sup>, ANDERS G.J. RHODIN<sup>2</sup>, MICHAEL OGLE<sup>3</sup>, RUSSELL A. MITTERMEIER<sup>4</sup>, HERILALA RANDRIAMAHAZO<sup>5</sup>, RICK HUDSON<sup>6</sup>, AND RICHARD E. LEWIS<sup>7</sup>

<sup>1</sup>Utah's Hogle Zoo, Salt Lake City, Utah, USA; <sup>2</sup>Chelonian Research Foundation, Lunenburg, Massachusetts, USA; <sup>3</sup>Knoxville Zoological Gardens, Knoxville, Tennessee, USA; <sup>4</sup>Conservation International, Arlington, Virginia, USA; <sup>5</sup>Turtle Survival Alliance, Antananarivo, Madagascar; <sup>6</sup>Turtle Survival Alliance, Fort Worth, Texas, USA; <sup>7</sup>Durrell Wildlife Conservation Trust Madagascar, Antananarivo, Madagascar

> CHELONIAN RESEARCH MONOGRAPHS Number 6



October 2013 Chelonian Research Foundation Lunenburg, Massachusetts

#### **COVER ILLUSTRATIONS**

- *Front Cover*: Radiated Tortoise, *sokake (Astrochelys radiata)*, on the brink along the top of the cliff of the steep escarpment in Cap Sainte Marie Special Reserve at the southern tip of Madagascar, foraging naturally high above the Indian Ocean in the late afternoon. Photo by Anders G.J. Rhodin.
- Title Page: Ploughshare Tortoise, angonoka (Astrochelys yniphora), from Madagascar. Drawing by Stephen D. Nash.
- *Frontispiece (Top)*: Madagascar Spider Tortoise, *kapila (Pyxis arachnoides arachnoides)* from the forests of Tsimanampetsotsa National Park. Photo by Ryan C.J. Walker.
- *Frontispiece (Bottom)*: Illegally poached Radiated Tortoises (*Astrochelys radiata*) being smuggled by sea at Itampolo. Photo courtesy of World Wildlife Fund.
- Back Cover (Top): Ploughshare Tortoise, angonoka (Astrochelys yniphora) at Cap Sada, Baly Bay National Park. Photo by Anders G.J. Rhodin.
- *Back Cover (Bottom)*: Madagascar Big-headed Turtle, *rere (Erymnochelys madagascariensis)* at Ampijoroa Breeding Centre. Photo by Anders G.J. Rhodin.

#### **RECOMMENDED CITATION FORMATS**

For entire volume:

CASTELLANO, C.M., RHODIN, A.G.J., OGLE, M., MITTERMEIER, R.A., RANDRIAMAHAZO, H., HUDSON, R., AND LEWIS, R.E. (Eds.). 2013. Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles. Chelonian Research Monographs No. 6, 184 pp.

For included articles:

VELOSOA, J., RANDRIAMAHITA, BEKARANY, E., RANDRIANARIMANGASON, F., MOZAVELO, R., WOOLAVER, L., GARCIA, G., AND LEWIS, R.E. 2013. An integrated research, management, and community conservation program for the Rere (Madagascar Big-headed Turtle), *Erymnochelys madagascariensis*. In: Castellano, C.M., Rhodin, A.G.J., Ogle, M., Mittermeier, R.A., Randriamahazo, H., Hudson, R., and Lewis, R.E. (Eds.). Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles. Chelonian Research Monographs 6:171–177.

 $CHELONIAN \ Research \ Monographs. \ Series \ Edited \ by \ Anders \ G.J. \ Rhodin.$ 

VOLUME NUMBER 6. Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles. Volume Edited by Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis.

CRM No. 6, published online at www.chelonian.org on 30 October 2013, printed 27 November 2013.

ISSN (monograph series): 1088-7105 ISBN (this volume): 978-0-9910368-0-6 (hardback), 978-0-9910368-1-3 (paperback)

Published and Copyright © 2013 by Chelonian Research Foundation, Lunenburg, Massachusetts, USA. Printed by MTC Printing, Inc., Leominster, Massachusetts, USA.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

### **TABLE OF CONTENTS**

Contributing Authors
INTRODUCTION
Introduction: Turtles on the Brink in Madagascar.
Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle,
RUSSELL A. MITTERMEIER, HERILALA RANDRIAMAHAZO, RICK HUDSON, AND RICHARD E. LEWIS
Madagascar: island continent of tortoises great and small.
Peter C.H. Pritchard
The tortoises and freshwater turtles of Madagascar in the context of biodiversity conservation
in the Madagascar Hotspot.
RUSSELL A. MITTERMEIER, PETER PAUL VAN DIJK, ANDERS G.J. RHODIN, AND STEPHEN D. NASH25
IUCN RED LISTING WORKSHOP
Turtles on the Brink in Madagascar: an IUCN Red Listing assessment workshop.
PETER PAUL VAN DIJK, THOMAS E.J. LEUTERITZ, ANDERS G.J. RHODIN,
RUSSELL A. MITTERMEIER, AND HERILALA RANDRIAMAHAZO
Vision sokatra gasy-Madagascar turtle vision.
(Reprint from 2008 Turtle and Tortoise Newsletter)
Russell A. Mittermeier, Anders G.J. Rhodin, Herilala Randriamahazo, Richard E. Lewis,
Peter Paul van Dijk, Rick Hudson, and Sébastien Rioux Paquette
Madagascar turtles and tortoises in CITES.
Thomas E.J. Leuteritz and Peter Paul van Dijk
IUCN RED LIST ASSESSMENTS
(Reprints from 2008 IUCN Red List, www.iucnredlist.org)
Astrochelys radiata. Thomas E.J. Leuteritz and Sébastien Rioux Paquette
Astrochelys yniphora. THOMAS E.J. LEUTERITZ AND MIGUEL PEDRONO
Pyxis arachnoides. Thomas E.J. Leuteritz and Ryan C.J. Walker
Pyxis planicauda. Thomas E.J. Leuteritz, Herilala Randriamahazo, and Richard E. Lewis
Erymnochelys madagascariensis. Thomas E.J. Leuteritz, Gerald Kuchling,
Gerardo Garcia, and Juliette Velosoa
CONSERVATION AND BIOLOGY

#### 

Decline in the range and population density of Radiated Tortoises, Astrochelys radiata, in	
southern Madagascar.	
TSILAVO H. RAFELIARISOA, RYAN C.J. WALKER, AND EDWARD E. LOUIS, JR	86
The SOKAKE Project: conservation of Astrochelys radiata in southern Madagascar.	
Bernard Devaux	93
Community outreach and education promoting the conservation of the Radiated Tortoise,	
Astrochelys radiata, in Lavavolo, Madagascar.	
SUSIE MCGUIRE, TSILAVO H. RAFELIARISOA, HERILALAINA RANDRIAMANANTENASOA,	
VELOARIVONY R.A. RANDRIANINDRINA, GARY D. SHORE, AND EDWARD E. LOUIS, JR	97
Sexual dimorphism in Radiated Tortoises (Astrochelys radiata).	
THOMAS E.J. LEUTERITZ AND DONALD T. GANTZ	105
Endoscopic imaging of gonads, sex ratio, and temperature-dependent sex determination in	
juvenile captive-bred Radiated Tortoises, Astrochelys radiata.	
GERALD KUCHLING, ERIC V. GOODE, AND PETER PRASCHAG.	113
Do bigger females produce bigger eggs? The influence of female body mass on egg mass	
in Astrochelys radiata.	
Jutta M. Hammer	119
Illegal poaching of Radiated Tortoises, Astrochelys radiata, in arid southern Madagascar:	
contributing factors, conservation initiatives, critical challenges, and potential solutions.	
TIANA A. RAMAHALEO AND MALIKA VIRAH-SAWMY	124
Repatriated Malagasy tortoises contribute to their survival.	
Léon A. Razafindrakoto.	132
Conservation of the Madagascar Spider Tortoise ( <i>Pyxis arachnoides</i> ) amid changing land	
use policy: assessing the spatial coincidence of relict populations with protected areas and	
mining concessions.	
RYAN C.J. WALKER, CHARLIE J. GARDNER, TSILAVO H. RAFELIARISOA, INGE SMITH,	
RICHARD RAZAFIMANATSOA, AND EDWARD E. LOUIS, JR.	135
Ecological husbandry and reproduction of the Madagascar Spider ( <i>Pyxis arachnoides</i> )	
and Flat-tailed ( <i>Pyxis planicauda</i> ) Tortoises.	
DANIEL W. PEARSON.	146
Proposed action plan for the conservation of the Madagascar Spider Tortoise.	
Pyxis arachnoides.	
RYAN C.J. WALKER, CHRISTINA M, CASTELLANO, MICHAEL OGLE, TSILAVO H, RAFELIARISOA,	
RIANA RAKOTONDRAINY, TIANA A. RAMAHALEO, HERILALA RANDRIAMAHAZO,	
AND CHARLIE J. GARDNER.	153
Conservation of the Angonoka (Ploughshare Tortoise), Astrochelvs vniphora.	
A. Ross Kiester, Angelo R. Mandimbihasina, Richard E. Lewis, Eric V. Goode,	
JAMES O. JUVIK, RICHARD YOUNG, AND TORSTEN BLANCK.	162
An integrated research, management, and community conservation program for the Rere	
(Madagascar Big-headed Turtle). Ervmnochelvs madagascariensis.	
JULIETTE VELOSOA, LANCE WOOLAVER, RANDRIAMAHITA, ERNEST BEKARANY.	
FI ORIOT RANDRIANARIMANGASON RICHARD MOZAVELO GERARDO GARCIA AND RICHARD E. LEWIS	171
Tortoise breeding and 're-wilding' on Rodrigues Island	
Owen Griefetths Alirei E Andre and Arnalid Meunied	178
Ower GRITTINS, HOREE HADRE, AND HEAVIND WEUNER.	

#### TURTLE POETRY

Ancient chelonians.
(Reprint from 1999 Chelonian Conservation and Biology)
ANDERS G.J. RHODIN

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

## **CONTRIBUTING AUTHORS**

#### AURELE ANDRE

Anse Quitor, Rodrigues [arpege@orange.mu]

#### ERNEST BEKARANY

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [ampijoroaa@yahoo.com]

#### TORSTEN BLANCK

Turtle Survival Alliance Europe, Forstgartenstrasse 44, Deutchlandsberg, 8530 Styria, Austria [cuora\_yunnanensis@yahoo.com]

#### CHRISTINA M. CASTELLANO

Utah's Hogle Zoo, 2600 Sunnyside Avenue, Salt Lake City, Utah 84108 USA [ccastellano@hoglezoo.org]

#### BERNARD DEVAUX

SOPTOM – Turtle Village, P.O. Box 24, 83590 Gonfaron, France [soptom@wanadoo.fr]

#### J. SEAN DOODY

Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, Tennessee 37996 USA [jseandoody@gmail.com]

#### JULIO DUCHENE

University of Tulear, 601 Tulear, Madagascar [djjosepha@gmail.com]

#### DONALD T. GANTZ

Department of Applied Information Technology, George Mason University, Fairfax, Virginia 22030 USA [dgantz@gmu.edu]

#### GERARDO GARCIA

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar; Present Address: Chester Zoo, Upton-by-Chester, Chester, CH2 1LH United Kingdom [g.garcia@chesterzoo.org]

#### CHARLIE J. GARDNER

Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NS, United Kingdom; and WWF Madagascar and Western Indian Programme Office, BP 738, Antananarivo 101, Madagascar [cjamgardner@yahoo.co.uk]

#### ERIC V. GOODE

Turtle Conservancy, 49 Bleecker Street, Suite 601, New York, New York 10012 USA [eric@turtleconservancy.org]; and Behler Chelonian Center, Ojai, California 93024 USA

#### **OWEN GRIFFITHS**

Autard Street #6, Souillac, Mauritius [owen@bcm.intnet.mu]

#### JUTTA M. HAMMER

Department of Animal Ecology and Conservation, University of Hamburg, Biozentrum Grindel und Zoologisches Museum, Universität Hamburg, Martin-Luther-King Platz 3, 20146 Hamburg, Germany [jutta.m.hammer@gmail.com]

#### **RICK HUDSON**

Turtle Survival Alliance, 1989 Colonial Parkway, Fort Worth, Texas 76110 USA [rhudson@fortworthzoo.org]

#### A. Ross Kiester

Turtle Conservancy, 49 Bleecker St., Suite 601, New York, New York 10012 USA [ross@turtleconservancy.org]

#### GERALD KUCHLING

Chelonia Enterprises, 28 Tokay Lane, The Vines, Western Australia 6069, Australia; and School of Animal Biology, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6008, Australia [Gerald.Kuchling@uwa.edu.au]

#### JAMES O. JUVIK

Turtle Conservancy, 49 Bleecker St., Suite 601, New York, New York 10012 USA [jim@turtleconservancy.org]

#### THOMAS E.J. LEUTERITZ

U.S. Fish and Wildlife Service, Division of Scientific Authority, 4401 N. Fairfax Dr. Suite 110, Arlington, Virginia 22203 USA [thomas leuteritz@fws.gov]

#### **RICHARD E. LEWIS**

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [richard.lewis@durrell.org]

#### Edward E. Louis, Jr.

Madagascar Biodiversity Partnership, ONG, VO 12 Bis A, Manakambahiny, Antananarivo 101, Madagascar; and Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, Nebraska 68107 USA [genetics@omahazoo.com]

#### ANGELO R. MANDIMBIHASINA

Durrell Wildlife Conservation Trust, BP 8511, Antananarivo, Madagascar [angelo.ramy@durrell.org]

#### SUSIE MCGUIRE

Conservation Fusion, Inc., 5820 Spring St., Omaha, Nebraska 68106 USA [conservationfusion@gmail.com]

#### ARNAUD MEUNIER

Fond la Digue, Port Mathurin, Rodrigues [arnaud@torti.intnet.mu]

#### **RUSSELL A. MITTERMEIER**

Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [rmittermeier@conservation.org]

#### **RICHARD MOZAVELO**

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [ampijoroaa@yahoo.com]

#### STEPHEN D. NASH

Conservation International, Dept. of Anatomical Sciences, Health Sciences Center, State University of New York, Stony Brook, New York 11794 USA [stephen.nash@stonybrook.edu]

#### MICHAEL OGLE

Knoxville Zoological Gardens, 3500 Knoxville Zoo Drive, Knoxville, Tennessee 37914 USA [mogle@knoxville-zoo.org]

#### **DANIEL W. PEARSON**

Florida Department of Environmental Protection, 4801 Camp Ranch Rd., Gainesville, Florida 32641 USA [Pyxis99@gmail.com]

#### MIGUEL PEDRONO

CIRAD, UPR AGIRs, B.P. 853, Antananarivo 101, Madagascar [miguel.pedrono@cirad.fr]

#### PETER PRASCHAG

Behler Chelonian Center, Ojai, California 93024 USA; Present Address: Am Katzelbach 98, 8054 Graz, Austria [peter@praschag.at]

#### PETER C.H. PRITCHARD

Chelonian Research Institute, 402 South Central Avenue, Oviedo, Florida 32765 USA [chelonianri@gmail.com]

#### TSILAVO H. RAFELIARISOA

Département de Biologie Animale, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar [rafelykely@hotmail.com]; and Madagascar Biodiversity Partnership, ONG, VO 12 Bis A, Manakambahiny, Antananarivo 101, Madagascar; and Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, Nebraska 68107 USA

#### **RIANA RAKOTONDRAINY**

Department of Animal Biology, Faculty of Sciences, University of Antananarivo, P.O. Box 906, Antananarivo 101, Madagascar [riana\_mia@yahoo.co.uk]

#### TANTELINIRINA RAKOTONDRIAMANGA

Department of Animal Biology, Faculty of Sciences, University of Antananarivo, P.O. Box 906, Antananarivo 101, Madagascar [ratah83@yahoo.fr]

#### TIANA A. RAMAHALEO

World Wildlife Fund Madagascar and Western Indian Ocean Programme Office, B.P. Antananarivo 101, Madagascar [tramahaleo@wwf.mg]

#### ZIGZAG RANDRIA

Forestier Betioky-sud, CP612, Madagascar

#### HERILALA RANDRIAMAHAZO

Wildlife Conservation Society, BP 8500, Antananarivo 101, Madagascar; Present Address: Turtle Survival Alliance, Antananarivo 101, Madagascar [herilala@turtlesurvival.org]

#### RANDRIAMAHITA

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [ampijoroaa@yahoo.com]

#### HERILALAINA RANDRIAMANANTENASOA

Conservation Fusion, Inc., 5820 Spring St., Omaha, Nebraska 68106 USA [conservationfusion@gmail.com]

#### FLORIOT RANDRIANARIMANGASON

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [floriot\_dw@yahoo.com]

#### VELOARIVONY R.A. RANDRIANINDRINA

Madagascar Biodiversity Partnership, ONG, VO 12 Bis A, Manakambahiny, Antananarivo 101, Madagascar; and Département de Biologie et Ecologie Végétales, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar [renceaimee@yahoo.fr]

#### **RICHARD RAZAFIMANATSOA**

Madagascar National Parks, BP 1424, 103 Antananarivo, Madagascar

#### LEON A. RAZAFINDRAKOTO

Association Salamandra Nature, 10 Route de Courcival, 72210 Rouperroux-Le-Coquet, France [razaleofr@yahoo.fr]

#### ANDERS G.J. RHODIN

Chelonian Research Foundation, 168 Goodrich St., Lunenburg, Massachusetts 01462 USA [rhodincrf@aol.com]

#### Sébastien Rioux Paquette

Département Sciences Biologiques, Université de Montréal, CP 6128, Succursale Centre-Ville, Montréal, H3C3J7 Québec, Canada [sebastien.rioux.paquette@umontreal.ca]

#### WILLIAM RONTO

Department of Animal Biology, Faculty of Sciences, University of Antananarivo, P.O. Box 906, Antananarivo 101, Madagascar [ronto84mananjara@yahoo.fr]

#### GARY D. SHORE

Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, Nebraska 68107 USA [genetics@omahazoo.com]

#### INGE SMITH

Gardline Marine Sciences Limited, Endeavour House, Admiralty Road, Great Yarmouth, Norfolk, NR30 3NG, United Kingdom [inge.smith@gardline.co.uk]

#### LORA L. SMITH

Joseph W. Jones Ecological Research Center, 3988 Jones Center Rd., Newton, Georgia 39870 USA [lora.smith@jonesctr.org]

#### PETER PAUL VAN DIJK

Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [pvandijk@conservation.org]

#### JULIETTE VELOSOA

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [juliette.velosoa@durrell.org]

#### MALIKA VIRAH-SAWMY

World Wildlife Fund Madagascar and Western Indian Ocean Programme Office, B.P. Antananarivo 101, Madagascar

#### RYAN C.J. WALKER

Nautilus Ecology, Oak House, Pond Lane, Greetham, Rutland, LE15 7NW, United Kingdom [ryan@nautilusecology.org]; and Department of Life Sciences, The Open University, Milton Keynes, MK7 6AA, United Kingdom

#### LANCE WOOLAVER

Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [lance.woolaver@durrell.org]

#### **RICHARD YOUNG**

Durrell Wildlife Conservation Trust, c/o Dept. of Biology and Biochemistry, University of Bath, Bath, BA2 7AY, Great Britain [richard.young@durrell.org]



# Endemic tortoise and freshwater turtle species of Madagascar, depicted in approximate relative sizes.

Top left: Ploughshare Tortoise (Astrochelys yniphora);Top right: Radiated Tortoise (Astrochelys radiata);Bottom left: Spider Tortoise (Pyxis arachnoides);Bottom center: Flat-tailed Tortoise (Pyxis planicauda);Bottom right: Big-headed Turtle (Erymnochelys madagascariensis).Drawings by Stephen D. Nash.

#### Introduction: Turtles on the Brink in Madagascar

#### CHRISTINA M. CASTELLANO<sup>1</sup>, ANDERS G.J. RHODIN<sup>2</sup>, MICHAEL OGLE<sup>3</sup>, RUSSELL A. MITTERMEIER<sup>4</sup>, HERILALA RANDRIAMAHAZO<sup>5</sup>, RICK HUDSON<sup>6</sup>, AND RICHARD E. LEWIS<sup>7</sup>

<sup>1</sup>Utah's Hogle Zoo, 2600 Sunnyside Avenue, Salt Lake City, Utah 84108 USA [ccastellano@hoglezoo.org];

<sup>2</sup>Chelonian Research Foundation, 168 Goodrich St., Lunenburg, Massachusetts 01462 USA [rhodincrf@aol.com];

<sup>3</sup>Knoxville Zoological Gardens, 3500 Knoxville Zoo Drive, Knoxville, Tennessee 37914 USA [mogle@knoxville-zoo.org];

<sup>4</sup>Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [rmittermeier@conservation.org];

<sup>5</sup>Turtle Survival Alliance, Antananarivo 101, Madagascar [herilala@turtlesurvival.org];

<sup>6</sup>Turtle Survival Alliance, 1989 Colonial Parkway, Fort Worth, Texas 76110 USA [rhudson@fortworthzoo.org]; <sup>7</sup>Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [richard.lewis@durrell.org]

In January 2008, a three-day IUCN Red Listing workshop on the conservation status of Malagasy tortoises and freshwater turtles was held in Antananarivo, Madagascar. Organized by the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group and co-sponsored by the Wildlife Conservation Society and Conservation International, the workshop brought together many chelonian specialists from several nations. Subsequently, a second workshop was held in August 2010 on the conservation of these species at the 8th Annual Joint Meeting of the Turtle Survival Alliance and the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group in Orlando, Florida. We now present the published proceedings of the Red List status updates generated there, as well as the presented papers by most of the participants at these workshops, along with additional invited contributions.

These workshops could not have come at a more pressing time. As a result of the Red Listing workshop, all five of Madagascar's endemic chelonians have now been assessed as Critically Endangered on the IUCN Red List of Threatened Species. In addition, they are all listed on either Appendix I or II of the Convention on International Trade in Endangered Species (CITES). Moreover, two species (the Ploughshare Tortoise and the Madagascar Big-headed Turtle)are currently listed among the world's top 25 endangered tortoises and freshwater turtles (Turtle Conservation Coalition, 2011).

Illegal collection for the international pet trade, human consumption, and medicinal products, along with massive habitat loss are driving these species to the brink of extinction. The Madagascar chelonian fauna is now among the most endangered in the world, and unless we act we will soon lose these iconic species in the wild. The threats of habitat loss and unsustainable overexploitation faced by these Malagasy species are similar to what has already decimated the turtle populations of Asia (van Dijk et al. 2000) and are increasingly also affecting turtles all over the world, including North America and Sub-Saharan mainland Africa (IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, 2010, and unpubl. data). Turtles and tortoises have unfortunately and alarmingly become one of the most threatened large groups of vertebrates in the world, with over 50% of all species classified as Critically Endangered, Endangered, or Vulnerable by the IUCN Red List (www. iucnredlist.org) and the IUCN Tortoise and Freshwater Turtle Specialist Group (Turtle Taxonomy Working Group, 2012).

Madagascar has nine native chelonian species, with five of them endemic (Leuteritz et al. 2008; Pedrono 2008). These include the Radiated Tortoise (*Astrochelys radiata*) (Fig. 1), the Ploughshare Tortoise (*Astrochelys yniphora*) (Fig. 2), the Spider Tortoise (*Pyxis arachnoides*, with three subspecies—*arachnoides*, *brygooi*, and *oblonga*) (Fig. 3), the Flat-tailed Tortoise (*Pyxis planicauda*) (Fig. 4), and the Madagascar Big-headed Turtle (*Erymnochelys madagascariensis*) (Fig. 5).

In addition, there are four species that also have widespread African continental distributions in addition to their occurrence on Madagascar. Whether their presence on Madagascar represents natural dispersal or human-mediated introductions in prehistoric times remains open for debate. These four species include: the Hinge-back Tortoise (*Kinixys zombensis domerguei* [formerly referred to *Kinixys belliana belliana*], possibly an endemic subspecies) (Fig. 6), the African Helmeted Turtle (*Pelomedusa subrufa*) (Fig. 7), the Yellow-bellied Mud Turtle (*Pelusios castanoides castanoides*) (Fig. 8), and the Black Mud Turtle (*Pelusios subniger subniger*) (Fig. 9).

Of the five endemic species, the once numerous Radiated Tortoise, found only in the southern spiny forest has vanished entirely from about 65% of its past range, while even more staggering is the disappearance of the sympatric Spider Tortoise from approximately 80% of its historical range. The Flat-tailed Tortoise population currently numbers about 28,000 (higher than previous estimates), but is restricted to habitat fragments in the Kirindy Forest in the west. And the Ploughshare Tortoise, with less than 600 individuals is restricted to a small area around Baly Bay in the northwest. The Madagascar Big-headed Turtle from the western lowlands has also suffered from severe population declines and in some areas is considered to be locally extinct.

More than 80 conservationists from over 12 different countries attended the workshop in Antananarivo, many of whom also presented at the workshop in Orlando and later contributed to the 27 papers (21 original and 6 reprinted articles by 55 authors) compiled in this special volume of *Chelonian Research Monographs*. The papers included here cover a wide range of subjects, including natural history, field-based research, population management, communitybased conservation, reintroduction, reproductive biology, and captive breeding. The five Red List assessments produced as a result of the first workshop are also included as reprinted publications, as is the summary statement issued after that first meeting.

Overall, this volume represents an eclectic mix of theory and practice, tradition and innovation, and expectation and practicality that provides a rich diversity of perspectives on conservation strategies and management options for these imperiled species. Natural history parameters and distribution patterns as well as threats and status are all documented and updated. Presented and discussed are also various conservation and management implementations, including habitat and nest protection, headstarting, protected area designations, captive breeding and repatriation programs, community outreach and engagement efforts, and needed enforcement measures against poaching and illegal trade.

Our hope is that the papers presented here will offer new information and insight that can be applied towards on-the-ground conservation action in Protected Areas and other habitats, as well as for both *in-situ* and *ex-situ* conservation and breeding programs. Equally important is that these papers also help to increase the collaboration between individuals and organizations that are working tirelessly to save these species on the brink of extinction.

Since these workshops were held, the plight of the two larger tortoises, A. yniphora and A. radiata, has worsened considerably. Astrochelys yniphora now faces imminent extinction due to a burgeoning black market trade that is rapidly depleting remnant wild populations. Populations of A. radiata are currently under intense collection pressures both juveniles and adults-that have truly reached crisis proportions. But there is some good news as well: although P. planicauda may have small numbers as a single-site endemic, its situation has improved over the last decade with the stemming of the international trade through a CITES Appendix I listing, and the designation of a Protected Area which includes most of its range. Similarly, the situation for *Erymnochelys* is not as bleak as it is for *Astrochelys*, given the series of wetland protected areas that are being established which will benefit the species.

Of major importance is that these two workshops and the resultant networking has also led directly to the convening of a national chelonian workshop held in Mahajanga in September 2011, with the subsequent publication of a Malagasy national global action framework plan for the conservation of Madagascar's chelonians (Raonintsoa et al. 2012). It is our hope that the vision and specific action plans articulated in that publication will help reverse the trend of increasing losses of turtle habitats and populations documented at the two original workshops and memorialized here.

The conservation of Madagascar's endemic turtles and tortoises is a daunting, but attainable mission. Since 2009 there has been significant political instability that has resulted in decreased humanitarian aid and increased exploitation of the country's natural resources. Consequently, in addition to primary *in-situ* conservation efforts, we must also focus our efforts on supporting environmental education and training, community-driven conservation initiatives, protected areas management, and science-based reintroduction programs. And of increasingly vital importance is that we must enhance and provide assistance to those agencies that are charged with preventing illegal collection of turtles and tortoises and protecting and restoring their natural habitats.

We hope that the people and organizations that care about the preservation of Madagascar's unique and spectacular biodiversity will feel inspired by this monograph to increase their efforts to make a difference both on the ground and in the political arena. The turtles and tortoises of Madagascar need all the help they can get, and grassroots organizations cannot do it alone. Without engaged participation from Madagascar's government and large multinational NGO's and key intergovernmental agencies, the future of Madagascar's wonderful chelonian diversity remains in precarious balance.

The future status of Madagascar's turtles and tortoises unfortunately remains uncertain and "on the brink". Perhaps the knowledge of the increasingly critically endangered status of Madagascar's turtles and tortoises can help stimulate a tipping point for enhanced conservation efforts directed at these species and their rapidly disappearing habitats. The recently published Malagasy national global action plan is a welcome and important step in that direction. We all owe it to our children and coming generations to preserve this globally important hotspot of unique biodiversity—in this we must not fail.

Acknowledgments. — Many share responsibility for the success of these workshops and the publication of these proceedings. Appreciation is extended to the Wildlife Conservation Society Madagascar, Conservation International Madagascar, Durrell Wildlife Conservation Trust Madagascar, Madagascar's Ministère de l'Environnement, des Eaux et Forêts et du Tourisme and l'Association Nationale pour la Gestion des Aires Protégées (ANGAP) (Parcs Nationaux Madagascar), World Wildlife Fund Madagascar, Turtle Conservation Fund, EAZA's Shellshock Campaign, Chelonian Research Foundation, Turtle Survival Alliance, Eric Goode and Behler Chelonian Center / Turtle Conservancy, Matt Frankel and Frankel Family Foundation, Moore Family Foundation, George Meyer and Maria Semple, Utah's Hogle Zoo, and the Andrew Sabin Family Foundation. We also most gratefully acknowledge Peter Paul van Dijk and Thomas Leuteritz for their major efforts in gathering and collating the data that served as the initial basis for the updated Red List assessments by the Antananarivo workshop participants, without which we could not have accomplished our task. Special thanks also to Andrew Walde and Beth Walton for helping to make the subsequent Orlando workshop a reality, and our gratitude to Riana Rakotondrainy for providing translated French résumés for all the articles.

#### LITERATURE CITED

- IUCN/SSC TORTOISE AND FRESHWATER TURTLE SPECIALIST GROUP. 2010. A study of progress on conservation of and trade in CITESlisted tortoises and freshwater turtles in Asia. CITES CoP15 Inf. 22, 34 pp.
- LEUTERITZ, T.E., GERLACH, J., MITTERMEIER, R.A., RHODIN, A.G.J., VAN DIJK, P.P., LEWIS, R., AND RANDRIAMAHAZO, H. 2008. Conservation International Tropical Pocket Guide Series: Turtles and tortoises of Madagascar and adjacent Indian Ocean islands. Arlington, Virginia: Conservation International.

PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota

Kinabalu: Natural History Publications (Borneo) Sdn. Bhd. 147 pp.

- RAONINTSOA, P., RAMIARISON, C., RABESIHANAKA, S., ROBSOMANI-TRANDRASANA, E., ZAFISOAMALALA, C., ANDRIAMANGA, A., RAN-DRIANASOLO, H., MANDIMBIHASINA, A., RANDRIAMANAMPISOA, H., RANDRIAMAHAZO, H., AND RAZAKAMANARINA, N. 2012. Plan Global d'Actions Pour la Protection des Tortues Endémiques de Madagascar. Antananarivo, Madagascar: Ministère de l'Environnement et des Forêts, 62 pp.
- TURTLE CONSERVATION COALITION [RHODIN, A.G.J., WALDE, A.D., HORNE, B.D., VAN DIJK, P.P., BLANCK, T., AND HUDSON, R. (Eds.)]. 2011. Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles — 2011. Lunenburg, MA: IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Turtle Conservation Fund, Turtle Survival Alliance, Turtle Conservancy, Chelonian Research Foundation, Conservation International, Wildlife Conservation Society, and San Diego Zoo Global, 54 pp.
- TURTLE TAXONOMY WORKING GROUP [VAN DIJK, P.P., IVERSON, J.B., SHAFFER, H.B., BOUR, R., AND RHODIN, A.G.J.]. 2012. Turtles of the world, 2012 update: annotated checklist of taxonomy, synonymy, distribution, and conservation status. Chelonian Research Monographs 5:000.243–328.
- VAN DIJK, P.P., STUART, B.L., AND RHODIN, A.G.J. (Eds.). 2000. Asian Turtle Trade: Proceedings of a Workshop on Conservation and Trade of Freshwater Turtles and Tortoises in Asia. Chelonian Research Monographs No. 2, 164 pp.

#### Madagascar's Endemic Tortoise and Freshwater Turtle Species



Figure 1. Radiated Tortoise, sokake (Astrochelys radiata) at the Cap Sainte Marie Special Reserve. Photo by Anders G.J. Rhodin.



Figure 2. Ploughshare Tortoise, angonoka (Astrochelys yniphora) at Cap Sada, Baly Bay National Park. Photo by Anders G.J. Rhodin.



Figure 3. Spider Tortoise, kapila (Pyxis arachnoides) at Berenty Nature Reserve. Photo by Anders G.J. Rhodin.



Figure 4. Flat-tailed Tortoise, kapidolo (Pyxis planicauda) at Kirindy Forest Nature Reserve. Photo by Anders G.J. Rhodin.



Figure 5. Madagascar Big-headed Turtle, rere (Erymnochelys madagascariensis) at Ampijoroa Breeding Centre. Photo by Anders G.J. Rhodin.

### Madagascar's Non-Endemic Tortoise and Freshwater Turtle Species



**Figure 6.** Hinge-back Tortoise (*Kinixys zombensis domerguei* [formerly *Kinixys belliana belliana*], possibly an endemic subspecies) on Nosy Faly island. Photo by Thomas E.J. Leuteritz.



**Figure 7.** African Helmeted Turtle (*Pelomedusa subrufa*) on the road to Cap Sainte Marie. Photo by Anders G.J. Rhodin.



**Figure 8.** Yellow-bellied Mud Turtle (*Pelusios castanoides castanoides*) from Ambatomainty, Baly Bay National Park. Photo by Maurice Rodrigues, Turtle Conservancy.



**Figure 9.** Black Mud Turtle (*Pelusios subniger subniger*) from continental eastern Africa. Photo by Donald G. Broadley.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a02p17 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

#### Madagascar: Island Continent of Tortoises Great and Small

**PETER C.H. PRITCHARD**<sup>1</sup>

<sup>1</sup>Chelonian Research Institute, 402 South Central Avenue, Oviedo, Florida 32765 USA [chelonianri@gmail.com]

ABSTRACT. – Most areas of the thousand-mile-long island of Madagascar do not have tortoises, and there is very little overlap in the ranges of the handful of species still found there today. True giant tortoises have been extinct there since early human times. The surviving tortoise species in Madagascar are notable for their extraordinary beauty, their slow growth and longevity, and the heavy human impact that is now pushing all towards extinction.

KEY WORDS. - Reptilia, Testudines, Testudinidae, body size, shell, extinction, Madagascar

The thousand-mile long island of Madagascar, partly within the tropics and partly temperate, was a biological paradise for millions of years before humans arrived from Asia and Africa about 2000 years ago. This halcyon fauna included extraordinary creatures, among them the elephant birds (three species of *Aepyornis* and three of *Mullerornis*); three species of *Hippopotamus*; an array of lemur genera and species that ranged from the diminutive mouse lemur (*Microcebus*) to some as large as bears (*Megaladapis, Archaeoindris,* and *Palaeopropithecus*); and, not forgetting the spectacular array of amphibians and reptiles, almost all endemic to the island. There are thought to be about 300 amphibian species, all but 35 endemic to the island.

Since the arrival of humans, overexploitation of the extraordinary endemic fauna and unsustainable agricultural practices, have systematically reduced that fauna from the top down. The large lemurs are gone, although we are left with some of medium size, including the wonderful and totally bizarre aye-aye (Daubentonia), and many small ones. The colossal elephant bird, Aepyornis maximus, is now recognized as having been exterminated just a millennium ago, with its formidable eggshells still a prestigious commodity for treasure seekers in the deserts in the extreme south of the island; and, one of the largest tortoise species in the world, Dipsochelys grandidieri, became extinct about 1200 years ago. This huge tortoise, with its depressed and extremely thick carapace, is known from about a dozen subfossil shells, mostly now in the Paris Museum (Fig. 1), and many fragments, found scattered over the southwestern quarter of the island and into the highlands. It was partially sympatric with another large tortoise species, Dipsochelys abrupta, which in sharp contrast to grandidieri was characterized by a very high, domed carapace (Fig. 2). The strongly depressed shell of D. grandidieri gave rise to the original name that Grandidier himself gave to this tortoise, namely Emys gigantea. Emys is the generic name for the European pond turtles, and in earlier days it encompassed all freshwater chelonians; in this case, Grandidier wrongly

assumed that a chelonian species with such a flat shell must be aquatic.

The question arises as to why D. grandidieri was not only very large (carapace length up to 125 cm), but also very thick-shelled (up to about 40 mm in the marginal areas). The specimen collection at the Chelonian Research Institute includes complete shells of two large tortoise species, Chelonoidis nigra duncanensis (from the Galápagos Islands) and C. denticulata (from continental South America) of identical length, but the latter weighs five times as much as the former. Some giant tortoises, especially the extinct species of the Mascarene Islands and also the recently extinct C.n. abingdonii in the Galapagos, had very thin shells. Hatchling tortoises of any kind are small enough to be swallowed whole by even small and medium-size predators. But the force behind the differences in shell thickness between the small island tortoises and the Madagascar giant may lie in the absence of large predators on the oceanic islands with, or formerly with, large tortoises, and their presence on Madagascar itself, with its spectacular megafauna (before the arrival of humans). In such a case, a thick carapace may indeed have provided some protection, at least in sub-adult and adult specimens, from predators such as the fossa (also called "foos"), a mammal appearing to the layman as being somewhere between a felid and a canid, as well as other predators now entirely extinct. It has been noted that the few mammalian carnivore species known from Madagascar are "derived from a single common ancestor that colonized Madagascar only once, sometime in the past" (Yoder and Flynn 2003). It is also important to realize that very large tortoises were widespread in Pleistocene times from the Bahamas, several Caribbean Islands, Florida, Spain, and through Europe to India and Asia, as far east as Java. Such large tortoises may have once been the norm throughout much of the world, not just on certain remote islands, until they were restricted to small islands by the spread of humanity over all the continents.

Perhaps the giant birds of Madagascar's past produced some predatory forms that may have been dangerous to



Figure 1. Dipsochelys grandidieri shell in the Paris Museum, collected at Etseré, Madagascar. Photo by Peter C.H. Pritchard.

young tortoises, just as Great Ground Hornbills today are serious predators of Leopard Tortoises up to at least halfgrown in size in Botswana and South Africa, and ravens in the California deserts, their populations swollen by access to tourist trash, are constant predators upon hatchling desert tortoises.

One may assume that *D. grandidieri* had ancestors in East Africa, the passive ocean crossing to Madagascar being an entirely feasible one, especially when Madagascar was closer to the continent than it is today. In this case, the massive carapace, of adult tortoises at least, might well have deterred predation by the classic carnivores that remain in East Africa today – lions, hyenas, cheetahs, leopards, hunting dogs, etc., and their ancestors and forebears, and perhaps the remarkable armor, while no longer essential, was at least not a hindrance to survival in Madagascar.

An interesting specialized morphological feature, the remarkable upward expansion of the nasal opening at the front of the skull of *D. grandidieri*, must have been an adaptation for "snorting" water from very shallow and otherwise inaccessible rain puddles, in places and at times where rain could be a very limiting and indeed a limited commodity. On its own, this statement about behavior in an extinct species would appear to be rank speculation, but there is evidence that this is not the case. The Aldabra tortoise (variously known as either *Dipsochelys dussumieri* or *Aldabrachelys gigantea*), and the closest relative to *grandidieri*, survives and indeed flourishes on its isolated

atoll not far from northern Madagascar and has the ability to secure a drink during hard times in exactly this fashion. Dipsochelys grandidieri's ancestors came from the west, but its descendants went north, or perished; the relationship between the extinct giants of Madagascar and the surviving large tortoises of Aldabra has now been confirmed by genetic comparison (Palkovacs et al. 2002). Genetic analysis has also indicated that the tortoises formerly found on the northern tier of the Western Indian Ocean Islands that bear the species names *ponderosa*, *gouffei*, *daudinii*, arnoldi, sumeirei, hololissa, dussumieri, etc. cannot readily be distinguished genetically from the Aldabra tortoise (Palkovacs et al. 2003). However, full genomic analysis of all the various forms has not been carried out, and morphological evidence suggests that at least some morphotypes (arnoldi and hololissa) may be genetically distinct (Gerlach 2011). Some factor has resulted in tortoises throughout this far-flung chain of islands having sufficient genetic contact by occasional passive flotation that they failed to speciate even though a number of them seem to be easily distinguished by the human eye. In contrast, the tortoises of the islands of the Mascarenes (i.e., Reunion, Rodrigues, and Mauritius), all now extinct, had diversified and speciated substantially before their extinction by the beginning of the 19th century. Curiously, grandidieri and abrupta shared at least one feature with the Mascarene tortoises that was not present in the surviving tortoises from Aldabra etc., namely the absence of an anal notch.

Novel techniques can generate new insights into extinct animal species, especially with sub-fossil material in caves or other sites that offer natural protection from humidity, sun, and rainfall. Not long ago one needed to carry flasks of liquid nitrogen to field-preserve DNA samples; today, we are learning about the DNA sequences of animals that have been dead for 1000 years or more. Moreover, the large keratinous scutes that cover the carapace and plastron of turtles and tortoises may reveal data about the natural diet of both living and extinct species. Examining stable isotopes of the elements that are present in the scutes (e.g., carbon and nitrogen), as well as in the bones, may offer different isotope ratios for herbivorous animals that forage in different ecosystems and at different times. Such dietary items will, to different degrees, become laid down in characteristic ways in the hard tissues of the browsers and grazers in question, and may even allow identification of different diets at different stages of ontogeny.

Such techniques have yielded findings relevant to the two extinct giant tortoise species of Madagascar. It is of great interest that there is a major geographic overlap between the territories occupied by these two species, *abrupta* having the wider apparent range in central, southwest, and southern Madagascar. The usual assumption is that giant tortoise species, being generalized feeders and tolerant of many habitat types, do not usually show sympatry. This is the case with the various taxa of Galapagos tortoises, and even with the smaller tortoises of North America, no two species are found together. One of the few exceptions to this



Figure 2. Variation in star-shaped shell pattern in Pyxis arachnoides. Photo by Peter C.H. Pritchard.

rule is the case of the extinct giant tortoises of the island of Rodrigues in the Mascarenes, where tortoise specimens found included the rather large and strongly saddle-backed Cylindraspis vosmaeri and the smaller, dome-shelled species C. peltastes. The island is very small, and the two tortoise species were apparently sympatric, judging by locations of subfossil remains, yet it is not apparent why or how the two forms were able to evolve their contrasting morphotypes. If Galapagos tortoises are anything to go by, the long-necked, relatively large vosmaeri may be based upon male specimens, and the smaller, domed tortoises (peltastes) may have been the females. Possibly, too, the sub-fossil material may have accumulated over a relatively long span of time, perhaps spanning the duration of occupancy of two tortoise species in the same place, but not at the same time.

Nicholas Arnold at the Natural History Museum (London) was able to determine the "order of events" of arrival and evolution of tortoises in the Mascarenes by examining both DNA of subfossil tortoises and also that of individual museum tortoises (London, Paris, and Vienna) that had been collected with external scutes intact from the islands before the resident species became extinct. The conclusion was that the ancestral Cylindraspis (presumably a gravid female) first arrived on Mauritius, where it speciated into two taxa (C. triserrata and C. inepta), the latter then giving rise to a propagule on Rodrigues, where it speciated into vosmaeri and peltastes, and another propagule from the same lineage colonizing Reunion to produce C. indica. Reunion is the largest of the islands and the most intensively volcanic and there may have been earlier tortoise colonizations there, of which all traces disappeared when

the fauna of the island was overwhelmed by lava flows.

On Madagascar itself, the parallels to the tortoise situation in the Mascarenes and even the Galápagos are striking. Stable isotope analysis has indicated that the heavy, flat grandidieri was a grazer, probably in open, herbaceous habitats, including wetlands; whereas abrupta was a browser in more closed habitats and may have coexisted with humans for more than 1300 years. They were not strikingly different in size, but grandidieri reached 125 cm CL and abrupta only 115 cm. Both taxa have parallels with the Galápagos tortoises that still survive: the Galápagos equivalent of grandidieri is the very large, strikingly flattened Chelonoidis n. guentheri found in certain areas of Sierra Negra on southern Isabela Island and the adults normally show erosion and pitting of the carapace that would seem to be evidence of a wet habitat favoring erosive keratin fungi. Elsewhere on Isabela, tortoises, especially adult females, are often of the more domed *abrupta* form.

With the giants long gone, we are left with tortoises of merely medium size in Madagascar (*Astrochelys yniphora* and *A. radiata*), or small size (*Pyxis arachnoides* ssp. and *Pyxis planicauda*). This size breakdown also occurs in southern Africa, where the medium-sized Leopard Tortoise (*Stigmochelys pardalis*) coexists with the Angulate Tortoise (*Chersina angulata*), and in different places with the various small species of the genera *Homopus* and *Psammobates*.

Many of these smaller tortoises have a characteristic, although variable, pattern on the carapace, by which the design on each scute looks (more or less) like a star (Fig. 2). On the continent, this occurs, with considerable variation, throughout the genus *Psammobates*. In Madagascar, *A. radiata* is famed for its beautiful, starred carapace, a



Figure 3. Pyxis planicauda in the Kirindy Forest, western Madagascar. Photo by Peter C.H. Pritchard.

feature shared with the genus *Pyxis*, as well as the various forms of *Psammobates*.

Two subspecies of the genus Pyxis (P. arachnoides arachnoides and P. a. oblonga) are remarkable for having an anterior plastral-hinged flap. Perhaps even more remarkable is that the third subspecies P. a. brygooi, separated from the other subspecies by the Onilahy River, and with a profoundly discontinuous range, lacks plastral kinesis. Moreover, the function of the flap in the first two of these subspecies is unclear. Plastral kinesis is quite common among chelonians, and takes many forms. In kinosternids, there are often, but not always, two lines of kinesis and the plastron may be large enough to close the shell openings completely, or it may be much too small for this. In the American box turtles, there is a powerful hinge across the middle of the plastron, allowing elevation of both fore and hind plastral lobes, whereas in other species (e.g., the Asian Cyclemys dentata) the hinge is not strong, and may not even be functional. Most Pelusios species (African side-neck turtles) have a well-developed kinetic anterior plastral lobe with the unusual feature of the anterior plastral buttresses being modified into "levers" with muscle attachments for elevation of the anterior lobe, although in one species (*P. broadleyi*) there is no kinesis. In the Spiny Turtle from Asia (Heosemys spinosa), the adult female has functional posterior plastral kinesis (perhaps to facilitate laying the startlingly large egg), whereas the entire shell of the adult male is completely rigid.

In tortoises, plastral kinesis, if it exists at all, is usually manifested by a slight flexion of the posterior plastral lobe, probably to assist oviposition. But the kinesis in *Pyxis* lies across the base of the anterior lobe, and instead of being forceful, is rather loose and floppy. In the unrelated *Staurotypus*, a kinosternid turtle from Central America, there is a rather limp anterior plastral hinge, but the anterior lobe is very small and its function seems to be to allow this large-headed and predatory turtle to lower the front of the

plastron passively when the head is retracted and the jaws opened widely in a threat gesture. Among Madagascar tortoises, it has been suggested that the anterior plastral hinge, being found only in the two subspecies that live in the driest part of coastal Madagascar, is associated with resistance to dehydration. Another possibility is that, because the front edge of the anterior lobe is the thickest part of the plastron, it may serve to protect the retracted head from certain predators. Also, noting that these tortoises, although burrow builders, are able to push their way into fine sand during times of extreme heat, this may help the tortoise from getting sand pushed into the nose and mouth when they retreat underground. The plastral hinge is located between the humeral and the pectoral scutes, and this would normally be on a line that would traverse the entoplastral bone, but, as the tortoise matures, a realignment of the anterior plastral elements takes place, so that the humeral/ pectoral junction becomes perfectly transverse, with the reduced entoplastron entirely within the anterior moveable part of the plastron.

It is curious that Siebenrock (1906), working with no fewer than 630 Vienna Museum specimens of *Pyxis* of all ages from close to Tulear, did not notice that the specimens from north of Tulear itself were different from those to the south, and it was not until 1972 that Vuillemin and Domergue examined a specimen from near Lake Ihotry that had the carapace of a typical *Pyxis*, but had an entirely rigid anterior plastral lobe. They named it *Pyxoides brygooi*, but the taxon was reduced to subspecific rank (*Pyxis arachnoides brygooi*) by Bour (1979).

One might seek to establish a relationship between the continental and island species of comparable size, such as leopard tortoises and radiated tortoises; or between the diminutive star tortoises of South Africa and those of the genus *Pyxis* in Madagascar. But this is not the case. DNA analysis indicates that the various tortoises of Madagascar are more closely related to each other than to any continental tortoises, despite their wide size range. The star pattern has in fact originated quite frequently in the evolution of turtles and tortoises, and today there are star tortoises in northwestern and southern India, Sri Lanka, southern Africa, and Myanmar, as well as in Madagascar, and the pattern even shows up in non-testudinid turtles such as the Florida and ornate box turtles of the genus *Terrapene*. One assumes that it is relatively easy to code genetically, as the rays of the stars elongate passively as each scute undergoes peripheral expansion. The pattern is also significantly advantageous in the field; most star tortoises live in relatively arid habitats, in which they often retreat into tussocks of dry grass, a medium in which they become almost invisible.

There is little sympatry among the tortoises of Madagascar, although there was more in the past. No other tortoise comes close to *A. yniphora* in its minuscule range in northwestern Madagascar, and the Flat-tailed Tortoise, *P. planicauda*, is isolated in a tiny area known as the Menabe Region, 40 km north of the city of Morondava, on the mid-western coast (Fig. 3).

The range of *A. radiata* incorporates a considerable stretch of coastal terrain in southern Madagascar, once extending inland as far as 50 km, and at least formerly reaching as far as, or beyond, Tulear on the southwest coast, and Tolagnaro on the southeast coast. Different parts of this range are shared, or were shared, with one or another of the subspecies of *P. arachnoides*, namely *P. a. oblonga* in the southeast, *P. a. arachnoides* in the south, and *P. a. brygooi* in the southwest. All *Pyxis* taxa are much smaller than adult *A. radiata*, and they are confined much more closely to the coastal area, especially in places with good sand dune development, than is *radiata*. The range of *brygooi* is very disjunct, and there are only three centers of distribution, one being very small.

There are a fair number of situations in which related chelonian species are able to coexist by having a significant size difference between the adults – they can avoid damaging competition by using different types of retreats, eating different plant species, and so on. Furthermore, it is

possible that the very different carapace patterns may help avoid cross-mating attempts, especially between male Pyxis and juvenile A. radiata. Astrochelys radiata is remarkably variable in pattern, both as hatchlings and juveniles, and especially so as adults. The typical pattern of animals half grown or beyond consists of a yellow or golden center to each of the vertebral and costal scutes, from which yellow bands, increasing in width the further they get from the areolae, extend in all directions on the vertebral scutes and mostly in a downward direction on the costal scutes, and upwards on the marginal scutes (Fig. 4). However, variation is rampant and in some individuals, mostly old ones, the pattern imitates the South American Chelonoidis carbonaria in just showing yellow areolar blotches, without any radiations (Fig. 5). Large numbers of A. radiata are kept in captivity on the island of Reunion, and in one case a live hybrid tortoise (radiata/carbonaria) was produced in one of these facilities. In other cases, older tortoises may show a broad proliferation of the yellow areas of the carapace, sometimes with complete elimination of the shell pattern with age.

The shell pattern of *P. arachnoides* differs from that of *A. radiata* in having a single black blotch on each of the lateral marginals (two on each anterior marginal), and with a bold yellow band separating costal from marginal scutes on each side. The costal radiations extend anteriorly and posteriorly, but not downwards. The yellow areas expand, and black ones recede, with age, and the oldest individuals may have a plain brown or yellowish carapace. The plastron is usually immaculate, but in the subspecies *oblonga*, there are variable black blotches on the sides of the pectoral and abdominal scutes.

Most of Madagascar lacks tortoises, but the spectacular *A. radiata* still survives – and in some places flourishes – in the extreme south and southeast of the island. Its historic range encompasses about 21,000 square kilometers, but shrinks every year, as local people continue to consume this most beautiful of all tortoises, and others are caught for illegal trade or export. The remaining tortoises of Madagascar include the largest one, the very rare Angonoka, *A. yniphora*,



**Figure 4.** Radiating lines on shell of typical young adult *Astrochelys radiata*. Photo by Peter C.H. Pritchard.



Figure 5. Near-obliteration of radiating lines on shell of very old *Astrochelys radiata*. Photo by Peter C.H. Pritchard.



Figure 6. Old male Astrochelys yniphora with prominent gular "ploughshare" strut. Photo by Peter C.H. Pritchard.

confined to a minuscule area in the northwest, the small species P. arachnoides (all three subspecies) in southern coastal areas, and the extremely localized P. planicauda near Morondava in the west. All of these tortoise species tolerate extremely high field temperatures, and their habit of remaining immobile for long periods during the hot season may result in their growth annuli being very narrow, but also remaining distinct and unabraded for decades after the hatchling stage. Adult A. radiata typically show up to about twenty broad growth annuli on each scute, after which growth is sharply curtailed and annuli are bunched together and too narrow to count, as asymptotic size is approached. The smaller species (Pyxis) also tend to retain growth annuli that can be counted quite easily on the scutes of both carapace and plastron, and in the extreme case (P. planicauda), examination of the intact areolae on the shell scutes indicates that the adults are only about twice the length of the hatchlings; annulus counts indicate that the tortoises took about 15-16 years before annuli became too narrow to count and growth presumably stopped. The hatchlings of *planicauda* are in fact remarkably large, and the typical clutch consists of just a single egg. I once had responsibility of caring for several dozen adult planicauda, and kept them in an outdoor enclosure with a layer of dead leaves several inches thick. The tortoises were amazingly still almost all the time, with heads extended above the leaf litter, and remaining immobile and (seemingly) totally alert for many hours at a time. When rain fell they would thrust head and neck deep into the leaf litter, apparently seeking the moisture below the surface.

The Radiated Tortoise, *A. radiata*, is durable in captivity and may be the most long-lived of all chelonians, with two individuals of this species (one raised in Bundaberg, Australia, the other in Tonga) having reached ages well into their second century. One of these, known as Tui Malila, lived for a great many years on the island of Tonga, where it was kept, at large most of the time, in the Royal Gardens. Oral history insisted that this tortoise was presented to the King of Tonga by Captain Cook in 1773, or 1777, and it died on 19 May 1966 (possibly 189 years old) after which the preserved animal was kept for a while in the lobby of the International Date Line Hotel before being transferred permanently to the Tonga National Museum. The specimen indeed appears to be of great age, with no trace of the radiating carapace markings typical of the species, and with one side of the shell badly damaged and also scorched by a grass fire in the palace grounds. It is said to have been totally blind in its latter years and had to be fed by hand.

Another Radiated Tortoise that lived a very long time was known by the name of Torty. This animal was brought to Australia as a hatchling from Madagascar by John Powe in 1847, and resided with succeeding generations of the Powe family, living in Sydney, Gladstone, and finally Bundaberg. In 1964, the last of the Powe family, being in ill health, donated the tortoise to the Queen Alexandra Park Zoo, where it was still alive in 1981 (about 134 years old). Several years later I visited Bundaberg with the intention of filming Torty, but was sorry to hear that she had died recently, and even more unfortunately, the deceased animal was not preserved or kept.

The smaller tortoises of Madagascar do not share the resilience of *radiata*, and are very difficult to keep alive in captivity, although a few specialists have been able to breed *Pyxis*. The situation is paralleled by that of South Africa, where the larger tortoises (*Stigmochelys pardalis* and *Chersina angulata*) are relatively robust in captivity,

whereas the dwarf tortoises of the genera *Psammobates* and *Homopus* are very hard to maintain, or breed. The difference probably lies in the fact that the miniature species in both areas are ecological specialists, with ecosystems, diets, and temperature and humidity preferences that are hard to replicate in captivity.

The final species, the Angonoka, *A. yniphora*, is a unique and spectacular animal, the largest surviving Madagascar tortoise, with the highest domed carapace of any tortoise, and although now considered to be a congener of *A. radiata*, it is so distinctive that one could possibly justify a separate genus for this species, and this was indeed proposed by Le et al. (2006), who Latinized the local vernacular for the



**Figure 7.** Male *Astrochelys yniphora* using his gular strut in courtship to hook, overturn, and successfully mate with a female. Photo sequence at the Honolulu Zoo by Sean McKeown.

species, i.e., *Angonoka*. When young, the species is yellow with bold black borders to the dorsal scutes, whereas the carapace of older animals becomes uniformly golden. The domed carapace has a remarkable structure, in that the scutes are extremely thickened except around the periphery of each, and the bulbous undersides of the scutes fit into shallow concavities in the bony carapace, the latter being extremely thin. The only other tortoise that shows this osteological feature is *Manouria impressa*, from Southeast Asia.

The most conspicuously unique feature of *yniphora* is the great development of the gular area of the plastron, the gular scutes being fused into a single, rigid unit, which in adult males extends forward 10 cm or more as a gular strut from the anterior plastron, akin to a "ploughshare" (Fig. 6). It always shows very distinct growth annuli, and follows a gently rising curve, and would seem to be a lifelong inconvenience to the animal, forced to spend its life looking at its own ploughshare and forced to reach out sideways with its head and neck at a sharp angle to be able to feed. With misguided mercy, local tribal people have been known to sometimes cut off the ploughshare structure in order to make it easier for the tortoise to feed, but unfortunately this action would severely jeopardize the ability, at least of the male tortoises, to prevail in courtship and combat (Fig. 7; see description of courtship in McKeown et al. 1982), thus removing the individual from the ranks of successful breeders. Few other tortoises have this feature, but the much smaller Chersina angulata, plentiful in South Africa, shows a very similar development, although with its gular strut extending straight forward rather than curving progressively upwards. In both species, the gular strut of the female is much smaller than that of the male.

Madagascar is a nation, and an island-even a continent - with a tragic level of habitat destruction and a population of twenty million people, the vast majority of whom suffer from extreme poverty. The pressure upon edible fauna is thus extreme. Tortoises of all kinds have the problem of being highly esteemed for food, and so slow moving that, once spotted, can be picked up with ease and taken home - or to market. Vulnerability is different for each of the Madagascar tortoise species. The range of the angonoka in the northeast around Baly Bay, where it is limited to bamboo habitats, has probably always been very limited, and predation by both local people and visiting Arabs, as well as imported African pigs, has a long history. In recent years, there has been successful captive breeding of the angonoka, especially at the Durrell Wildlife Conservation Trust facility at Ampijoroa, and this has resulted in some successful releases of captive-raised specimens. Consumption by local people no longer seems to be the main problem. However, the great size and spectacular appearance of the angonoka, and its extreme rarity, have resulted in avaricious animal dealers and keepers in several European and Asian countries being prepared to pay enormous sums for living specimens, to a degree that the species itself is now critically threatened. At one point, a thief broke into the breeding facility at Ampijoroa and was able to escape with a significant part of the entire colony, including both juveniles and adults. The future of the species is thus highly uncertain, but captive breeding – behind high walls and with well-armed guards – will be a significant part of it.

The situation with the Radiated Tortoise, the *sokake* (A. radiata), in southern Madagascar is somewhat different, but is also somewhat dire. In pre-human times, there is evidence that the species once extended as far north as Ambato and Ankevo, and shared the ecosystems of the Morombe area with the kapidolo (P. planicauda). However, subsequent human pressure reduced the range to the level of Tulear and, on the eastern side of the island, to Tolagnaro. The sheer beauty of this tortoise has made it sought after by hobbyists, animal dealers, and many others. This category of consumers includes individuals who at least want their tortoises to survive and prosper (and possibly even to breed), but the pressure on radiated tortoises for food has been unrestrained and frightening in its scale. Relatively recently, a new form of exploitation has appeared, wherein tortoise shells are found with evidence of the carapace having been broken open on one side with a hammer or a rock - proof positive that the tortoise had been killed for its liver. Only a few years ago, Lewis (1995) made an estimate that, in the reduced area still well-populated by tortoises between Tsimanampetsotsa and Cap Sainte Marie, there was an estimated total population of between 12 to 54 million tortoises. Just a few years later, Leuteritz (2002) agreed with Lewis' estimate of the remaining radiated tortoise range, but indicated that the current population had been massively harvested for both food and the pet trade, yet he was still able to calculate an estimate of about 2522 tortoises/sq km in the southern part of the range.

Today, the massive consumption continues, and the numbers get lower and lower. One can find slaughtered *radiata* shells on every garbage dump in southern Madagascar, and one notable dump near Tulear had no fewer than 495 adult shells. There are still many live tortoises in captive colonies provided by confiscated animals, and the species breeds freely in a number of American collections. There are still thousands, mostly kept in captivity, on the island of Reunion, but the trend line for *radiata* in the wild is not optimistic.

#### Résumé

La majorité du territoire de l'île de Madagascar, longue d'un millier de milles, ne possède pas de tortues, et les aires de répartition des quelques espèces encore présentes de nos jours se chevauchent très peu. Les véritables tortues géantes s'y sont éteintes peu après l'arrivée de l'homme. Les espèces actuelles de tortues de Madagascar sont connues pour leur beauté extraordinaire, leur lente croissance et leur longévité, ainsi que pour l'impact massif des activités humaines sur elles qui les pousse toutes vers l'extinction.

#### LITERATURE CITED

- GERLACH, J. 2011. Development of distinct morphotypes in captive Seychelles–Aldabra giant tortoises. Chelonian Conservation and Biology 10(1):102–112.
- LE, M., RAXWORTHY, C.J., MCCORD, W.P., AND MERTZ, L. 2006. A molecular phylogeny of tortoises (Testudines: Testudinidae) based on mitochondrial and nuclear genes. Molecular Phylogenetics and Evolution 40:517–531.
- LEUTERITZ, T.E. 2002. Distribution, status and reproductive biology of the radiated tortoise, *Geochelone radiata* (Shaw, 1802) in south-west Madagascar. Ph.D. Thesis, George Mason University, Fairfax, VA, USA.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). Unpublished Report, World Wildlife Fund, Madagascar Country Office.
- MCKEOWN, S., JUVIK, J.O., AND MEIER, D.E. 1982. Observations on the reproductive biology of the land tortoises *Geochelone emys* and *Geochelone yniphora* in the Honolulu Zoo. Zoo Biology 1:223–235.
- PALKOVACS, E.P., GERLACH, J., AND CACCONE, A. 2002. The evolutionary origin of Indian Ocean tortoises (*Dipsochelys*). Molecular Phylogenetics and Evolution 24:216–227.
- PALKOVACS, E.P., MARSCHNER, M., CIOFI, C., GERLACH, J., AND CAC-CONE, A. 2003. Are the native giant tortoise from the Seychelles really extinct? A genetic perspective based on mtDNA and microsatellite data. Molecular Ecology 12:1403–1413.
- YODER, A.D. AND FLYNN, J.J. 2003. Origin of Malagasy Carnivora. In: Goodman, S.M. and Benstead, J. (Eds.). The Natural History of Madagascar. University of Chicago Press, pp. 1253–1256.

#### The Tortoises and Freshwater Turtles of Madagascar in the Context of Biodiversity Conservation in the Madagascar Hotspot

#### RUSSELL A. MITTERMEIER<sup>1</sup>, PETER PAUL VAN DIJK<sup>1</sup>, ANDERS G.J. RHODIN<sup>2</sup>, AND STEPHEN D. NASH<sup>3</sup>

<sup>1</sup>Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [rmittermeier@conservation.org, pvandijk@conservation.org]; <sup>2</sup>Chelonian Research Foundation, 168 Goodrich St., Lunenburg, Massachusetts 01462 USA [rhodincrf@aol.com]; <sup>3</sup>Conservation International, Department of Anatomical Sciences, Health Sciences Center, State University of New York, Stony Brook, New York 11794 USA [stephen.nash@stonybrook.edu]

ABSTRACT. – Madagascar is a Megadiversity country as well as the core of the Madagascar and Indian Ocean Islands Biodiversity Hotspot, with exceptionally high numbers and percentages of endemic species and higher taxa of plants and animals. Much of Madagascar's biodiversity is severely threatened, with less than 60,000 sq. km, or 10% of the total land surface, retaining natural vegetation. Developing a comprehensive system of protected areas accelerated from 2003, but went into reverse since political turmoil erupted in 2009. The tortoise and freshwater turtle fauna of Madagascar comprises 9 species (one with 3 subspecies) in 6 genera; of these, 3 genera, 5 species, and 8 terminal taxa are endemic to the country. All 5 endemic species are rated as Critically Endangered in the IUCN Red List, primarily as a result of targeted exploitation for human consumption and international pet trade, as well as habitat loss. Two species of *Aldabrachelys* tortoises have gone extinct since humans settled Madagascar. Preventing further extinctions of Madagascar's unique tortoises and turtles will require urgent and coordinated conservation action focused on species, ecosystems, and socio-economic development.

#### KEY WORDS. - Reptilia, Testudines, Madagascar, conservation, endemism, biodiversity hotspots

Biodiversity is the wealth of genes, species, ecosystems, and ecological processes that make our living planet what it is. It can also be described as the sum total of all life on Earth, our living legacy to future generations, and the basic underpinning of sustainable development. To many of us, biodiversity warrants conservation for its intrinsic values, or for a moral imperative, or for its aesthetic, cultural, or scientific value. In addition, there is the clear economic value, as demonstrated by biotechnology, biomimetics, agriculture, and recreation and ecotourism. And finally, the values of ecosystem services are beginning to be understood, including forests and watersheds as supply systems for healthy drinking water and other resources, as disaster prevention or impact reduction services (e.g., fires, landslides, floods, tsunamis), and the key role forests and other natural systems play in climate change buffering, making the case for avoiding deforestation. Notably, there is a high spatial correspondence between areas of highest priority for biodiversity conservation, and areas with high ecosystem service values for humanity.

Biodiversity is under a multitude of threats worldwide, including deforestation for agriculture, timber, fuelwood extraction,human-initiated forest fires,dams,reservoirs and water diversion projects, mining and effluent runoff, urban sprawl, roads and other major infrastructure development, pollution from sewage, agro-chemical runoff, and oil spill, the spread of invasive species, and targeted exploitation of wildlife species for food, medicine, pets, and other purposes, and the side effects of such exploitation on other species through by-catch. Hovering over all of these threats is the specter of human-induced climate changes, the impacts of which are still difficult to measure, but which are already affecting the distributions and survival prospects of many species from tropical mountains to the polar ice-caps, with effects ranging from average temperature change to habitat aridification and desertification and the prevalence of extreme weather events.

Species loss is irreversible. Once a species goes extinct, it is gone forever and will never be seen again, unless at some future date we are successful in cloning at least those species that have disappeared in the recent past, and even then their ecological roles will be exceptionally difficult to restore. We face an impending extinction crisis, potentially one of the largest extinction episodes in our planet's history, and many of us consider this to be the most critical phenomenon of our time.

#### **Conservation Strategies**

How do we best preserve the wealth of biodiversity for future generations? Conservation actions need to be continued and scaled up: understand the basic taxonomy of species, assess their conservation status (recorded in the IUCN Red List), determine priorities, develop strategies and action plans, get the word out (through both professional and popular channels), and raise the funds needed to get the job done. A basic premise of conservation is that all biodiversity is important, and that all nations should do everything possible



Figure 1. Map of the global Biodiversity Hotspots, including Madagascar.

to conserve their living resources. However, biodiversity is by no means evenly distributed over the face of the planet; rather, it is heavily concentrated in a relatively small total area, a large proportion of which has already been heavily impacted by human activities.

Clear strategic priorities, based on the best available science, facilitate fundraising and attract donors. At Conservation International, we have prioritized Megadiversity Countries, Biodiversity Hotspots, and High Biodiversity Wilderness Areas for targeted conservation strategies. The Megadiversity Country concept was first developed by Mittermeier (1988) and elaborated in Mittermeier et al. (1997). It recognizes that of the nearly 200 countries on our planet, 18 of these, the biologically wealthiest nations, collectively contain over two-thirds of all known terrestrial, freshwater, and marine species

The second category, and the most influential over the past 20 years, is that of Biodiversity Hotspots, which prioritizes areas with high irreplaceability (as measured by endemic species, especially plants) and high threat (as measured by remaining natural vegetation). First formulated by Myers (1988, 1990), and then expanded and refined several times by Conservation International (Mittermeier et al. 1999, 2004; Myers et al. 2000; Williams et al. 2011), the latest analysis now documents 35 Hotspots globally (Fig. 1). The original extent of the 35 hotspots comprises 23,747,300 km<sup>2</sup>, or 15.9% of earth's land surface; of this, over 85% has lost its natural vegetation cover and associated biodiversity. The result is that what remains in the 35 Hotspots is now no more than 3,438,146 km<sup>2</sup>, or 2.3% of Earth's land surface. Over half the world's total species of plants (over 150,000 of about 300,000 species) are endemic to the Hotspots, and occur nowhere else. In addition, more than 12,220 (or>42%) of all known tetrapod vertebrates are endemic to Hotspots. What is more, a major portion of all Threatened species (i.e., IUCN Red List Critically Endangered, Endangered, or Vulnerable) occur in the hotspots, including 82% of all Threatened mammal species, 83% of Threatened birds, and 90% of Threatened amphibians.

However, the Hotspots are more than tropical rain forests and concentrations of species richness; they also host concentrations of higher levels of diversity, such as families and genera, many of these endemic and representing deep lineages and evolutionary histories found nowhere else. Moreover, Hotspots largely coincide with the Vavilov centers of origin and diversity of cultivated plants, and Hotspots and High Biodiversity Wilderness Areas combined host 73.7% of all human languages spoken worldwide, again including some of the most threatened languages spoken by rapidly disappearing human cultures (Gorenflo et al. 2012) (Fig. 2).

The third concept, High Biodiversity Wilderness Areas, another first developed by Mittermeier (1988) and originally referred to as Major Tropical Wilderness Areas, are those places that host high biodiversity, yet still remain largely intact (Mittermeier et al. 2002). Collectively, Hotspots and High Biodiversity Wilderness Areas contain the vast majority of terrestrial and freshwater species and ecosystems, and represent the top priorities in terrestrial biodiversity conservation. If conservation fails in these areas, especially the Hotspots, we will lose a major portion of the world's terrestrial biodiversity, *regardless* of how successful we are in other areas. Given their high-priority biodiversity status and great importance for human well-being and cultural values, hotspots remain one of the most effective tools for conservation fund-raising, including dedicated mechanisms like the Critical Ecosystem Partnership Fund (CEPF), which continues to provide significant support to civil society organizations in Hotspots (www.cepf.net), and the Global Conservation Fund (GCF) which focuses on creating new parks and reserves in Hotspots and Wilderness Areas.

On the ground, the process of identifying a Key Biodiversity Area (KBA; Langhammer et al. 2007) focuses on specific areas for conservation within Hotspots and Wilderness Areas, with the most critical areas represented by the Alliance for Zero Extinction (AZE) sites, single sites representing the only remaining areas of occurrence of Critically Endangered and Endangered species whose loss will result in the extinction of those species (www.zeroextinction.org).

#### Madagascar – Possibly the World's Highest Priority Biodiversity Hotspot

Madagascar is both a Megadiversity Country and a Biodiversity Hotspot. This island-continent, located off the east coast of Africa in the Indian Ocean, covers about 587,041 km<sup>2</sup> and has just over 20 million inhabitants (2009 estimate). Its remarkable and distinct vegetation zones contain about 14,000–15,000 plant species, with over 80% of these endemic. Of 363 reptile species, 92% are endemic; 260 bird species occur, of which about 140 species and an amazing 5 families are endemic. A special place is taken by the lemurs, a major primate branch that includes 5 families, 15 genera, and at least 101 species, every one of them endemic to Madagascar (Mittermeier et al. 2010).

With 25 endemic families across plants and vertebrates, Madagascar exceeds the next three Hotspots with endemic families *combined* (New Zealand, New Caledonia, and Chilean Winter Rainfall / Valdivian Forests Hotspots, each with 7 endemic families). Madagascar's total number of endemic genera, 478, nearly matches that of the next two Hotspots *combined* (the Caribbean, 269 and the Atlantic Forest, 210). In addition, new species continue to be discovered in Madagascar, ranging from more than doubling the number of lemur species between 1994 to 2010, to new palm species being discovered and censused using Google Earth, to several new lizards being described annually, to an estimated 119–221 new species of frogs still to be described (Vieites et al. 2009).

Madagascar's environment has arguably suffered greater degradation than any other comparable area. Slash-and-burn agriculture is widespread, and its undulating landscape and delicate soils have suffered some of the most devastating erosion on Earth, with the resulting runoff in turn choking riverine and coastal ecosystems. Well over 90% of Madagascar's natural vegetation is already lost, and the total area of remaining natural habitat is estimated at between 50,000 and 60,000 km<sup>2</sup>. Hunting since first human settlement, some 2500–2300 years ago, has extirpated the entire radiation of giant elephant birds (at least eight species in two genera), at least two hippopotamus species, and at least three families, eight genera, and 17 species of giant lemurs, all of them larger than the surviving species (Mittermeier et al. 2010). What is more, many of the currently surviving species are under significant threat from continuing subsistence consumption hunting and trade, as well as massive habitat destruction. When one considers all these factors, Madagascar can be considered the world's highest priority biodiversity hotspot.

Needed conservation actions applicable to the Madagascar situation include developing and supporting Protected Areas, supporting and facilitating the establishment of green economies including PES (Payment for Ecosystem Services) and REDD+ (Reducing Emissions from Deforestation and Forest Degradation Plus Forest Management and Biodiversity Conservation; www.unredd.org), and initiatives linking ecotourism and local communities.

In sensitive environments like Madagascar's, the critical importance of Protected Areas cannot be overstated. This received a tremendous boost with the Durban Vision, launched at the World Parks Congress in September 2003, when Madagascar's then new President Marc Ravalomanana committed to tripling protected area coverage over the next five years. Further to this, at the United Nations General Assembly in New York in September 2005, he committed 8% of debt relief granted by the developed countries to the developing world to Protected Areas, the only head-of-state to do so. An additional boost came when the CEO of DreamWorks, Jeffrey Katzenberg, creator of the film "Madagascar", committed \$500,000 to ecotourism development after a visit to the country in December



Figure 2. Map of the Madagascar and Indian Ocean Islands Hotspot.



Figure 3. Map of existing and proposed protected areas of Madagascar.

2004. At the time of the Durban announcement, President Ravalomanana requested a \$50 million trust fund to help implement and maintain this ambitious new program, which was achieved by March 2008, including the first million deposited from CI's Global Conservation Fund (Fig. 3).

By August 2010, major progress had been made towards achieving the Durban Vision: the existing 47 Protected Areas managed by Madagascar National Parks / ANGAP (IUCN categories I, II, and IV) cover 1.7 million ha, extensions to these parks cover 505,488 ha, creation of 40 new Protected Areas covering 1,168,419 ha is in progress, and 29 new Protected Areas (mostly in IUCN categories V and VI) covering 2,997,145 ha have provisional status. Together these would protect over 6.3 million ha, roughly equal to the area of remaining natural habitat.

The prospects for Green Economies in Madagascar are also positive. Protected Areas serve as the anchors in larger corridors, where PES and REDD+ can generate income from local and international sources. Of particular interest is 'greening' of the mining sector, where initial steps have been made by Rio Tinto and others to reforest mined areas. Ecotourism was the second highest foreign exchange earner in 2008, at \$430 million, and is nowhere near its full potential. Ecotourism has clear benefits to communities and linkages to biodiversity, and generates opportunities for educational initiatives and private enterprise, through Guide Associations, Community Protected Areas, and village entrepreneurs; hundreds of new sites could be developed at very low cost.

However, events took a turn for the worse in early 2009, when president Ravalomanana was driven from office by Andry Rajoelina, the Mayor of Antananarivo, who established a caretaker government that until now is not internationally recognized. With the breakdown of the democratically-elected government, protected areas were invaded by loggers and poachers almost immediately, and natural treasures ranging from rosewood and palissandre (*Dalbergia* spp.) to tortoises and frogs started hemorrhaging out of the country onto the world's black markets.

Despite its international pariah status, or exactly because of it, there has never been a more critical time for a truly global commitment to conserving Madagascar's biodiversity as a Global Good. There are no final victories in biodiversity conservation, but at any given time we must collectively prevent the extinction of species and degra-

**Table 1.** Numbers of tortoises and freshwater turtles in selected Megadiversity Countries, Biodiversity Hotspots (HS), and High Biodiversity Wilderness Areas (HBWA); excludes recently extinct taxa. Data current as of TTWG (2012).

Region	Total Species	Number of Threatened Species	Percent Threatened	Number of Endemic Species	Number of Threatened Endemic Species	Percent Threatened
USA	52	20	38%	32	12	38%
Mexico	41	11	27%	15	5	33%
Australia	24	7	29%	21	6	29%
Brazil	31	10	32%	6	3	50%
China	31	26	84%	8	7	88%
Madagascar	9	5	56%	5	5	100%
Madagascar and Indian Ocean Islands HS	10	6	60%	6	6	100%
IndoBurma HS	50	40	80%	19	15	79%
Sundaland HS	20	16	80%	2	1	50%
MesoAmerica HS	27	5	19%	16	4	25%
Tumbes-Choco-Magdalena HS	19	12	63%	12	10	83%
Southest USA Turtle Priority Area	41	15	37%	10	8	80%
Amazonia HBWA	20	8	40%	9	3	33%
New Guinea HBWA	12	5	42%	9	4	44%



Figure 4. Numbers of species and terminal taxa (in brackets) of tortoises and freshwater turtles in the Megadiversity Countries (labeled in black letters) and countries with high turtle diversity (labeled in blue). National counts *include* species and taxa listed as unconfirmed or extinct in TTWG 2010.



Figure 5. Numbers of *endemic* species and terminal taxa of tortoises and freshwater turtles in Megadiversity Countries (black labels) and other countries (blue labels) with at least three endemic turtle taxa. Species and taxa were designated as endemic to a country in the absence of *confirmed* occurrence in another country. Extinct taxa are *excluded* from counts.

dation of ecosystems to maintain option values, and the impacts on Madagascar's natural heritage and resources have never been greater than at present.

#### **Turtles and Tortoises in Madagascar**

Turtles trace their ancestry back to the late Triassic, over 200 million years ago. At 14 living families, about 94 genera, 322 surviving species, and 441 terminal taxa (TTWG 2012), turtles are a modestly speciose group. To conserve total biodiversity, the basic Unit of Conservation should at least be the lowest named taxonomic unit (i.e., subspecies), and conservation of identified Evolutionarily Significant Units (ESU's) and Management Units (MU's) is arguably as important. Different species concepts and differing interpretations by individual turtle taxonomists mean that turtle taxonomy remains dynamic, but the general outlines are well understood and effectively summarized by the an-



Figure 6. Genera of tortoises and freshwater turtles endemic to a single country.

nual Turtles of the World checklist of the Turtle Taxonomy Working Group (2007a, b, 2012), working under the auspices of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group.

The IUCN Red List of Threatened Species<sup>TM</sup> (www. iucnredlist.org) is the global standard to assess the threat status of any species. Not all turtle species have been fully assessed for the Red List yet, but an analysis of completed assessments and those in progress indicate that between 47% and 53% of all turtles are Threatened with extinction (TTWG 2012). This is a higher percentage than almost any other major animal group, more than birds (ca. 13%), mammals (ca. 21–25%), cartilaginous fishes (ca. 17–31%), or amphibians (ca. 30–41%), and paralleled among the larger vertebrate groups only by the primates (ca. 48%) (Hoffmann et al. 2010).

Madagascar has a relatively modest turtle fauna, with a total of 9 species and 11 taxa of tortoises and freshwater turtles, and 5 marine turtle species. On a global scale, for an area this large, this is not particularly rich or diverse, and Madagascar does not rank among the top turtle-rich countries by any criterion (except for a joint 25th place in the list of all terminal taxa of marine, freshwater and terrestrial turtles) (TTWG 2012) (Table 1; Fig. 4).

But the simple number of 9 tortoise and freshwater turtle species (one with 3 subspecies) belies a remarkable evolutionary history: three genera, Astrochelys (with two species, A. radiata and A. yniphora), Pyxis (with one species, P. arachnoides, and three subspecies, P. a. arachnoides, P. a. oblonga, and P. a. brygooi), and Erymnochelys (with one species, E. madagascariensis), are endemic (Fig. 7), with Erymnochelys being considered by some taxonomists as the sole surviving species of an illustrious subfamily, the Erymnochelyinae. Only a single country exceeds three endemic turtle genera (Australia, with four endemic genera), and no country matches it, making Madagascar runner-up in this category. With five species and eight terminal taxa endemic, Madagascar takes a respectable joint 9th place in the global league for endemic turtle species, and joint 6th place when comparing endemic terminal taxa (Table 1; Figs. 5, 6).

Moreover, until rather recently in prehistoric times, Madagascar was home to at least two species of endemic giant tortoises, Aldabrachelys grandidieri and A. abrupta, which both went extinct some 750-1050 years ago (Gerlach 2004). Regarding the other non-marine turtle species, Kinixys zombensis domerguei, traditionally considered a subspecies of K. belliana, may be a human introduction of the widespread Eastern African hingeback tortoise species, and may thus be of debatable taxonomic validity, while the three pelomedusid taxa (Pelomedusa subrufa, Pelusios subniger, and Pelusios castanoides) are not considered taxonomically distinct from the African populations of their species, and in the case of Pelomedusa and P. subniger they have been hypothesized to be recent arrivals in Madagascar, either by human transport or natural dispersal (Vargas-Ramirez et al. 2010; Wong et al. 2010).

Madagascar has another stunning statistic: all five (100%) of its endemic turtle and tortoise species in its three endemic genera have recently (2008) been assessed as Critically Endangered on the IUCN Red List (van Dijk et al. 2013, this volume). This represents 56% of its total tortoise and freshwater turtle species, and 73% of its terminal taxa of tortoises and freshwater turtles. Only China has a comparable number of Critically Endangered endemic species, but has no endemic genera nor a 100% Critically Endangered rate for its endemic species. A similar picture emerges when comparing the turtles of Madagascar against those of other Megadiversity Countries or Biodiversity Hotspots: the actual numbers and proportions of threatened turtles of



Figure 7. Endemic tortoise and freshwater turtle species of Madagascar, depicted in approximate relative sizes. Top left: Ploughshare Tortoise (*Astrochelys yniphora*); Top right: Radiated Tortoise (*Astrochelys radiata*); Bottom left: Spider Tortoise (*Pyxis arachnoides*); Bottom center: Flat-tailed Tortoise (*Pyxis planicauda*); Bottom right: Big-headed Turtle (*Erymnochelys madagascariensis*). Drawings by Stephen D. Nash.

the IndoBurma, Sundaland, and the Himalayan Foothills Hotspots are comparable to those of Madagascar.

Madagascar's endemic tortoises and freshwater turtles are on some of the steepest decline trajectories, and populations of at least the Angonoka (*A. yniphora*) are among the smallest of any chelonian worldwide; consequently, this species, as well as *E. madagascariensis*, is currently included on the list of Top 25 turtles and tortoises worldwide most severely threatened with extinction (Turtle Conservation Coalition 2011). The need for immediate action to address crisis issues is immense, as is the need to implement the Vision Sokatra Gasy, a strategic, coordinated and sustainable long-term approach to conserving Madagascar's unique turtles (Mittermeier et al. 2008, reprinted in this volume). We need to remain optimistic and keep working. There is only a small window of time in which to act, but it can be done.

#### Résumé

Madagascar est autant un pays de Mégadiversité que le cœur du Hotspot de Biodiversité Madagascar et Iles de l'Océan Indien, avec des nombres et pourcentages exceptionnels d'espèces et taxons supérieurs endémiques de plantes et d'animaux. La majorité de la biodiversité de Madagascar est sévèrement menacée, avec la végétation naturelle présente sur moins de 60,000 km<sup>2</sup>, soit 10% de la surface totale des terres. Le développement d'un vaste système d'aires protégées a été accéléré depuis 2003, mais a régressé suite aux agitations politiques apparues en 2009. La faune de tortues terrestres et d'eau douce de Madagascar compte 9 espèces (une avec 3 sous-espèces) comprises dans 6 genres, parmi lesquelles 3 genres, 5 espèces et 8 taxons terminaux sont endémiques au pays. Toutes les 5 espèces endémiques sont classées Gravement Menacées dans la Liste Rouge de l'UICN, à la suite surtout d'une exploitation ciblée pour la consommation humaine et pour le commerce d'animaux exotiques, ainsi que de la perte de leur habitat. Deux espèces de tortues *Aldabrachelys* se sont éteintes depuis l'arrivée des hommes à Madagascar. Afin d'empêcher d'autres extinctions de tortues uniques de Madagascar, des actions de conservation urgentes et coordonnées, concentrées sur les espèces, les écosystèmes et le développement socio-économique s'imposent.

#### LITERATURE CITED

- GERLACH, J. 2004. Giant Tortoises of the Indian Ocean the genus *Dipsochelys* inhabiting the Seychelles Islands and the extinct giants of Madagascar and the Mascarenes. Frankfurt am Main: Edition Chimaira, 207 pp.
- GORENFLO, L.J., ROMAINE, S., MITTERMEIER, R.A., AND WALKER PAINE-MILLA, K. 2012. The co-occurrence of linguistic and biological diversity. Proceedings of the National Academy of Sciences of the United States 109(21):8032–8037.
- ${\it Hoffmann}, M., {\it Hilton-Taylor}, C., {\it Angulo}, A., {\it B\"ohm}, M., {\it Brooks},$ T.M., BUTCHART, S.H.M., CARPENTER, K.E., CHANSON, J., COL-LEN, B., COX, N.A., DARWALL, W.R.T., DULVY, N.K., HARRISON, L.R., KATARIYA, V., POLLOCK, C.M., QUADER, S., RICHMAN, N.I., RODRIGUES, A.S.L., TOGNELLI, M.F., VIÉ, J.-C., AGUIAR, J.M., AL-LEN, D.J., ALLEN, G.R., AMORI, G., ANANJEVA, N.B., ANDREONE, F., ANDREW, P., AQUINO ORTIZ, A.L., BAILLIE, J.E.M., BALDI, R., Bell, B.D., BIJU, S.D., BIRD, J.P., BLACK-DECIMA, P., BLANC, J.J., BOLAÑOS, F., BOLIVAR-G., W., BURFIELD, I.J., BURTON, J.A., CAP-PER, D.R., CASTRO, F., CATULLO, G., CAVANAGH, R.D., CHANNING, A., CHAO, N.L., CHENERY, A.M., CHIOZZA, F., CLAUSNITZER, V., Collar, N.J., Collett, L.C., Collette, B.B., Cortez Fernandez, C.F., CRAIG, M.T., CROSBY, M.J., CUMBERLIDGE, N., CUTTELOD, A., DEROCHER, A.E., DIESMOS, A.C., DONALDSON, J.S., DUCKWORTH, J.W., DUTSON, G., DUTTA, S.K., EMSLIE, R.H., FARJON, A., FOWLER, S., FREYHOF, J., GARSHELIS, D.L., GERLACH, J., GOWER, D.J., GRANT, T.D., HAMMERSON, G.A., HARRIS, R.B., HEANEY, L.R., HEDGES, S.B., HERO, J.-M., HUGHES, B., HUSSAIN, S.A., ICOCHEA M., J., INGER, R.F., ISHII, N., ISKANDAR, D.T., JENKINS, R.K.B., KANEKO, Y., KOTTELAT, M., KOVACS, K.M., KUZMIN, S.L., MARCA, E.L.,

LAMOREUX, J.F., LAU, M.W.N., LAVILLA, E.O., LEUS, K., LEWI-SON, R.L., LICHTENSTEIN, G., LIVINGSTONE, S.R., LUKOSCHEK, V., MALLON, D.P., MCGOWAN, P.J.K., MCIVOR, A., MOEHLMAN, P.D., MOLUR, S., ALONSO, A.M., MUSICK, J.A., NOWELL, K., NUSSBAUM, R.A., OLECH, W., ORLOV, N.L., PAPENFUSS, T.J., PARRA-OLEA, G., PERRIN, W.F., POLIDORO, B.A., POURKAZEMI, M., RACEY, P.A., RAGLE, J.S., RAM, M., RATHBUN, G., REYNOLDS, R.P., RHODIN, A.G.J., RICHARDS, S.J., RODRÍGUEZ, L.O., RON, S.R., RONDININI, C., Rylands, A.B., Sadovy de Mitcheson, Y., Sanciangco, J.C., SANDERS, K.L., SANTOS-BARRERA, G., SCHIPPER, J., SELF-SULLIVAN, C., SHI, Y., SHOEMAKER, A., SHORT, F.T., SILLERO-ZUBIRI, C., SIL-VANO, D.L., SMITH, K.G., SMITH, A.T., SNOEKS, J., STATTERSFIELD, A.J., SYMES, A.J., TABER, A.B., TALUKDAR, B.K., TEMPLE, H.J., TIMMINS, R., TOBIAS, J.A., TSYTSULINA, K., TWEDDLE, D., UBEDA, C., VALENTI, S.V., VAN DIJK, P.P., VEIGA, L.M., VELOSO, A., WEGE, D.C., WILKINSON, M., WILLIAMSON, E.A., XIE, F., YOUNG, B.E., AKÇAKAYA, H.R., BENNUN, L., BLACKBURN, T.M., BOITANI, L., DUBLIN, H.T., FONSECA, G.A.B. DA, GASCON, C., LACHER, T.E., JR., MACE, G.M., MAINKA, S.A., MCNEELY, J.A., MITTERMEIER, R.A., REID, G.M., RODRIGUEZ, J.P., ROSENBERG, A.A., SAMWAYS, M.J., SMART, J., STEIN, B.A., AND STUART, S.N. 2010. The impact of conservation on the status of the world's vertebrates. Science Express 26 October 2010, doi: 10.1126/science.1194442.

- LANGHAMMER, P.F., BAKARR, M.I., BENNUN, L.A., BROOKS, T.M., CLAY, R.P., DARWALL, W., DE SILVA, N., EDGAR, G.J., EKEN, G., FISHPOOL, L.D.C., FONSECA, G.A.B. DA, FOSTER, M.N., KNOX, D.H., MATIKU, P., RADFORD, E.A., RODRIGUES, A.S.L., SALAMAN, P., SECHREST, W., AND TORDOFF, A.W. 2007. Identification and Gap Analysis of Key Biodiversity Areas: Targets for Comprehensive Protected Area Systems. Gland, Switzerland: IUCN, 116 pp.
- MITTERMEIER, R.A. 1988. Primate diversity and the tropical forest case studies from Brazil and Madagascar and the importance of the Megadiversity Countries. In: Wilson, E.O. (Ed.). Biodiversity. Washington DC: National Academy Press, pp. 145-154.
- MITTERMEIER, R.A., ROBLES-GIL, P., AND MITTERMEIER, C.G (Eds.). 1997. Megadiversity: Earth's Biologically Wealthiest Nations. Mexico City: CEMEX, 503 pp.
- MITTERMEIER, R.A., MYERS, N., AND MITTERMEIER, C.G. (Eds.). 1999. Hotspots – Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. Mexico City: CEMEX, 431 pp.
- MITTERMEIER, R.A., MITTERMEIER, C.G., ROBLES-GIL, P., PILGRIM, J., FONSECA, G., BROOKS, T., AND KONSTANT, W.B. (Eds.). 2002. Wilderness – Earth's Last Wild Places. Mexico City: CEMEX, 576 pp.
- MITTERMEIER R.A., ROBLES GIL, P., HOFFMANN, M., PILGRIM, J., BROOKS, T., MITTERMEIER, C.G., LAMOREUX, J., AND FONSECA, G.A.B.DA (Eds.). 2004. Hotspots Revisited - Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. Mexico City: CEMEX, 392 pp.
- MITTERMEIER, R.A., RHODIN, A.G.J., RANDRIAMAHAZO, H., LEWIS, R.E., VAN DIJK, P.P., HUDSON, R., AND RIOUX PAQUETTE, S. 2008. Vision sokatra gasy—Madagascar turtle vision. Turtle and Tortoise Newsletter 12:7–9.
- MITTERMEIER, R.A., LOUIS JR., E.E., RICHARDSON, M., SCHWITZER, C., LANGRAND, O., RYLANDS, A.B., HAWKINS, F., RAJAOBELINA, A., RATSIMBAZAFY, J., RASOLOARISON, R., ROOS, C., KAPPELER, P.M., MACKINNON, J., AND NASH, S.D. 2010. Lemurs of Madagascar (Third edition). Arlington, VA: Conservation International Tropical Field Guide Series, 767 pp.
- MYERS, N. 1988. Threatened biotas: 'Hotspots' in tropical forests. The Environmentalist 8:1–20.
- MYERS, N. 1990. The biodiversity challenge: expanded hot-spots analysis. The Environmentalist 10:243–256.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B.

DA, AND KENT, J. 2000. Biodiversity Hotspots for Conservation Priorities. Nature 403:853–858.

- TURTLE CONSERVATION COALITION [RHODIN, A.G.J., VAN DIJK, P.P., HORNE, B.D., WALDE, A.D., AND BLANCK, T. (Eds.)]. 2011. Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles—2010. Lunenburg, MA: IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Turtle Conservation Fund, Turtle Survival Alliance, Turtle Conservancy, Chelonian Research Foundation, Conservation International, and Wildlife Conservation Society, 42 pp.
- TURTLE TAXONOMY WORKING GROUP [BICKHAM, J.W., PARHAM, J.F., PHILIPPEN, H.D., RHODIN, A.G.J., SHAFFER, H.B., SPINKS, P.Q., AND VAN DIJK, P.P.]. 2007a. Turtle taxonomy: methodology, recommendations, and guidelines. In: Shaffer, H.B., FitzSimmons, N.N., Georges, A., and Rhodin, A.G.J. (Eds.). Defining Turtle Diversity: Proceedings of a Workshop on Genetics, Ethics, and Taxonomy of Freshwater Turtles and Tortoises. Chelonian Research Monographs No. 4, pp. 73–84.
- TURTLE TAXONOMY WORKING GROUP [BICKHAM, J.W., IVERSON, J.B., PARHAM, J.F., PHILIPPEN, H.D., RHODIN, A.G.J., SHAFFER, H.B., SPINKS, P.Q., AND VAN DIJK, P.P.J. 2007b. An annotated list of modern turtle terminal taxa with comments on areas of taxonomic instability and recent change. In: Shaffer, H.B., FitzSimmons, N.N., Georges, A., and Rhodin, A.G.J. (Eds.). Defining Turtle Diversity: Proceedings of a Workshop on Genetics, Ethics, and Taxonomy of Freshwater Turtles and Tortoises. Chelonian Research Monographs No. 4, pp. 173–199.
- TURTLE TAXONOMY WORKING GROUP [VAN DJJK, P.P., IVERSON, J.B., SHAFFER, H.B., BOUR, R., AND RHODIN, A.G.J.]. 2012. Turtles of the world, 2012 update: annotated checklist of taxonomy, synonymy, distribution, and conservation status. In: Rhodin, A.G.J., Pritchard, P.C.H., van Dijk, P.P., Saumure, R.A., Buhlmann, K.A., Iverson, J.B., and Mittermeier, R.A. (Eds.). Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group. Chelonian Research Monographs No.5, pp.000.243–000.328, doi:10.3854/crm.5.000.checklist.v5.2012, www.iucn-tftsg.org/cbftt/.
- VAN DIJK, P.P., LEUTERITZ, T.E., RHODIN, A.G.J., MITTERMEIER, R.A., AND RANDRIAMAHAZO, H. 2013. Turtles on the Brink in Madagascar: an IUCN Red Listing assessment workshop. Chelonian Research Monographs 6:33–36.
- VARGAS-RAMÍREZ, M., VENCES, M., BRANCH, W.R., DANIELS, S.R., GLAW, F., HOFMEYR, M.D., KUCHLING, G., MARAN, J., PAPENFUSS, T.J., ŠIROKY, P., VIEITES, D.R., AND FRITZ, U. 2010. Deep genealogical lineages in the widely distributed African helmeted terrapin: evidence from mitochondrial and nuclear DNA (Testudines: Pelomedusidae: *Pelomedusa subrufa*). Molecular Phylogenetics and Evolution doi:10.1016/j.ympev.2010.03.019.
- VIEITES, D.R., WOLLENBERG, K.C., ANDREONE, F., KÖHLER, J., GLAW, F., AND VENCES, M. 2009. Underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. Proceedings of the National Academy of Sciences 106:8267–8272.
- WILLIAMS, K.J., FORD, A., ROSAUER, D., DE SILVA, N., MITTERMEIER, R.A., BRUCE, C., LARSEN, F.W., AND MARGULES, C. 2011. Forests of East Australia - the 35th Biodiversity Hotspot. In: Zachos, F.E. and Habel, J.C. (Eds.). Biodiversity Hotspots - Distribution and Protection of Conservation Priority Areas. Springer Verlag, pp. 295–310.
- WONG, R.A., FONG, J.J., AND PAPENFUSS, T.J. 2010. Phylogeography of the African helmeted terrapin, *Pelomedusa subrufa*: genetic structure, dispersal, and human introduction. Proceedings of the California Academy of Sciences 61:575–585.

#### Turtles on the Brink in Madagascar: An IUCN Red Listing Assessment Workshop

PETER PAUL VAN DIJK<sup>1</sup>, THOMAS E.J. LEUTERITZ<sup>2</sup>, ANDERS G.J. RHODIN<sup>3</sup>, RUSSELL A. MITTERMEIER<sup>1</sup>, AND HERILALA RANDRIAMAHAZO<sup>4,5</sup>

<sup>1</sup>Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [pvandijk@conservation.org, rmittermeier@conservation.org]; <sup>2</sup>U.S. Fish and Wildlife Service, Division of Scientific Authority, 4401 N. Fairfax Dr. Suite 110, Arlington, Virginia 22203 USA [thomas\_leuteritz@fws.gov]; <sup>3</sup>Chelonian Research Foundation, 168 Goodrich Street, Lunenburg, Massachusetts 01462 USA [rhodincrf@aol.com]; <sup>4</sup>Wildlife Conservation Society, BP 8500, Antananarivo 101, Madagascar; <sup>5</sup>Present Address: Turtle Survival Alliance, Antananarivo 101, Madagascar [herilala@turtlesurvival.org]

ABSTRACT. – In January 2008 we organized and convened an IUCN Red Listing workshop in Antananarivo, Madagascar. The overall goals of the workshop were: 1) inclusion of updated Red List assessments for Madagascar's tortoises and freshwater turtles on the 2008 IUCN Red List, 2) development, publication, and implementation of a Conservation Action Plan for Madagascar's tortoises and freshwater turtles, and 3) the establishment of a broad-based Madagascar Tortoise and Freshwater Turtle Working Group to collaborate and facilitate conservation action, including addressing conservation gaps and synergistic fundraising.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, Podocnemididae, Pelomedusidae, freshwater turtles, tortoises, IUCN Red List of Threatened Species, Madagascar

In January 2008 we organized an IUCN Red Listing workshop in Antananarivo, Madagascar: *Turtles on the Brink in Madagascar: A Workshop on Current Status, Conservation Prioritization, and Strategic Action Planning for Madagascan Tortoises and Freshwater Turtles* (Fig. 1). The workshop was convened and co-hosted by Wildlife Conservation Society/Madagascar (WCS), Conservation International/Madagascar (CI), and the International Union for Conservation of Nature / Species Survival Commission IUCN/SSC Tortoise and Freshwater Turtle Specialist Group (TFTSG).

The overall goals of the workshop were: 1) inclusion of updated Red List assessments for Madagascar's tortoises and freshwater turtles on the 2008 IUCN Red List, 2) development, publication, and implementation of a Conservation Action Plan for Madagascar's tortoises and freshwater turtles, and 3) the establishment of a broadbased Madagascar Tortoise and Freshwater Turtle Working Group to collaborate and facilitate conservation action, including addressing conservation gaps and synergistic fundraising.

The IUCN Red List of Threatened Species<sup>™</sup> provides taxonomic, conservation status, and distribution information on plants and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of extinction of a species. The main purpose of the IUCN Red List is to catalogue and highlight those plants and animals that are facing a high risk of global extinction (i.e., those listed as Critically Endangered, Endangered, and Vulnerable, with species in these three categories considered to be Threatened under IUCN criteria).

The IUCN Red List also includes information on plants and animals that are categorized as Extinct or Extinct in the Wild, species that cannot be evaluated because of insufficient information (Data Deficient), species that are either close to meeting the Threatened thresholds or that would be Threatened were it not for an ongoing taxonspecific conservation program (Near Threatened), and species that are relatively secure and at no current risk of extinction being categorized as Least Concern (IUCN 2011) (Fig. 2).

To evaluate the risk of extinction of a species, a Red List assessment requires sourcing and collating the best information on the species including: 1) species classification, 2) geographic range (including a distribution map), 3) population status and trends, 4) habitat preferences, 5) major threats, 6) species utilization, 6) conservation measures in place and needed, 7) other general information, and 8) key literature references.

The information collated is used to assess the extinction risk of each species according to the IUCN Red List Categories and Criteria (current Version 3.1). The majority of assessments appearing on the IUCN Red List are carried out by members of the IUCN/SSC Specialist Groups, or by participants of Global Biodiversity Assessment workshops. An initial draft assessment is usually prepared by one or a few authors, or assessors. This step involves the development of a draft species account, draft map, and a compilation of relevant questions for specialists involved in the assessment. This draft assessment is then made available to specialist group members or workshop participants to seek



Figure 1. The emblematic and iconic symbol for the workshop, a Radiated Tortoise, *Astrochelys radiata*, on the brink along the top of the cliff of the steep escarpment in Cap Sainte Marie Special Reserve at the southern tip of Madagascar, foraging naturally high above the Indian Ocean in the late afternoon. Photo by Anders G.J. Rhodin.

additional information, review, expansion, and correction as appropriate. Following incorporation of this information, the assessment is then submitted for review by the Red List Authority for the particular species group. A Red List Authority is usually composed of members of the pertinent specialist group. For tortoises and freshwater turtles, the official Red List Authority is the Steering Committee of the TFTSG. Individuals can be an assessor or reviewer for any particular species, but may not sign off on a review to which they contributed significantly in the assessment. At least two members of the Red List Authority review the draft to ensure that: 1) the information presented is both complete and correct, and 2) the Red List assessment has been completed correctly. Following approval by the Red List Authority, the staff of IUCN's Red List Programme provides a second review of the information for completeness, accuracy, and consistency before publication on the IUCN Red List website (www.iucnredlist.org). All assessments appearing on the IUCN Red List web site are open to challenge, and a petitions process has been developed to handle potential disagreements with current listings appearing on the Red List (IUCN 2012).

The status of Madagascar's tortoises and freshwater turtles have previously been assessed a number of times and was included in the 1982 reptiles volume of the IUCN Red Data Book (Groombridge 1982), the 1996 global assessment of tortoises and freshwater turtles (under Red List criteria version 2.3), and the 2001 Conservation Breeding Specialist Group Conservation Assessment and Management Plan (CBSG CAMP) evaluations. As the impacts on Madagascar's tortoises and freshwater turtles have continued to escalate, updated assessments were essential and the Red Listing workshop was convened in January 2008 to update these species' status and to formulate a conservation strategy.

#### The Workshop

Present at the workshop were over 80 participants from 12 countries, the most being from Madagascar, that represented government agencies, universities, international and local NGO's, local communities, and the TFTSG. Over four days, the participants heard updates and presentations on current research and conservation efforts. They focused on IUCN Red List status assessments and updated threat categorizations, identified and developed focused conservation actions, and initiated a process to synthesize and prioritize conservation needs into a strategic vision and focused Conservation Action Plans for all Madagascan tortoise and freshwater turtle species. Critical issues of concern for turtles and tortoises included in the discussion were:

• Addressing the illegal trade at both the local consumption and international pet trade levels;

• Including community-based and education programs in future conservation efforts;

• Obtaining additional field data, which are necessary for appropriate management decisions, on the distribution and status of remaining populations;

• Identifying key unprotected habitats and their subsequent proposal as new protected areas in the Durban Vision process;
Table 1. Pre- and Post-Workshop IUCN Red List Status of Madagascan turtles and tortoises. Endemic species marked with an asterisk.

Species Evaluated	Previous Assessment (1996)	Current Assessment (2008)	
Astrochelys radiata *	VU	CR	
Astrochelys yniphora *	EN	CR	
Pyxis arachnoides * (ssp. arachnoides, brygooi, oblonga	VU	CR	
Pyxis planicauda *	É EN	CR	
Erymnochelys madagascariensis *	EN	CR	
Kinixys belliana (now zombensis)	LC	NE	
Pelusios castanoides	LC	NE	
Pelusios subniger	LC	NE	
Pelomedusa subrufa	LC	NE	

 Continuing and establishing reintroduction programs;

• Examining the potential of establishing captive breeding programs and assurance colonies outside of Madagascar (particularly for the Ploughshare Tortoise, *Astrochelys yniphora*, and the Madagascar Big-headed Turtle, *Erymnochelys madagascariensis*).

The participants created an informal *Madagascar Turtle Conservation Working Group* for implementing the recommendations that emanated from the workshop, and recommended the formal establishment of a Madagascarbased *Turtle and Tortoise Advisory Committee* in which government authorities, conservationists, scientists, and community leaders would work together to help local communities benefit from the sustainable use of Madagascar's turtles and tortoises (Mittermeier et al. 2008; article reprinted below as the next contribution in this monograph).

The workshop assessed nine freshwater turtle or tortoise species occurring in Madagascar. Five of these turtle and tortoise species, the Radiated Tortoise (*Astrochelys radiata*), the Ploughshare Tortoise (*A. yniphora*), the Spider Tortoise (*Pyxis arachnoides*), the Flat-tailed Tortoise (*P. planicauda*), and the Madagascar Big-headed Turtle (*Erymnochelys madagascariensis*), all endemic to Madagascar, were each assessed as Critically Endangered, the highest possible IUCN Red List category of threat of extinction (Table 1). These recommendations were subsequently adopted by the IUCN in 2008, and are posted on the IUCN Red List website (www.iucnredlist.org).

Status data were also collected for the Madagascar populations of the species that are not endemic to Madagascar (*Kinixys belliana* [now *zombensis*], *Pelomedusa subrufa*, *Pelusios castanoides*, and *P. subniger*) for incorporation into range-wide assessments for these species, to be concluded once the populations on mainland Africa have been assessed, but until such time those species are considered Not Evaluated (NE).

Following the conclusion of the Madagascar Red Listing workshop, we have continued to work closely with other NGO's focused on the conservation of Madagascar's tortoises and freshwater turtles, notably Durrell Wildlife Conservation Trust, Turtle Survival Alliance (TSA), and the Turtle Conservancy. We have all worked together to help advance the conservation action plans developed and articulated at both the original workshop as well as



Figure 2. The purpose of the IUCN Red List is to catalogue, categorize, and highlight the global conservation status of all plants and animals and to assess their relative risk of extinction. The current (2013) Red List has more than 70,000 species listed, with over 21,000 in the three Threatened categories (www.iucnredlist.org).

at the follow-up Madagascar turtle and tortoise workshop organized at the TSA/TFTSG 8th Annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles, held in Orlando, Florida, in August 2010.

#### Résumé

Un atelier axé sur le statut actuel, les priorités de conservation et l'élaboration d'actions stratégiques pour les tortues terrestres et d'eau douce de Madagascar s'est tenu en janvier 2008 à Antananarivo, Madagascar. L'atelier s'intitulait: «Les tortues en péril à Madagascar: atelier d'évaluation du statut et des priorités de conservation, et d'élaboration de plans d'action stratégiques pour les tortues terrestres et d'eau douce de Madagascar». Il a été convoqué et co-présenté par la Wildlife Conservation Society/Madagascar (WCS), Conservation International/ Madagascar(CI),etl'UnionInternationale de Conservation de la Nature/Commission Survie des Espèces Groupe de Spécialistes de Tortues Terrestres et d'Eau Douce (IUCN/ SSC TFTSG). Les principaux objectifs de l'atelier étaient: 1) d'inclure les statuts réévalués des tortues de Madagascar dans la Liste Rouge de l'UICN pour l'année 2008.; 2) de développer, publier et exécuter un Plan d'Action pour les tortues de Madagascar; et 3) créer un groupe solide travaillant sur les tortues terrestres et d'eau douce pour collaborer et faciliter les actions de conservation, parmi lesquelles l'identification des failles de la conservation et la tenue de levées de fonds.

#### LITERATURE CITED

- IUCN. 2011. IUCN Red List of Threatened Species. Version 2011.1. http://www.iucnredlist.org, http://www.iucnredlist. org/about. Downloaded on 16 June 2011.
- MITTERMEIER, R.A., RHODIN, A.G.J., RANDRIAMAHAZO, H., LEWIS, R.E., VAN DIJK, P.P., HUDSON, R., AND RIOUX PAQUETTE, S. 2008. Vision sokatra gasy—Madagascar turtle vision. Turtle and Tortoise Newsletter 12:7–9.

This article reprinted from Turtle and Tortoise Newsletter 12(2008):7-9

## Vision Sokatra Gasy-Madagascar Turtle Vision

# RUSSELL A. MITTERMEIER<sup>1</sup>, ANDERS G.J. RHODIN<sup>2</sup>, HERILALA RANDRIAMAHAZO<sup>3</sup>, RICHARD E. LEWIS<sup>4</sup>, PETER PAUL VAN DIJK<sup>1</sup>, RICK HUDSON<sup>5</sup>, AND SÉBASTIEN RIOUX PAQUETTE<sup>6</sup>

 <sup>1</sup>Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [ramittermeier@aol.com; p.vandijk@conservation.org];
 <sup>2</sup>Chelonian Research Foundation, 168 Goodrich Street, Lunenburg, Massachusetts 01462 USA [RhodinCRF@aol.com];
 <sup>3</sup>Wildlife Conservation Society, B.P. 8500, Antananarivo 101, Madagascar [Herilala@wcs.org];
 <sup>4</sup>Durrell Wildlife Conservation Trust, BP 8511, Antananarivo 101, Madagascar [richard.lewis@durrell.org];
 <sup>5</sup>Fort Worth Zoo, 1989 Colonial Parkway, Fort Worth, Texas 76110 USA [RHudson@fortworthzoo.org];
 <sup>6</sup>Département Sciences Biologiques, Université de Montréal, CP 6128, Succursale Centre-Ville, Montréal, H3C3J7 Québec, Canada [sebastien.rioux.paquette@umontreal.ca]



Figure 1. Participants in the Turtles on the Brink in Madagascar Workshop.

Madagascar is one of the world's most important megadiversity countries and one of its highest priority biodiversity hotspots, with levels of endemism at the species, genus, and family levels that are unsurpassed among the world's priority regions. Madagascar is also a country that has suffered greatly from loss of natural habitat, with more than 90% of its original natural vegetation already gone and habitat destruction continuing in many of the most important remaining areas of natural habitat.

Fortunately, President Marc Ravalomanana of Madagascar has recognized both the threat and the enormous scientific and economic value of his country's biodiversity and has taken major steps to ensure its survival. In September 2003, at the World Parks Congress in Durban, South Africa, he took the bold step of committing to tripling the protected-area coverage in his country over the next 5 years, and he is well on his way to meeting that commitment. What is more, he has made the environment a centerpiece in his national development strategy, the Madagascar Action Plan, which bodes well for the future. Nonetheless, many conservation issues remain to be resolved and many of Madagascar's unique species and ecosystems remain at great risk. People of Madagascar used to say "*tsy ho lany ny ala atsinanana*," which literally means "the eastern forest will never disappear," but now it is disappearing, and actions must be taken to safeguard it. Likewise, the radiated tortoise (*sokake*) was once too numerous to count, but now it also is disappearing before our eyes.

Among the most important and best known of Madagascar's species are the tortoises and freshwater turtles, which include 9 species, 5 of which are endemic, including 3 endemic genera (*Astrochelys, Pyxis*, and *Erymnochelys*). These animals, and especially the radiated tortoise (*sokake*), the ploughshare tortoise (*angonoka*), and the Madagascar big-headed turtle (*rere*) rank with the indri, the sifakas, and the chameleons as Madagascar's most important flagship species, symbols for which the country is renowned around the world.

Unfortunately, these turtles and tortoises are at very high risk of extinction and have been heavily impacted by human activities, especially in the last few decades. All have been affected by habitat destruction, some by hunting as a food source, and others by live capture for the illegal international wildlife trade. Previous meetings of conservation specialists have highlighted the threats facing Madagascar's turtles and tortoises, but the situation of all 5 endemic species has continued to decline.

To help remedy this situation, some 80+ conservation specialists from Madagascar and 12 other countries met in Antananarivo, Madagascar, from 14-17 January 2008 to carry out an International Union for Conservation of Nature (IUCN) Red List assessment of the conservation status of Madagascar's turtles and tortoises and to develop an Action Plan to identify specific projects and other interventions needed to ensure the survival of these important animals. The workshop was entitled Turtles on the Brink in Madagascar: A Workshop on Current Status, Conservation Prioritization, and Strategic Action Planning for Madagascan Tortoises and Freshwater Turtles. Convened by the IUCN/ Species Survival Commission (SSC) Tortoise and Freshwater Turtle Specialist Group and Madagascar's Ministère de l'Environnement, des Eaux et Forêts et du Tourisme, the workshop was co-organized by Wildlife Conservation Society, Conservation International, and Durrell Wildlife Conservation Trust, with participation, support, and partnership from multiple organizations, including Association Nation-ale pour la Gestion des Aires Protégées (ANGAP) (Parcs Nationaux Madagascar), World Wildlife Fund (WWF), Turtle Conservation Fund, Shellshock Campaign, Chelonian Research Foundation, IUCN Turtle Survival Alliance, Behler Chelonian Center, Frankel Family Foundation, Moore Family Foundation, and George Meyer and Maria Semple. A summary of the results of this important meeting are presented here.

Five turtle and tortoise species, the radiated tortoise or sokake (Astrochelys radiata), the ploughshare tortoise or angonoka (Astrochelys yniphora), the spider tortoise (Pyxis arachnoides sspp.), the flat-tailed tortoise or kapidolo (Pyxis planicauda), and the Madagascar big-headed turtle or rere (Erymnochelys madagascariensis), all endemic to Madagascar, were all assessed as Critically Endangered, the highest possible IUCN Red List category of threat of extinction. For all these species, this represented a major worsening of their survival status in comparison to their previous IUCN Red List assessments. This is a very high number of Critically Endangered species and represents a significant portion (approx. 1/6) of the global total of turtle taxa in this category (= 31 species and subspecies). The angonoka in particular is literally on the brink of extinction, with only a few hundred adults remaining in the wild.

The illegal trade in radiated tortoises (especially adults) as a source of food to serve major regional markets in Tuléar and Fort-Dauphin was recognized as a major threat to the survival of this very important species, and it was recommended that a special Tortoise Brigade be created to monitor and control this trade. Unfortunately, most of these illegal activities are going unpunished, in spite of the appropriate protective legislation being in place and the strong desire of local communities in the range of these tortoises to have the problem addressed and curtailed.

In addition to this regional trade of radiated tortoises for food, there is also an ongoing major illegal trade in small radiated tortoises and spider tortoises for the international pet trade, with confiscations occurring often both within and outside Madagascar.

Local communities within the range of the radiated tortoise have expressed concerns that they would like to see these animals repatriated or reintroduced to the areas around their villages where populations have been decimated by the illegal trade. The fate of tortoises confiscated from the trade was discussed, and it was recommended that the existing Village des Tortues at Ifaty could play a key role in holding, quarantining, and eventually redistributing confiscated animals, as well as serving an important education function.

Additionally, the illegal trade demand for the *angonoka* and the *kapidolo* represents a major threat to these species as well, with the *angonoka* in a particularly vulnerable position because of its very small and remote habitat and its very high value on the illegal international pet market. The relatively recent inclusion of the *kapidolo* on Convention on International Trade in Endangered Species (CITES) Appendix I seems to have had significant success in decreasing the international trade in that species, at least for now, but the *angonoka* continues to be smuggled out despite being on CITES Appendix I as well. Several recent confiscations highlight this ongoing severe threat.

As a potential means to achieve protection and local community value for radiated tortoises, it was proposed to focus on reversing the status decline and the trend in regional trade of the species over the course of the next few years and to also develop economic incentives for its conservation with local communities, including prospects for developing ecotourism focused on this charismatic species, as well as considering the potential for breeding centers for the international trade, guided by appropriate CITES regulations.

The need for major *community involvement* at the village level—as part of a national effort to decentralize authority—was identified as a critical element in efforts to protect the radiated tortoise, including creation of demonstration projects of reintroduction and protection of tortoises in selected villages, essentially pilot projects to demonstrate successful synergy between local communities, NGOs, and governmental organizations. The creation of Mobile Education Units to increase awareness of the issue within the region was also recommended as part of this effort.

Previously, some of these species were protected by local traditions, such as the Antandroy and Mahafaly *fady* (taboo) protecting the *sokake*, as well as other traditions regulating fishing practices in the range of the *rere*. These cultural traditions have partially broken down over the past few decades but should be revitalized as part of the overall conservation effort.

More detailed survey work to determine the precise distribution and status of remaining populations was identified as a high priority for the radiated tortoise, the spider tortoise, the flat-tailed tortoise, and the Madagascar big-headed turtle. The precise distribution of the *angonoka* is well known, tiny as it is, but continued vigilance on the status of the remaining wild populations remains a very high priority.

The need to identify key unprotected habitats and propose them as new protected areas in the Durban Vision process was cited as a priority for the radiated tortoise, the spider tortoise, and the Madagascar big-headed turtle. New protected areas are not necessary for the ploughshare tortoise and the flat-tailed tortoise, the entire remaining ranges of which are included in existing national parks declared in part under the Durban Vision.

Continued reintroduction of captive-reared animals into depleted habitats was recognized as a priority for the ploughshare tortoise and the Madagascar big-headed turtle. Reintroduction of trade-confiscated radiated and spider tortoises into areas of local extirpation was also recommended.

Captive-breeding programs were identified as priority safety measures (assurance colonies) for all species, both within Madagascar and internationally. Colonies of radiated tortoise, spider tortoise, and flat-tailed tortoise already exist both within Madagascar and internationally. In contrast, the Madagascar big-headed turtle and the ploughshare tortoise only have a single colony each, both at the Ampijoroa Station in Ankarafantsika National Park in Madagascar, but none outside the country.

Because of the importance of the captive breeding program to the survival of the ploughshare tortoise, the facility and capacity of Ampijoroa should be significantly expanded in the near future. The establishment of additional assurance colonies for the ploughshare tortoise, both within and outside Madagascar, was recommended as an important precautionary safety measure to avoid catastrophic loss of the single existing colony and to help ensure the survival of the species. Just as importantly, confiscated ploughshare tortoises should be integrated into accredited captive breeding programs, either within or outside Madagascar.

It was also noted by the workshop participants that there is an overall lack of adequate financial resources to carry out the priority activities identified. A cadre of conservation professionals and dedicated individuals exists to carry out the conservation activities required, but adequate funding has in general not been available. One of the objectives of this Action Plan will be to help raise additional resources focused on Madagascan turtle and tortoise conservation and to help guide their most effective and prioritized disbursement.

Lastly, the participants created an informal Madagascar Turtle Conservation Working Group as their authorship name for work and recommendations emanating from the workshop and recommended the formal establishment of a Madagascar-based Turtle and Tortoise Advisory Committee in which government authorities, conservationists, scientists, and community leaders would work together to help local communities benefit from wise and sustainable use of Madagascar's natural turtle and tortoise treasures.

During closing ceremonies for the workshop, with the Minister of Ministre de l'Environnement, des Eaux et Forêts et du Tourisme in attendance, several international organizations made significant initial commitments of financial resources to bring to bear on the numerous focused actions identified in the preliminary Action Plan, with over \$300,000 committed to support a variety of immediate and long-term projects, both specific and general.

The participants in the Turtles on the Brink in Madagascar workshop (Fig. 1) concluded the meeting with a sense of hope that by working together they would achieve their conservation goals with success through synergy and help keep Madagascar's turtles and tortoises off the brink of extinction.

# Madagascar Turtles and Tortoises in CITES

THOMAS E.J. LEUTERITZ<sup>1</sup> AND PETER PAUL VAN DIJK<sup>2</sup>

<sup>1</sup>U.S. Fish and Wildlife Service, Division of Scientific Authority, 4401 N. Fairfax Dr. Suite 110, Arlington, Virginia 22203 USA [thomas\_leuteritz@fws.gov]; <sup>2</sup>Conservation International, 2011 Crystal Drive, Suite 500, Arlington, Virginia 22202 USA [pvandijk@conservation.org]

ABSTRACT. – Madagascar has nine species of tortoises and freshwater turtles, five of which are endemic to the island. The five endemics (*Astrochelys radiata*, *A. yniphora*, *Pyxis arachnoides*, *P. planicauda*, and *Erymnochelys madagascariensis*) plus one non-endemic tortoise, *Kinixys belliana* (now *zombensis*), are currently listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendices.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, Podocnemididae, CITES, Madagascar, freshwater turtles, tortoises

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is an international agreement between governments. Its aim is to ensure that international trade in specimens of animals and plants does not threaten their survival in the wild. CITES was drafted as a result of a resolution adopted in 1963 at a meeting of members of the IUCN (International Union for the Conservation of Nature). The text of the Convention was agreed upon at a meeting of representatives of 80 countries in Washington DC in 1973, and in 1975 CITES entered in force. Currently, 178 countries are party to CITES and the convention covers about 29,000 species of plants and another 5,000 species of animals (CITES 2011a). At this time there are 176 species of freshwater turtles and tortoises covered by the convention.

The CITES Appendices consist of three lists of species given different levels or types of protection from over-exploitation within international trade. Appendix I lists species that are prohibited from commercial international trade, and tend to be the most endangered species. Appendix II lists species that are not necessarily currently threatened with extinction but that may become so unless international trade is regulated and sustainable. Species are put on, removed from, or transferred between these two appendices only by a 2/3 majority vote of the Parties attending the Conference of the Parties, held every three years. Appendix III is a list of species included at the request of a Party (i.e. individual country) that already regulates trade in the species and that needs the cooperation of other countries to prevent unsustainable or illegal exploitation (CITES 2011b).

At the heart of international trade in Appendix II species, and thus at the core of CITES, is the concept of sustainability, or non-detriment of trade in a species to its survival in the wild. For international trade in an Appendix II listed species to be authorized, the Management Authority of a country should only issue export permits if the Scientific Authority has made a non-detriment finding (NDF) for the proposed export, a rationale for why a proposed trade of a certain

number of animals is considered sustainable. NDFs should incorporate considerations of population status and resilience to exploitation, and can be made on a case-by-case basis, or by determining quotas annually or programmatically. The challenges of making sound NDFs are substantial for species that often have limited status and population biology data available; guidance was developed by the IUCN (Rosser and Haywood 2002), and expanded in the results of a dedicated NDF workshop held in 2008 (CITES 2008). An independent review process, the Review of Significant Trade, is implemented by the CITES Animals Committee to evaluate the non-detriment requirement of overall reported international trade quantities against available data regarding biological status and population dynamics. Issues of illegal and unreported trade are considered by the CITES Standing Committee.

We now review the status and history of Madagascar turtle and tortoise species in CITES. Madagascar has nine species of turtles, five of which are endemic to the island (Leuteritz et al. 2008; Pedrono 2008). The five endemics and one non-endemic species are listed in the CITES Appendices.

#### Radiated Tortoise (Astrochelys radiata) and Ploughshare Tortoise (Astrochelys yniphora)

Both these endemic tortoises (formerly part of the genus *Geochelone*) have been listed on CITES Appendix I since the treaty entered into force in 1975. Illegal collection for the international pet trade, as well as collection locally for *A. radiata*, continues to be the main threat (Leuteritz et al. 2008; TFTSG 2011). After a significant theft of many *A. yniphora* from the Ampijoroa captive breeding facility in 1996 (Smith et al. 1999; Pedrono 2008), animals eventually emerged in a number of places, notably in Europe, resulting in confiscation and return of some of these animals to Madagascar, and a formal Notification to Parties that any trade in the species should be investigated

and reported to the CITES Secretariat (CITES Notification 2004/044). In recent years, ploughshare tortoises have been confiscated in Madagascar before illegal export, and in Hong Kong SAR, Malaysia, Taiwan, and Thailand after illegal export; some of these animals have been returned to the care of the Madagascar authorities, while others have become part of a global *ex-situ* assurance colony initiative.

# Spider Tortoise (*Pyxis arachnoides* – including subspecies *arachnoides*, *brygooi*, and *oblonga*)

This endemic species was originally included in CITES by virtue of the genus-level listing of Pyxis in Appendix II in 1975. After many years of not being recorded in the trade at all, small numbers of *P. arachnoides* appeared in the legal international pet trade in the mid-1990s (see Table 2). In 1998, 154 animals were exported from Madagascar, while by the year 2000 the number of declared traded animals had risen to 2656. Declared export quotas were 1000 live animals for 2000, zero in 2001, and 'in prep' for 2002. As a result of widespread concern about these escalating export numbers, Pyxis arachnoides was proposed for transfer to Appendix I at CoP13 (Bangkok, Thailand, October 2004) because of serious habitat degradation and harvesting for the international pet trade (CoP13 Prop. 15, 2004). The species was listed specifically under CITES Biological criteria for listing on Appendix I: "wild populations are small, and are characterized by an observed, inferred or projected decline in the number of individuals or the area, and because the quality of habitat and a majority of individuals, during one or more life-history phases, were concentrated in one subpopulation" (Conf. 9.24 [Rev. CoP12], Annex 1, paragraphs B.i), iii), and iv), and C.i), 2004). The proposal was adopted by consensus (CoP13 Com. I. Rep. 15 [Rev. 1]: 1) and entered into force in January 2005.

## Flat-tailed Tortoise (*Pyxis planicauda*)

This endemic species was originally listed in CITES Appendix II in 1975, as part of the genus-level listing of *Pyxis*. Trade in the species was minimal, involving only

very small numbers of animals exported from Madagascar to the Jersey and Bronx zoos for their integrated captive breeding programs, until commercial trade started in 1998. In response to recorded commercial trade volumes of dozens, later over 1000, animals per year (Table 2), and an export quota of 800 animals for the year 2000, Pyxis planicauda was included as a matter of urgency in the Review of Significant Trade at the 16th meeting of the CITES Animals Committee (AC) (Shepherdstown, USA, December 2000; CITES 2001:20). A detailed review of its biology and trade was discussed at the 18th AC meeting (San José, Costa Rica, April 2002; AC18 Doc 7.1), concluding that the species' trade levels were of urgent concern. Madagascar had communicated a zero quota for 2001, yet animals continued to appear in importing countries. In consultation with the Animals Committee at its 18th meeting, Madagascar reiterated its moratorium on further exports (AC18 Summary Record: 73). While the measures agreed by the Animals Committee were being implemented, the new government of Madagascar proposed the transfer of the species from Appendix II to I because of severe habitat degradation and harvesting for the international pet trade (CoP12 Prop. 12.55, 2002). This proposal was adopted by consensus at the 12th Conference of the Parties (Santiago, Chile, November 2002; CoP12 Plen. 9: 4) and took effect in February 2003, thus ending any commercial trade in the species (with some exceptions for specimens exported before the inclusion in App. I, as well as their offspring).

Specifically, the species was listed under CITES' Biological criteria for listing in Appendix I: "wild population are small, and are characterized by an observed, inferred or projected decline in the number of individuals or the area and quality of habitat; each sub-population being very small; and a high vulnerability due to the species' biology or behaviour (including migration)". In addition "the wild population has a restricted area of distribution and is characterized by fragmentation or occurrence at very few locations; a high vulnerability due to the species' biology or behaviour (including migration); and an observed, inferred or projected decrease in any one of the following: the area of distribution; or the number of sub-populations; or the number of individuals; or the area or quality of habitat; or reproductive potential".

 Table 1. Current status of Madagascar tortoises and freshwater turtles; \* = endemic species.

Species	CITES Appendix (year listed)	IUCN Status	
Astrochelvs radiata *	I (1975)	CR	
Astrochelys yniphora *	I (1975)	CR	
Pyxis arachnoides * ssp. arachnoides, brygooi, oblonga	I (2005; II since 1975)	CR	
Pyxis planicauda *	I (2003; II since 1975)	CR	
Kinixys belliana (now zombensis)	II (1975)	LC	
Erymnochelys madagascariensis *	II (1975)	CR	
Pelusios castanoides castanoides	Not Listed	LC	
Pelusios subniger subniger	Not Listed	LC	
Pelomedusa subrufa	Not currently listed; III from 1976 to 2007	LC	

 
 Table 2. CITES-reported gross exports of live specimens of native tortoises and *Erymnochelys* from Madagascar, excluding scientific samples and specimens, but including zoo transfers.

Year	Astr. rad.	Astr. yniph.	Pyx. arach.	Pyx. planic.	Kin. bell.	Erymn. madag.
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	1	0	0	0	0	0
1984	13	0	0	0	0	0
1985	190	0	0	0	0	0
1986	4	0	0	0	0	0
1987	0	0	0	0	0	0
1988	2	0	0	0	0	0
1989	2	0	0	0	0	0
1990	0	1	0	6	0	0
1991	0	0	0	0	0	0
1992	1	0	0	0	0	0
1993	0	0	0	8	0	0
1994	0	0	0	0	0	0
1995	0	0	4	5	0	0
1996	0	0	2	2	0	0
1997	0	0	6	3	0	0
1998	62	0	154	64	0	12
1999	0	0	46	30	0	25
2000	0	0	2656	1592	148	65
2001	0	0	2033	1103	200	42
2002	0	0	0	0	0	41
2003	0	0	0	0	0	36
2004	0	0	0	0	0	29
2005	0	0	0	0	0	33
2006	0	0	0	0	0	12
2007	0	0	0	0	0	14
2008	0	0	0	0	0	16
2009	0	0	0	0	0	14
2010	0	0	0	0	0	16
2011	0	0	0	0	0	34

And finally "a decline in the number of individuals in the wild, which has been observed as ongoing or as having occurred in the past (but with a potential to resume)" (Res.Conf. 9.24, Annex 1, sections A. i), ii), and v); B. i), iii), and iv); and C. I).

#### Madagascar Big-headed Turtle (Erymnochelys madagascariensis)

This endemic turtle has been listed on CITES Appendix II since 1975, and continues to be traded under an annual quota of 25 live animals since at least the year 2000; this quota was consistently exceeded during 2000–05, but has been adhered to from 2006 onwards. Local consumption continues to be a major threat for this species' decline (Leuteritz et al. 2008).

# Bell's Hinge-back Tortoise (Kinixys belliana)

This tortoise is wide-ranging throughout mainland Africa, from which it is believed to have been introduced to Madagascar by humans in the last 2300 years. It has been listed on CITES Appendix II since 1975 under the family listing of Testudunidae, and has been legally traded from Madagascar only occasionally, and is not subject to an annual quota. The valid species name for the Madagascar population has recently been recognized as *zombensis* rather than *belliana* (Turtle Taxonomy Working Group 2012).

## African Helmeted Turtle (Pelomedusa subrufa)

This turtle is also wide ranging throughout mainland Africa and was listed on CITES Appendix III by Ghana in 1976. It was subsequently removed from Appendix III in 2007 and is currently not a CITES listed species. It was removed according to Article XVI, paragraph 3, of the Convention: "A Party which has submitted a species for inclusion in Appendix III may withdraw it at any time by notification to the Secretariat which shall communicate the withdrawal to all Parties. The withdrawal shall take effect 30 days after the date of such communication". The only recorded live exports of the species from Madagascar during the period 1976–2007 took place in 2000, when 60 live animals were exported.

## African Mud Turtles (Pelusios castanoides and Pelusios subniger)

Both of these species of turtles, which are also found in mainland Africa and in the Seychelles, have never been listed on the CITES Appendices.

#### Résumé

Madagascar possède neuf espèces de tortues, dont cinq sont endémiques à la Grande IIe. Les cinq espèces endémiques (*Astrochelys radiata*, A. *yniphora*, *Pyxis arachnoides*, *P. planicauda*, et *Erymnochelys madagascariensis*), en plus d'une autre tortue, *Kinixys belliana* (maintenant *zombensis*), sont actuellement inscrites dans les Annexes (Tableau 1) de la Convention Internationale sur le Commerce International des Espèces de Faune et de Flore menacées.

#### LITERATURE CITED

- CITES. 2001. Proceedings Sixteenth meeting of the Animals Committee, Shepherdstown (United States of America), 11-15 December 2000. http://www.cites.org/eng/com/ac/16/16AC-Proceedings.pdf.
- CITES. 2002. Conf. 9.24 (Rev. CoP12), Annex 1. Criteria for amendment of Appendices I and II. http://www.cites.org/eng/ res/09/09-24.shtml.
- CITES. 2002. CoP12 Prop. 12.55. Consideration of proposals for amendment of Appendices I and II. http://www.cites.org/eng/ cop/12/prop/e12-p55.pdf.
- CITES. 2004. CoP13 Prop. 15. Consideration of proposals for amendment of Appendices I and II. http://www.cites.org/eng/ cop/13/prop/e13-p15.pdf.
- CITES. 2008. International Expert Workshop on CITES Non-

Detriment Findings. Cancun, Mexico, November 17th to 22nd, 2008. http://www.conabio.gob.mx/institucion/cooperacion\_internacional/TallerNDF/taller\_ndf.html.

- CITES. 2010. Res.Conf. 9.24 (Rev. CoP15), Annex 1. Criteria for amendment of Appendices I and II. http://www.cites.org/eng/ res/09/09-24R15.shtml.
- CITES. 2011a. What is CITES? http://www.cites.org/eng/disc/ what.shtml. Downloaded 18 July 2011.
- CITES. 2011b. The CITES Appendices. http://www.cites.org/eng/ app/index.shtml. Downloaded 18 July 2011.
- CITES AND UNEP-WCMC. 2011. The UNEP-WCMC CITES Trade Database. http://www.unep-wcmc-apps.org/citestrade/ trade.cfm. Consulted 14 Sept 2011.
- IUCN TFTSG. 2011. A study of progress on conservation of and trade in CITES-listed tortoises and freshwater turtles in Asia. Document AC25 Doc. 19. http://www.cites.org/eng/com/ac/25/ E25-19.pdf.
- LEUTERITZ, T.E., GERLACH, J., MITTERMEIER, R.A., RHODIN, A.G.J., VAN DIJK, P.P., LEWIS, R., AND RANDRIAMAHAZO, H. 2008. Conservation International Tropical Pocket Guide Series: Turtles

and tortoises of Madagascar and adjacent Indian Ocean islands. Arlington, Virginia: Conservation International.

- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu: Natural History Publications (Borneo) Sdn. Bhd. 147 pp.
- ROSSER, A.R. AND HAYWOOD, M.J. (Compilers). 2002. Guidance for CITES Scientific Authorities: checklist to assist in making nondetriment findings for Appendix II exports. Gland, Switzerland, and Cambridge, UK: IUCN, 146 pp. http://data.iucn.org/themes/ ssc/publications/CITES/CITES-guidance-prelims.pdf.
- SMITH, L.L., REID, D., ROBERT, B., JOBY, M., AND CLÉMENT, S. 1999. Status and distribution of the angonoka tortoise (*Geochelone yniphora*) of western Madagascar. Biological Conservation 91:23–33.
- TURTLE TAXONOMY WORKING GROUP [P. P. VAN DIJK, J. B. IVERSON, H. B. SHAFFER, R. BOUR, AND A. G. J. RHODIN]. 2012. Turtles of the world, 2012 update: annotated checklist of taxonomy, synonymy, distribution, and conservation status. Chelonian Research Monographs 5:000.243–328.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a07p44 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This IUCN Red List assessment reprinted from *The IUCN Red List of Threatened Species*™ www.iucnredlist.org/details/9014/0 (2008)



# Astrochelys radiata

THOMAS E.J. LEUTERITZ AND SÉBASTIEN RIOUX PAQUETTE



## **Taxonomy:**

Kingdom ANIMALIAPhylum CHORDATAClass REPTILIAOrder TESTUDINESFamily TESTUDINIDAEScientific Name: Astrochelys radiataSpecies Authority: (Shaw, 1802)Common Name/s:English – Radiated TortoiseFrench – Tortue Radiée De Madagascar, Tortue RayonnéeSpanish – Tortuga Estrellada De Madagascar, Tortuga Rayada

# Synonym/s:

Asterochelys radiata (Shaw, 1802) [orth. error] Geochelone radiata (Shaw, 1802) Testudo coui Daudin, 1802 Testudo desertorum Grandidier, 1869 Testudo hypselonata Bourret, 1941 Testudo radiata Shaw, 1802

#### **Assessment Information:**

Red List Category & Criteria: Critically Endangered A4d; E ver 3.1 Year Published: 2008 Date Assessed: 2008-01-15 Assessor/s: Leuteritz, T. & Rioux Paquette, S. (Madagascar Tortoise and Freshwater Turtle Red List Workshop) Reviewer/s: Rhodin, A. & Mittermeier, R.A. (IUCN SSC Tortoise & Turtle Freshwater Turtle Red List Authority)

# Justification:

Generation time is considered as 42 years; the assessment is carried out by considering documented impacts over a period encompassing less than two past generations (67 years) and anticipated impacts on the next generation (next 33 years) for a maximum assessment period of 100 years. Available information indicates that the species has disappeared entirely from about 40% of its past range through a combination of habitat loss and exploitation, and that remaining populations have been severely depleted by recent and ongoing exploitation predominantly for domestic consumption; an overall population reduction of 80% over two past and one future generation is a conservative estimate, thus qualifying as Critically Endangered under criterion A4d. Population modeling indicates collapse and extinction in a period of on average 45 years into the future, thus meeting Critically Endangered under criterion E. Habitat loss rates approach or exceed 80% over the three generation period, thus A4c may also be met.

# History:

1996 – Vulnerable (Baillie and Groombridge 1996)
1994 – Vulnerable (Groombridge 1994)
1990 – Vulnerable (IUCN 1990)
1988 – Vulnerable (IUCN Conservation Monitoring Centre 1988)
1986 – Vulnerable (IUCN Conservation Monitoring Centre 1986)
1982– Vulnerable

# **Geographic Range:**

Range Description: Radiated Tortoises are found in the dry spiny forests of southern and southwestern Madagascar, from the area of Amboasary in the south across the Karimbola and Mahafaly plateaus north of Tuléar (where the habitat is highly fragmented and tortoises may be close to extinction) to Morombe. They are usually found in a narrow band within about 50 to 100 km from the coast (Glaw and Vences 1994, Leuteritz et al. 2005). Is sympatric with *Pyxis arachnoides*. The species' core range comprise about 10,000 square km.

Countries: Native: Madagascar

Range Map: See Figure.

# **Population:**

Historically this species has been quite abundant, often being found along roadways and has served as symbol of Madagascar's south. This is not the case anymore. Tortoises are not found along major roadways but may be locally abundant in certain areas. According to O'Brien et al. (2003) the species is declining, with its range having contracted by one fifth over the last 25 years. Lewis (1995) reports density estimates based on line distance sampling of 262.2 to 1,076.7 tortoises/km<sup>2</sup>, from which he extrapolated a conservative total population size of 1.6-4 million. Leuteritz et al. (2005) reported densities of 27-5,744 tortoises/km<sup>2</sup> with a total population estimate of 12 million. Rioux Paquette et al. (2006) undertook a microsatellite genetic analysis, which identified three distinct conservation units with relatively high assignments rates. The study supported the role of the Menarandra and Manambovo Rivers as major barriers to the dispersal for most Radiated Tortoises.



Population models were calculated at the 2005 Population and Habitat Viability Analysis (PHVA) workshop based on a number of variables including estimated population size and annual harvest intensity. Depending on the variables selected, the species was predicted to reach extinction at various times, with most estimates clustering around 45 years into the future (range 20-100+ years) (Randriamahazo et al. 2007).

Population Trend: Decreasing.

#### Habitat and Ecology:

- The Radiated Tortoise is found in low irregular rainfall areas with xerophytic spiny vegetation dominated by Didiereaceae and Ephorbia (Durrell et al. 1989). They can be found on the high plateaus inland and also on the sandy dunes close to the coast (Leuteritz et al. 2005).
- Radiated Tortoises are herbivores feeding predominantly on grasses and in some areas on the alien invasive *Opuntia*. On occasion they are also known to ingest animal matter. During the rainy season wild tortoises drink from water that collects on rocks after it rains (Leuteritz 2003).
- Adult female tortoises range in carapace length from 24.2 35.6 cm and males ranged in from 28.5 39.5 cm (Pedrono 2008). Males exhibit distinct secondary sexual characteristics by about 26 cm carapace length (Leuteritz 2002). Mature females produce up to three clutches per season with 1–5 eggs per clutch (Leuteritz and Ravolanaivo 2005), leading to an estimated average production of two clutches of four eggs each per breeding female; an estimated 82% of mature females breed in an average

year (Randriamahazo et al. 2007). No solid data exists on longevity but estimated life span is believed to be up to 100 years (Randriamahazo et al. 2007). A detailed overview of natural history is presented by Pedrono (2008). Systems: Terrestrial.

#### Major Threat(s):

- Threats to the tortoise's survival include collection and habitat loss (Durrell et al. 1989, Nussbaum and Raxworthy, 1998, O'Brien 2002, O'Brien et al. 2003). "Collection" can be subdivided into two further categories: collection for the international wildlife trade and collection for utilization by local people.
- International collection has been documented with Asian smugglers collecting tortoises for the pet trade and for their livers (Behler 2002).
- However, domestic utilization of this species is of greater concern. Within Madagascar, the Mahafaly and the Antandroy, whose land covers the range of the Radiated Tortoise do not utilize the tortoise. They have a taboo (teremed a 'fady') against eating or touching the tortoises (Nussbaum and Raxworthy 1998, Lingard et al. 2003). However, large quantities of Radiated Tortoises are gathered by people from other areas of Madagascar who recently moved into this region, or by Malagasy people who are passing through. O'Brien et al. (2003) estimated that up to 45,000 adult Radiated Tortoises are harvested each year. Anecdotal information indicates that annual harvest numbers have increased since then; estimates calculated at the 2005 PHVA workshop ranged from 22,000 to 241,000 tortoises collected annually. Tortoise meat is especially popular around Christmas and Easter (Lewis 1995). Declared protected areas are insufficiently patrolled and resourced to deter large-scale collection right inside these nominal strongholds.
- Besides being used as food, the Malagasy often keep the tortoises as pets and in pens with chickens and ducks as a means of warding off poultry diseases (Durrell et al. 1989, Leuteritz et al. 2005).
- Habitat loss includes deforestation for use as agricultural land, the grazing of livestock, and the burning of wood for charcoal (Nussbaum and Raxworthy 1998). Recent analyses by Conservation International (May 2007) of the state of the spiny forest biome, using aerial imagery, indicate that deforestation rates have significantly increased over the last five years (compared with the period 1990-2000) (H. Crowley pers. comm. to Leuteritz). The 2001 Conservation Assessment and Management Plan (CAMP) workshop estimated habitat loss at 21-50% during the period 1990-2000, and forecast a habitat loss rate of 51-80% for the period 2001-2010. Harper et al. (2007) documented a consistent annual forest loss rate of 1.2% for the spiny forest (primary Radiated Tortoise habitat) throughout the period 1970-2000, and measured an overall reduction from 29,782 to 21,322 sq km over this period, a 29% reduction in less than one tortoise generation.

Invasive plant species affecting habitat suitability were considered a significant threat at the 2001 CAMP workshop.

#### **Conservation Actions:**

Very little research has been done on this species and most of it only in the last ten years.

- The species is protected nationally under Malagasy law (Decree 60126; October, 1960). Internationally, the Radiated Tortoise was listed as Category A of the African Conservation Convention of 1968, and, since 1975, it has been listed on Appendix I of CITES, which affords species the highest level of protection (Durrell et al. 1989, Hilton-Taylor 2000).
- Four protected areas and three additional sites (Lac Tsimanampetsotsa National Park 43,200 ha, Beza-Mahafaly Special Reserve 67,568 ha, Cap Sainte Marie Special Reserve 1,750 ha, Andohahela National Park 76,020 ha, and Berenty Private Reserve 250 ha, Site of Biological Interest – (1) Hatokaliotsy 21,850 ha and (2) PK3 north of Tulear 12,500 ha) fall within the range of this species. A captive breeding centre (Village de Tortues de Mangily) was established in Ifaty.
- In August 2005, an international meeting of the Population and Habitat Viability Assessment (PHVA) group produced an alarming prediction that without immediate and significant intervention, viable populations of Radiated Tortoises will likely be extirpated from the wild within one tortoise generation, that is, 45 years (Randriamahazo et al. 2007). It was suggested that a systematic monitoring program be established. This will have to involve the training of local people so that the programme can be viable. This and other recommended conservation measures are detailed in the PHVA workshop report (Randriamahazo et al. 2007). In addition, monitoring of exploitation trends at the wholesale and consumer parts of the trade chain (surveys of markets, traders and restaurants in Madagascar; monitoring international pet trade) is important.
- Additionally, ensuring adequate coverage of Radiated Tortoise populations as Madagascar expands its protected area network is essential. Research on habitat usage, specifically the impacts and benefits from *Opuntia* and other invasive vegetation, is desirable.

#### **Bibliography:**

BEHLER, J. 2000. Madagascar Tortoise Crisis – Letter to CITES Animal Committee and Concerned Parties. 9 January 2002. Turtle & Tortoise Newsletter: 18-19.

- BOUR, R. 1985. Les tortues terrestres et d'eau douce de Madagascar et des iles voisines. Madagascar Recherches Scientifique 18: 54-80.
- DURRELL, L., GOOMBRIDGE, B., TONGE, S. AND BLOXAM, Q. 1989. Geochelone radiata, Radiated Tortoise. In: I.R. Swingland and M.W. Klemens (eds), The Conservation Biology of Tortoises, pp. 96-98. IUCN, Gland, Switzerland.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Moos Druck / FARBO, Leverkusen & Koln.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D. AND HAWKINS, F. 2007. Fifty years of deforestation and fragmentation in Madagascar. Environmental Conservation 34(4): 1-9.
- IUCN. 2008. 2008 IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. (Accessed: 5 October 2008).
- LEUTERITZ, T.E.J. 2002. Distribution, status, and reproductive biology of the radiated tortoise, *Geochelone radiata* (Shaw, 1802) in southwest Madagascar. George Mason University.
- LEUTERITZ, T.E.J. 2003. Observations on the diet and drinking behaviour of radiated tortoises (*Geochelone radiata*) in southwest Madagascar. African Journal of Herpetology 52(2): 127-130.
- LEUTERITZ, T.E.J. AND RAVOLANAIVO, R. 2005. Reproductive ecology and egg production of the radiated tortoise (*Geochelone radiata*) in southern Madagascar. African Zoology 40(2): 233-242.
- LEUTERITZ, T.E.J., LAMB, T. AND LIMBERAZA, J.C. 2005. Distribution, status, and conservation of radiated tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124(4): 451-461.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). WWF Madagascar country office.
- LINGARD, M., RAHARISON, N., RABAKONANDRIANINA, E., RAKOTOARISOA, J.-A. AND ELMQVIST, T. 2003. The role of local taboos in conservation and management of species: the Radiated Tortoise in southern Madagascar. Conservation and Society 1: 223-246.
- NUSSBAUM, R.A. AND RAXWORTHY, C.J. 1998. Commentary on conservation of "Sokatra," the radiated tortoise (*Geochelone radiata*) of Madagascar. Amphibian and Reptile Conservation 2: 6-14.
- O'BRIEN, S., EMAHALALA, E.R., BEARD, V., RAKOTONDRAINY, R.M., REID, A., RAHARISOA, V. AND COULSON, T. 2003. Decline of the Madagascar radiated tortoise *Geochelone radiata* due to overexploitation. Oryx 37: 338-343.
- O'BRIEN, S.H. 2002. Population dynamics and exploitation of the radiated tortoise *Geochelone radiata* in Madagascar. Darwin College, University of Cambridge.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Sabah, Malaysia.
- RANDRIAMAHAZO, H., TRAYLOR-HOLZER, K., LEUS, K. AND BYERS, H.O. 2007. Population and Habitat Viability Assessment Workshop for Endemic Tortoise Species in Madagascar Geochelone radiata (Madagascar Radiated Tortoise) Pyxis arachnoides (Spider Tortoise). IUCN SSC Conservation Breeding Specialist Group, Apple Valley, MN.
- RIOUX PAQUETTE, S., BEHNCKE, S.M., O'BRIEN, S.H., BRENNEMAN, R.A., LOUIS JR., E.E. AND LAPOINTE, F.-J. 2007. Riverbeds demarcate distinct conservation units of the radiated tortoise (*Geochelone radiata*) in southern Madagascar. Conservation Genetics 8: 797-807.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a08p47 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This IUCN Red List assessment reprinted from *The IUCN Red List of Threatened Species*™ www.iucnredlist.org/details/9016/0 (2008)



# Astrochelys yniphora

# THOMAS E.J. LEUTERITZ AND MIGUEL PEDRONO



#### Taxonomy:

Kingdom ANIMALIA Phylum CHORDATA Class REPTILIA Order TESTUDINES Family TESTUDINIDAE Scientific Name: Astrochelys yniphora Species Authority: (Vaillant, 1885) Common Name/s: English – Ploughshare Tortoise, Madagascar Tortoise,

Angonoka, Madagascar Angulated Tortoise

French – Tortue à plastron éperonné, Tortue à éperon, Tortue à soc de Madagascar, Tortue de Madagascar

Spanish – Tortuga de Madagascar, Tortuga Globulosa Malagache

# Synonym/s:

Angonoka yniphora (Vaillant, 1885) Geochelone yniphora (Vaillant, 1885) Testudo yniphora Vaillant, 1885

# **Assessment Information:**

Red List Category & Criteria: Critically Endangered A4ad; B2ab(v); C1; E ver 3.1

Year Published: 2008

Date Assessed: 2008-01-15

Assessor/s: Leuteritz, T. & Pedrono, M. (Madagascar Tortoise and Freshwater Turtle Red List Workshop)

Reviewer/s: Rhodin, A. & Mittermeier, R.A. (IUCN SSC Tortoise & Turtle Freshwater Turtle Red List Authority)

# Justification:

The Ploughshare Tortoise qualifies as Critically Endangered under several criteria:

Its population, historically depleted for local/regional consumption and habitat burning to less than 1,000 animals for the past few decades, has declined sharply in recent years as a result of poaching for the illegal pet trade, with the current population estimate being somewhere near 200 mature animals in the wild and the threat of poaching increasing; thus, criterion A4ad appears to be met.

As a result of historical exploitation and habitat loss, the species is now restricted to five small subpopulations which are discontinuous from each other, with an estimated area of occupancy of about 12 square km, and ongoing threat of losses of animals from poaching, thus very nearly meeting B2a+b(v) (it just exceeds the area threshold for CR, but is so close that listing as CR under this criterion seems justified). With the lower population estimate at 200 mature animals and a high threat of removal of some of these animals for the illegal pet trade, a 25% population decline over one generation (42 years) is met by poaching levels as low as three animals every two years; current (2008) documented confiscation numbers exceed this. Thus criterion C1 is met.

Based on population dynamics and threat impacts, by analogy with *Astrochelys radiata*, the species is nearly certain to go extinct within the next generation if current threats continue unabated.

# History:

- 1996 Endangered (Baillie and Groombridge 1996)
- 1994 Endangered (Groombridge 1994)
- 1990 Endangered (IUCN 1990)

1988 – Endangered (IUCN Conservation Monitoring Centre 1988)

1986 – Endangered (IUCN Conservation Monitoring Centre 1986)

# **Geographic Range:**

Range Description: This species has a very small distribution and is known from a 25 to 60 sq. km range around Baly Bay in northwestern Madagascar (Durrell et al. 1989, Glaw and Vences 1994, Bour 2007). The area of suitable habitat may extend up to 70-92 sq.km. (DWCT survey results 1999-2000), while the area of occupancy may be restricted to just 12.4 sq. km (Pedrono 2008).

Countries: Native: Madagascar

Range Map: See Figure.

# **Population:**

It was estimated that the total wild population is about 600 individuals (440 to 770). These are found within five subpopulations: two to the east of the Andranomavo river (Sada and Beheta) and three to the west of the river (Ambatomainty, Betainalika, Andrafiafaly) (Smith et al. 1999, Pedrono 2000). Based on distance sampling surveys and the extent of suitable habitat (by 2005), DWCT estimated a maximum of 800 wild animals. Recent impacts (illegal collection for the international pet trade) have reduced the estimated population substantially, and the wild population is currently estimated to possibly be as low as 400 individuals, of which 200 adults (G. Pedrono pers.comm., 2008).

Based on the Population Viability Analysis performed for this species (Pedrono et al. 2004), and recent level of



poaching for international trade, the Angonoka is at extreme risk of extinction in the wild within 10 to 15 years, less than one generation time of 42 years.

Population Trend: Decreasing.

## Habitat and Ecology:

- The species is found in the Baly Bay region (over an area of approximately 700 km<sup>2</sup>, though only 66 km<sup>2</sup> of this is considered suitable habitat). This region is comprised of dry deciduous forest, savanna, and mangrove swamps. The climate is tropical with a distinctly seasonal rainfall patterns. Angonoka utilize bamboo-scrub habitat, which is considered to be a secondary stage of the dry deciduous forest (Curl et al. 1986). Bamboo-scrub habitat consists of a mosaic of shrubs, bamboo, savanna grasses, and open, non vegetated areas. The shrubs are generally under 2 m and the dominant species include Bauhinia sp. and Terminalia sp. Bamboo (Perrierbambos madagascariensis) occurs in dense thickets within the habitat. Andrianandrasana (2000) estimates there are 7,975 ha of suitable habitat of which 6,669 ha have tortoises occupying them. Elevation is less than 50 m above sea level (Smith et al. 1999a and b).
- Adult male tortoises are larger and heavier than females. Mean adult male length and weight is 414.8 mm (range 361-486 mm) and 10.3 kg (range 7.2-18.9 kg) respectively. Mean adult female length and weight is 370.1 mm (range 307-426 mm) and 8.8 kg (range 5.5-12 kg) respectively (Pedrono and Markwell 2001).
- According to Smith (1999) grasses and forbs in open rocky areas of bamboo scrub habitat appeared to be important

food items. Feeding was observed from October through May. Tortoises were observed to feed upon herbs, forbs and shrubs (Bauhinia sp. and Terminalia sp.) rather than grasses. Tortoises were never observed feeding on live bamboo, however, on several occasions they consumed leaf litter that included dead bamboo leaves. Angonoka were also observed feeding on dried carnivore and African bush pig feces (Smith 1999).

Smith (1999) estimates sexual maturity at a minimum of 15 years old. A study by Pedrono et al. (2001) showed the reproductive period was from 15 January to 30 May and tortoises produced 1-6 eggs (mean 3.2) per clutch and up 4 (mean 2.45) clutches per season. Despite low densities the egg fertility rate was 71.9% and resulting hatching success was 54.6% (Pedrono et al. 2001). This yields an estimated annual production of 3.2x2.45x54.6% = 4.3 hatchlings per reproducing female. By analogy with *Astrochelys radiata*, the average age of reproducing animals per generation time is estimated as being 42 years (Madagascar WS 2008).

Systems: Terrestrial.

### Major Threat(s):

The tortoise's restricted distribution and threatened status are believed to result from exploitation in historical times and from frequent human-caused fires, which were deliberately started to create and improve grazing conditions for Zebu cattle (Juvik et al. 1981, Curl et al. 1985). According to Lewis et al. (2005) "since 1995, the local communities, with the assistance of the Water and Forests Department and Durrell Wildlife, have annually burnt the savannah fringes during the wet season creating a system of natural firebreaks". Outbreaks of fires within tortoise habitat have continued to decrease annually. There was less than 50 ha of tortoise habitat burnt in 2004, but larger areas of Angonoka habitat were burnt in other years.

The other major and ongoing threat comes from illegal collection for the international pet trade (Lewis et al. 2005, Pedrono 2008); marked wild animals have been recorded from pet trade in Asia and despite some successful enforcement and confiscation actions, the species remains in extremely high demand in the global illegal pet trade which severely threatens the remaining wild animals.

#### **Conservation Actions:**

The species is protected under Madagascar national law and is also included in CITES Appendix I (Lewis et al. 2005). The species' area of occurrence at Soalala (area west of Baly Bay; 113,000 ha) was considered a "Site of Biological Interest" but it held no legal protection status (Nicoll and Langrand 1989), until in 1997 the Baly Bay area was gazetted as a national park (Lewis et al. 2005). The parks authority have had a permanent presence (eight personnel) at Soalala since 2001. There is also a network of 40 village 'para-rangers' who actively watch out for possible smugglers (and outbreaks of fires).

- Durrell Wildlife Conservation Trust established a conservation program for the Ploughshare Tortoise in 1986 that strongly integrated local people (Durbin et al. 1996). A summary of early research concerning the species was provided by Bour (2007). The history of Durrell Wildlife Conservation Trust's Project Angonoka was described by Lewis et al. (2005): Project Angonoka began in 1986 as a project to safeguard A. yniphora. The project was established as collaboration between Durrell Wildlife Conservation Trust (then known as Jersey Wildlife Preservation Trust) and the Water and Forests Department of the Government of Madagascar, together with support from the Worldwide Fund for Nature (WWF). Given the extreme rarity of the species, the initial goal was the establishment of a captive-breeding project. This was successfully achieved. In December 2004, the captive project had 224 captive-bred juveniles from 17 founder adults (10 males, 7 females). From the 1990s, work progressed to ecological research on the species in the wild, and developing conservation strategies with the surrounding local communities. The latter work formed the basis of communityled firebreaks and with the communities themselves proposing the creation of a park to safeguard the tortoise and the remaining forests.
- Ongoing monitoring of the species' occurrence in the global pet trade is needed, along with effective enforcement and repatriation and/or safe, conservation-oriented maintenance of confiscated animals in appropriate facilities.

#### **Bibliography:**

- ANDRIANANDRASANA, T.H. 2000. Survey of the habitat of the ploughshare tortoise *Geochelone yniphora* in the Baly Bay region, Madagascar. Dodo 36: 92.
- Bour, R. 1985. Les tortues terrestres et d'eau douce de Madagascar et des iles voisines. Madagascar Recherches Scientifique 18: 54-80.
- Bour, R. 2007. The Plowshare Tortoise: past, present, and uncertain future the type of *Testudo yniphora* Vaillant, 1885, with a selected bibliography. Emys 14(1): 33-46.
- CBSG. 2001. Evaluation et Plans de Gestion pour la Conservation (CAMP) de la Faune de Madagascar: Lémuriens, autres Mammifères, Reptiles et Amphibiens, Poissons d'eau douce et Evaluation de la Viabilité des Populations et des Habitats de Hypogeomys antimena (Vositse). IUCN SSC Conservation Breeding Specialist Group.

CURL, D. 1986. The rarest tortoise on Earth. Oryx 20(1): 35-39.

- CURL, D., SCOONES, I.C., GUY, M.K. AND RAKOTOARISOA, G. 1985. The Madagascan tortoise *Geochelone yniphora*: current status and distribution. Biological Conservation 34: 35-54.
- DURBIN, J., RAJAFETRA, V., REID, D. AND RAZANDRIZANAKANIRINA, D. 1996. Local people and Project Angonoka - conservation of the poughshare tortoise in north-western Madagascar. Oryx 30: 113-120.
- DURRELL, L., GOOMBRIDGE, B., TONGE, S. AND BLOXAM, Q. 1989. Geochelone yniphora. In: I.R. Swingland and M.W. Klemens (eds), The Conservation Biology of Tortoises, IUCN, Gland, Switzerland.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Moos Druck / FARBO, Leverkusen & Koln.
- IUCN. 2008. 2008 IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. (Accessed: 5 October 2008).
- JUVIK, J.O., ANDRIANARIVO, A.J. AND BLANC, C.P. 1981. The ecology and status of *Geochelone yniphora*: a Critically Endangered tortoise in northwestern Madagascar. Biological Conservation 19: 297-316.
- LEWIS, R., PEDRONO, M., RATSIMBAZAFY, J., BEKARANY, E. AND LOPEZ, A. 2005. Proposal for the Reintroduction of *Geochelone yniphora* at Beaboaly, Baly Bay National Park, Madagascar.
- NICOLL, M.E. AND LANGRAND, O. 1989. Madagascar : revue de la conservation et des aires protégées. World Wildlife Fund, Gland, Switzerland.
- PEDRONO, M. 2000. Interactive management of wild and captive populations: Conservation strategies for the ploughshare tortoise *Geochelone yniphora* in Madagascar. Dodo 36: 92.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Sabah, Malaysia.
- PEDRONO, M. AND MARKWELL, T. 2001. Maximum size and mass of the ploughshare tortoise, *Geochelone yniphora*. Chelonian Conservation and Biology 4(1): 190.
- PEDRONO, M., SMITH, L.L., CLOBERT, J., MASSOT, M. AND SARRAZIN, F. 2004. Wild-captive metapopulaion viability analysis. Biological Conservation 119: 463-473.
- PEDRONO, M., SMITH, L.L., SAROVY, A., BOUROU, R. AND TIANDRAY, H. 2001. Reproductive ecology of the Ploughshare Tortoise (*Geochelone yniphora*). Journal of Herpetology 35: 151-156.
- SMITH, L.L. 1999. The status and ecology of the Angonoka tortoise (*Geochelone yniphora*) of western Madagascar. Department of Wildlife Ecology and Conservation, University of Florida.
- SMITH, L.L., REID, D., ROBERT, B., JOBY, M. AND CLEMENT, S. 1999a. Status and distribution of the angonoka tortoise (*Geochelone ynipho-ra*) of western Madagascar. Biological Conservation 91: 23-33.
- SMITH, L.L., ROBERT, B., JOBY, M. AND CLEMENT, S. 1999b. Home range and microhabitat use in Angonoka (*Geochelone yniphora*) in Madagascar. Chelonian Conservation and Biology 3: 393-400.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a09p50 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This IUCN Red List assessment reprinted from *The IUCN Red List of Threatened Species*™ www.iucnredlist.org/details/19035/0 (2008)



# Pyxis arachnoides

# THOMAS E.J. LEUTERITZ AND RYAN C.J. WALKER



#### Taxonomy:

Kingdom ANIMALIAPhylum CHORDATAClass REPTILIAOrder TESTUDINESFamily TESTUDINIDAEScientific Name: Pyxis arachnoidesSpecies Authority: Bell, 1827Common Name/s:English – Spider TortoiseFrench – Pyxide Arachnoide, Tortue-araignéeSpanish – Tortuga Araña, Tortuga De Plastrón Articulado

# Synonym/s:

Bellemys arachnoides (Bell, 1827) Pyxis aranoides Gray, 1831 Pyxis madagascariensis Lesson, 1831 Testudo arachnoides (Bell, 1827)

# **Taxonomic Notes:**

Three subspecies are recognized: *Pyxis arachnoides arachnoides* Bell, 1827 *Pyxis arachnoides brygooi* (Vuillemin & Domergue, 1972) *Pyxis arachnoides oblonga* Gray, 1869

#### **Assessment Information:**

Red List Category & Criteria: Critically Endangered A4cd; E ver 3.1

Year Published: 2008

Date Assessed: 2008-01-15

Assessor/s: Leuteritz, T. & Walker, R. (Madagascar Tortoise and Freshwater Turtle Red List Workshop)

Reviewer/s: Rhodin, A. & Mittermeier, R.A. (IUCN SSC Tortoise & Turtle Freshwater Turtle Red List Authority)

# Justification:

- Based on habitat loss of this habitat-specific species, it has lost about 40% of suitable habitat in the period 1970-2000; habitat loss is accelerating and exacerbated by progressive fragmentation of remaining habitat, leading to an estimate of over 50% loss of remaining habitat in the next generation if current trends continue. Thus the species appears to meet the criteria for Critically Endangered (CR) under criterion A4c (90% habitat loss in three generations).
- In addition, the species has come under increasing direct exploitation for consumption in the past decade, mainly to meet the void created by declining populations of radiated tortoises (a larger and preferred species for con-

sumption. This may amount to meeting the criteria for CR under criterion A4d.

These factors combine to an estimated population reduction of at least 80% over the past two plus one future generation. In parallel, population modeling predicts the species' extinction in 60 to 80 years, thus meeting CR under criterion E. The northern subspecies, *P. a. brygooi*, is under most severe pressures and requires priority conservation action.

# History:

#### 1996 – Vulnerable

1994 – Indeterminate (Groombridge 1994)

1990 - Indeterminate (IUCN 1990)

1988 – Indeterminate (IUCN Conservation Monitoring Centre 1988)

1986 – Indeterminate (IUCN Conservation Monitoring Centre 1986)

# **Geographic Range:**

Range Description: The Spider Tortoise is found only in the arid region of the coastal areas of southwestern Madagascar, from the coast up to 10-50 kilometres inland going as far north as Morombe (Glaw and Vences 1994, Henkel and Schmidt 2000). It is sympatric with the Radiated Tortoise except for the northern extent of its range.

- *Pyxis arachnoides arachnoides*: This subspecies occurs in the region of the Onilahy River in southwestern Madagascar near Toliara. Its area of distribution is limited to north of the Manambo River and south of Lake Tsimanapetsotsa. A field survey carried out in 2001 by Behler and Randriamahazo has shown that the area of distribution of the sub-species extends up to north of the Menarandra River (H. Randriamahazo pers. comm.).
- *Pyxis arachnoides brygooi*: This subspecies occurs south of the Mangoky River. Tortoises are commonly found in the region between Morombe and Lake Ihotry (Ernst et al. 2000).
- *Pyxis arachnoides oblonga*: This subspecies (the southern subspecies) is found along the southern coast between the Menarandra River to the west and Lake Anony near Amboasary to the east. The majority of animals have been found between Ambovombe and Lavanono (Glaw and Vences 1994, Ernst et al. 2000).
- Participants at the 2001 Conservation Assessment and Management Plan (CAMP) workshop (CBSG 2001) estimated the extent of occurrence as between 5,000 and 20,000 sq. km, and the area of occupancy as less than 500 sq. km.



Countries: Native: Madagascar Range Map: See Figure.

#### **Population:**

- The earliest information on populations comes from Bour (1981), who anecdotally stated that *P. arachnoides* was localized but not rare. Raxworthy and Nussbaum (2000) estimate that there were more than ten populations and that the area of distribution could cover more than 2,000 km<sup>2</sup>. Jesu and Schimmenti (1995) who undertook the first quantitative estimate of population density reported approximately three individuals per ha. Walker et al. (2008) report densities of 4.63 and 2.08 tortoises per ha in the wet and dry seasons respectively. Both these studies were on *P. a. arachnoides*. A rough total estimate of 2-3 million animals was recorded by Pedrono (2008).
- Hinge mobility of the three subspecies decreases from south to north (Glaw and Vences 1994, Walker et al. 2008):
- *P. a. oblonga* plastron with black markings on scutes and anterior lobe will close completely to touch carapace (mobile).
- *P. a. arachnoides* plastron totally devoid of markings and anterior lobe will close partially but not touch carapace (less mobile).

*P. a. brygooi* - plastron totally devoid of markings but anterior lobe will not close fully to touch carapace (rigid). Population Trend: Decreasing.

#### Habitat and Ecology:

The Spider Tortoise is found in Mikea forest habitat in the north and in communities of xerophytic spiny vegetation with low irregular rainfall dominated by Didiereaceae and Ephorbia in the south (Durrell et al. 1989, Walker et al. 2007). Their habitat consists of sandy areas with spiny vegetation close to the coast. They do not tend to utilize rocky areas like *A. radiata* does (T. Leuteritz pers. obs.). Acccording to Walker et al. (2008) P. a. arachnoides was only recorded as feeding during the wet months, a period of increased activity. Tortoises are known to eat young leaves and cow dung with insect larva (Glaw and Vences 1994). Spider Tortoises reach a curved carapace length of up to 200 mm.

Very little is known about the reproduction of this species but it is believed to produce single egg clutches although the number of clutches per year are unknown (Durrell et al. 1989). Reproductive age is thought to be at about 12 years (Walker et al. 2004), and average reproductive age (=generation time) was conservatively estimated at 20 years at the 2008 Red List workshop. No solid data exists on longevity but estimated life span is believed to be up to 70 yrs (Randriamahazo et al. 2007).

Systems: Terrestrial.

## Major Threat(s):

- Pyxis arachnoides faces threats from habitat destruction and fragmentation (through conversion for agriculture, charcoal prduction, human-induced wildfires, and alien invasive plants). Recent analyses by Conservation International (May, 2007) of the state of the spiny forest biome, using aerial imagery, indicate that deforestation rates have significantly increased over the last five years (compared with the period 1990-2000) (H. Crowley pers. comm.). A loss of 21-50% was estimated to have occurred over the period 1970-2000 (an average annual rate of 1.2% spiny forest loss; Harper et al. 2007), and a further loss of 51-80% of remaining habitat was projected for the period 2002-2012 (CBSG 2001). Invasive plant species affecting habitat suitability were considered a significant threat at the 2001 CAMP workshop (CBSG 2001).
- In addition, the species has increasingly become subject to collection for the local food trade as Radiated Tortoise populations have been depleted, and exploitation has recently included harvesting for livers for export to Asia (Behler 2000). A pulse of legal export trade occurred during the period 2000-2004; CITES trade records show that about 4,000 animals were exported for the international pet trade in that time (Walker et al. 2005).
- *Pyxis arachnoides* was recommended to be listed as Endangered (A3acd, B1b) at the 2001 CAMP workshop (CBSG, 2001).
- Overall, the northern subspecies *P. a. brygooi* is under more severe habitat loss and exploitation pressures than the other two subspecies, with some *brygooi* subpopulations already extirpated and others declining.
- The 2005 Population and Habitat Viability Analysis (PHVA) workshop (Randriamahazo et al. 2007) evaluated different threat and population scenarios, which

variously yielded estimates of about 60 to 80 years of decline into extinction based on harvest rates of 2005. With increasing exploitation and accelerating loss of remaining habitat, this may be a conservative set of estimates.

#### **Conservation Actions:**

- This species is nationally protected under Malagasy law (Decree 60126; October, 1960). Internationally, the tortoise, since 1975, has been listed in Appendix II of CITES. In 2005 P. arachnoides was uplisted to CITES Appendix I. It is included on Schedule B of EU wildlife regulations, and imports are suspended.
- Two protected areas and three additional sites (Lac Tsimanampetsotsa National Park 43,200 ha, Cap Sainte Marie Special Reserve 1,750 ha and Berenty Private Reserve 250 ha, Site of Biological Interest – (1) Hatokaliotsy 21,850 ha and (2) PK3 north of Tulear 12,500 ha) fall within the range of this species (CITES 2005, Randriamahazo et al. 2007). A captive breeding centre (Village de Tortues de Mangily) was established in Ifaty.
- Since 1991, the action plan of the IUCN SSC Tortoise and Freshwater Turtle Specialist Group has considered Pyxis arachnoides to be a "species that requires conservation projects and study of its status" (IUCN/SSC/TFTSG 1991, CITES 2005). In August 2005, an international meeting of the Population and Habitat Viability Assessment (PHVA) group produced a report that addressed the conservation status and recommended conservation actions for this species, these included the need to start a national conservation plan (Randriamahazo et al. 2007). Walker et al. (2004, 2007) call for more stringent conservation measures to ensure habitat protection and a widespread, region wide education programme to try and protect *P. a. arachnoides* from food and pet-trade hunting.
- Additionally, ensuring adequate coverage of populations of the different Spider Tortoise taxa, particularly the subspecies *brygooi*, is very important as Madagascar expands its Protected Area network.

# **Bibliography:**

- BEHLER, J. 2000. Madagascar Tortoise Crisis Letter to CITES Animal Committee and Concerned Parties. 9 January 2002. Turtle & Tortoise Newsletter: 18-19.
- BOUR, R. 1981. Etude systematique du genre endemique malgache Pyxis Bell, 1827 (Reptilia, Chelonii). Bulletin Mensuel de la Société Linnéenne de Lyon 50: 132-176.

- CBSG. 2001. Evaluation et Plans de Gestion pour la Conservation (CAMP) de la Faune de Madagascar: Lémuriens, autres Mammifères, Reptiles et Amphibiens, Poissons d'eau douce et Evaluation de la Viabilité des Populations et des Habitats de Hypogeomys antimena (Vositse). IUCN SSC Conservation Breeding Specialist Group.
- CITES. 2005. CoP13 Prop. 15 Transfer of Pyxis arachnoides from Appendix II to Appendix I, in accordance with Resolution Conf. 9.24 (Rev. CoP12).
- DURRELL, L., GROOMBRIDGE, B., TONGE, S. AND BLOXAM, Q. 1989. Pyxis arachnoides, Madagascar spider tortoise; Tsakafy; Kapila. In: I.R. Swingland and M.W. Klemens (eds), The Conservation Biology of Tortoises, pp. 103-104. IUCN, Gland, Switzerland.
- ERNST, C.H., ALTENBURG, R.G.M. AND BARBOUR, R.W. 1998. Turtles of the World - CD-ROM edition. ETI Expert Center for Taxonomic Identification, Amsterdam, UNESCO Publishing, Paris, and Springer Verlag, Heidelberg and New York.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Moos Druck / FARBO, Leverkusen & Koln.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D. AND HAWKINS, F. 2007. Fifty years of deforestation and fragmentation in Madagascar. Environmental Conservation 34(4): 1-9.
- HENKEL, F. AND SCHMIDT, W. 2000. Amphibians and Reptiles of Madagascar and the Mascarene, Seychelles, and Comoro Islands. Krieger Publishing Company, Malabar, FL.
- IUCN. 2008. 2008 IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. (Accessed: 5 October 2008).
- IUCN SSC Tortoise and Freshwater Turtle Specialist Group. 1989. Tortoises and Freshwater Turtles. An Action Plan for their Conservation. IUCN, Gland, Switzerland.
- JESU, R. AND SCHIMMENTI, G. 1995. A preliminary study on the status of a population of Malagasy Spider tortoise (Pyxis arachnoides Bell, 1927) from SW Madagascar. In: B. Devaux (ed.), Proceedings of the International Congress of Chelonian Conservation. Gonfaron, France. 6th–10th July 1995.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Sabah, Malaysia.
- RANDRIAMAHAZO, H., TRAYLOR-HOLZER, K., LEUS, K. AND BYERS, H.O. 2007. Population and Habitat Viability Assessment Workshop for Endemic Tortoise Species in Madagascar Geochelone radiata (Madagascar Radiated Tortoise) Pyxis arachnoides (Spider Tortoise). IUCN SSC Conservation Breeding Specialist Group, Apple Valley, MN.
- RAXWORTHY, C. AND NUSSBAUM, R. 2000. Extinction and extinction vulnerability of amphibians and reptiles in Madagascar. Amphibian and Reptile Conservation 2(1): 15-23.
- WALKER, R.C.J., RIX, C.E. AND WOODS-BALLARD, A.J. 2005. The export of the endangered Madagascar spider tortoise (Pyxis arachnoides) to support the exotic pet trade. Herpetological Bulletin: 2-9.
- WALKER, R.C., WOODS-BALLARD, A.J. AND RIX, C.E. 2008. Population density and seasonal activity of the threatened Madagascar spider tortoise (Pyxis arachnoides arachnoides) of the southern dry forests; South West Madagascar. African Journal of Ecology 46(1): 67-73.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a10p53 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This IUCN Red List assessment reprinted from *The IUCN Red List of Threatened Species*™ www.iucnredlist.org/details/19036/0 (2008)



# Pyxis planicauda

# THOMAS E.J. LEUTERITZ, HERILALA RANDRIAMAHAZO, AND RICHARD E. LEWIS



# Taxonomy:

Kingdom ANIMALIA Phylum CHORDATA Class REPTILIA Order TESTUDINES Family TESTUDINIDAE Scientific Name: *Pyxis planicauda* Species Authority: (Grandidier, 1867) Common Name/s:

English – Flat-tailed Tortoise, Madagascar Flat-shelled Tortoise, Flat-backed Spider Tortoise, Flat-shelled Spider Tortoise

French – Pyxide à dos plat, Pyxide à queue platte Spanish – Tortue de Cola Plana

# Synonym/s:

Acinixys planicauda (Grandidier, 1867) Testudo morondavaensis Vuillemin, 1972 Testudo planicauda Grandidier, 1867

#### **Assessment Information:**

Red List Category & Criteria:

Critically Endangered A4acd ver 3.1

Year Published: 2008

Date Assessed: 2008-01-15

Assessor/s: Leuteritz, T., Randriamahazo, H. & Lewis, R. (Madagascar Tortoise and Freshwater Turtle Red List Workshop)

Reviewer/s: Rhodin, A. & Mittermeier, R.A. (IUCN SSC Tortoise & Turtle Freshwater Turtle Red List Authority)

# Justification:

*Pyxis planicauda* has suffered a minimum of 32% essential habitat loss during the period 1963-1993, and habitat loss rates continue at a similar level, leading to a compound habitat loss of well over 70% in a three generation period. This habitat impact was compounded by the removal of at least 20-25% of the total estimated population of adults in the three-year period 2000-2002. Combined, this indicates a minimum of 60% population decline in the past two generations, with a further 30% anticipated for the next generation, qualifying the species as Critically Endangered under criterion A4acd. Population modelling predicting extinction before 2030 is no longer applicable as some of the the modelling assumptions are no longer operational.

# History:

1996 – Endangered (Baillie and Groombridge 1996) 1994 – Indeterminate (Groombridge 1994) 1990 - Indeterminate (IUCN 1990)

1988 – Indeterminate (IUCN Conservation Monitoring Centre 1988)

1986 – Indeterminate (IUCN Conservation Monitoring Centre 1986)

# **Geographic Range:**

- Range Description: This species mainly occurs in fragments of dry deciduous forest in the region of Menabe between the Morondava and Tsiribihina Rivers. However, a small subpopulation occurs north of the Tsiribihina Rivers (Behler et al. 1993, Bloxam et al. 1993, Goetz et al. 2003).
- At the 2001 Conservation Assessment and Conservation Planning (CAMP) workshop, *P. planicauda*'s extent of occurrence was estimated as less than 5,000 sq. km, and total area of occupancy was estimated as under 500 sq.km (CBSG 2001).

Countries: Native: Madagascar

Range Map: See Figure.

# **Population:**

- Based on density estimates, habitat reduction and trade figures it is believed that the total population of *P. planicauda* is less than 10,000 animals (Anonymous 2001). Recent surveys yield a calculated total population of over 16,000 animals, but the methodology used requires further data to confirm this number.
- Summary of various *P. planicauda* studies (from CITES AC18 Doc. 7.1, 2002):
- 1991 Kirindi 8 km<sup>2</sup> surveyed tortoises encountered on 54 occasions 6.75 per km<sup>2</sup>, but no data on recaptures Quentin and Hayes (1991).
- 1996 Kirindi 20 km² / 20,000 ha surveyed 12 tortoises in 11 days, 83% recapture 0.6/km2 Bloxam et al. (1996). "main forest block":
- 0.5/ha (50/km<sup>2</sup>) Durbin and Randriamanampisoa (2000).
- 2-6/ha (200-600/km<sup>2</sup>) Durbin and Randriamanampisoa (2000, as cited in CITES Proposal 12.55)
- 1/ha (100/km<sup>2</sup>) Kuchling in litt. 2001, Rakotombololona (2001 cited in Rakotombololona & Durbin in litt. to SSC Wildlife Trade Programme, 23 Nov 2001).

Population Trend: Decreasing.

# Habitat and Ecology:

The forests inhabited by *Pyxis planicauda* grow on loose sandy soils and the tortoises take refuge amongst the leaf



litter of the forest floor. They burrow and are inactive in leaf litter during dry season (late May through October), but become active in the wet season. They are crepuscular and seek shelter during mid-day (Durrell et al. 1989, Ra-kotombololona 1998, Gibson and Buley 2004). Tortoises feed on fallen fruits such as *Breonia perrieri* and *Alean-thus greveanus* (Glaw and Vences 1994, Gibson and Buley 2004). Fungi and fallen flowers have also been reported as diet items (Goetz et al. 2003).

Adult *P. planicauda* reach a carapace length of 13.7 cm (Ernst et al. 2000) to 14.8 cm (Pedrono 2008). Based on information from Durrell Wildlife breeding center in northwestern Madagascar females do not reach maturity until ten years of age. Generation time was estimated at the 2008 Madagascar Tortoise and Freshwater Turtle workshop as at least 25 years. Mating occurs in the first half of the wet season and females produce 1-3 single egg clutches in the latter half of the wet season (Goetz et al. 2003, Pedrono 2008). Observation of nests in the wild, show incubation periods of 250-340 days (Razandrima-milafiniarivo et al. 2000).

Systems: Terrestrial.

#### Major Threat(s):

*Pyxis planicauda* is exclusively associated with closedcanopy dry forest and its major threat comes from habitat loss, particularly from burning and clearing for agricultural lands/cattle grazing, highway development, mining, and petroleum exploration (Tidd et al. 2001, Goetz et al. 2003, Bonin et al. 2006). Analyses of satellite imagery by Tidd et al. (2001) between 1963 and 1993 showed a 32% reduction in the primary dry forests. Deforestation rates have increased, and up to 50% of the 76,000 ha remaining in the southern portion of the tortoises range may be destroyed before 2010. A 50% reduction in the remaining 73,000 ha of habitat in the northern portion of its known range may occur by 2040 (Tidd et al. 2001), for a combined forest habitat loss estimated at over 70% in the period 1963-2040. Similar deforestation rates were documented by Harper et al. (2007).

- Secondary pressure comes from collection for the pet trade (Goetz et al. 2003, Bonin et al. 2006); a pulse of exploitation for pet trade export removed about 4,000 adult animals during 2000 to 2002, representing 20 to 40% of the total number of adults (depending on total population estimates). The reproductive capacity and recruitment potential of this species are particularly low, even by tortoise standards.
- The species is not consumed locally or traded locally/regionally.
- Population modelling at the 2001 CAMP workshop (CBSG 2001) predicted extinction before 2030 based on rates of habitat loss and pet trade collection then in effect, but legal export trade is no longer permitted and thus the modelling assumptions are no longer valid.
- *Pyxis planicauda* was recommended to be listed as Critically Endangered (CR A3acd + B1b) at the 2001 CAMP workshop (CBSG 2001).

#### **Conservation Actions:**

- In 2003, *P. planicauda* was uplisted to CITES Appendix I from Appendix II (in which the tortoise had been listed since 1977; UNEP-WCMC 2007). This is generally perceived to have reduced exploitation of the species. The tortoise is protected nationally by Ordinance No. 60-126 of 3 October 1960, which regulates hunting and fishing and provides for the protection of nature, but the problem is that it is not stated what level of protection this legislation affords to P. planicauda, or how this is enforced (CITES AC18 Doc. 7.1, 2002).
- The tortoise is protected at three sites within its range. It is protected in the special reserve of Andranomena 6,420 ha and in the Sites of Biological Interest of (1) Analabe 2,000-12,000 ha and (2) the Kirindy Forest (Morondava) 100,000 ha by private or local interests [CFPF] (Nicoll and Langrand 1989).
- *Pyxis planicauda* is bred at the Durrell Wildlife chelonian captive breeding centre in Ampijoroa (Razandrimamilafiniarivo et al. 2000) and at a number of zoos around the world.

#### **Bibliography:**

- BEHLER, J.L., BLOXAM, Q.M.C., RAKOTOVAO, E.R. AND RANDRIA-MAHAZO, H.J.A.R. 1993. New Localities for *Pyxis planicauda* in West-Central Madagascar. Chelonian Conservation and Biology 1(49-51).
- BLOXAM, Q.M.C., BEHLER, J.L., RAKOTOVAO, E.R. AND RANDRIAMA-HAZO, H. 1993. Distribution of the Madagascar Flat-Tailed Tortoise *Pyxis planicauda*. Dodo (Jersey Wildlife Preservation Trusts) 29:

149-156.

- BLOXAM, Q.M.C., NODY, J.P., RABENJANAHARY, R.D. AND GIBSON, R.C. 1996. Estimating density abundance of the Madagascar flattailed tortoise, *Pyxis planicauda*. Dodo (Jersey Wildlife Preservation Trust) 32: 132-136.
- CBSG. 2001. Evaluation et Plans de Gestion pour la Conservation (CAMP) de la Faune de Madagascar: Lémuriens, autres Mammifères, Reptiles et Amphibiens, Poissons d'eau douce et Evaluation de la Viabilité des Populations et des Habitats de Hypogeomys antimena (Vositse). IUCN SSC Conservation Breeding Specialist Group.
- CITES. 2002. AC18 Doc. 7.1, 2002. Implementation of Resolution Conf. 8.9 (Rev.) (Decision 11.106). Progress on the implementation of the review of significant trade (phases IV and V). Eighteenth meeting of the Animals Committee, San José (Costa Rica), 8-12 April 2002.
- DURRELL, L., GROOMBRIDGE, B., TONGE, S. AND BLOXAM, Q. 1989. Acinixys planicauda Madagascar flat-tailed tortoise, Kapidolo. In: I.R. Swingland and M.W. Klemens (eds), The Conservation Biology of Tortoises, pp. 94-95. IUCN, Gland, Switzerland.
- ERNST, C.H., ALTENBURG, R.G.M. AND BARBOUR, R.W. 1998. Turtles of the World - CD-ROM edition. ETI Expert Center for Taxonomic Identification, Amsterdam, UNESCO Publishing, Paris, and Springer Verlag, Heidelberg and New York.
- GIBSON, R.C. AND BULEY, K.R. 2004. Biology, captive husbandry, and conservation of the Malagasy flat-tailed tortoise *Pyxis planicauda*. Herpetological Review 35(2): 111-116.

- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Moos Druck / FARBO, Leverkusen & Koln.
- GOETZ, M., BUELY, K., GIBSON, R. AND BLOXAM, Q. 2003. The extreme biology of *Pyxis planicauda* Grandidier, 1867. Implications for captive husbandry and conservation. In: M. Dehnhard and H. Hofer (eds), Advances in Ethology, Blackwell, Berlin, Vienna.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D. AND HAWKINS, F. 2007. Fifty years of deforestation and fragmentation in Madagascar. Environmental Conservation 34(4): 1-9.
- IUCN. 2008. 2008 IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. (Accessed: 5 October 2008).
- NICOLL, M.E. AND LANGRAND, O. 1989. Madagascar: revue de la conservation et des aires protégées. World Wildlife Fund, Gland, Switzerland.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Sabah, Malaysia.
- RAKOTOMBOLOLONA, W. 1998. Study of the distribution and density of the Madagascan flat-tailed tortoise *Pyxis planicauda* in the dry deciduous forest of Menambe. Dodo 34: 172-173.
- RAZANDRIMAMILAFINIARIVO, O.C., REID, D. AND BEKARANY, E. 2000. Captive management and reproduction of the Madagascar flattailed tortoise *Pyxis planicauda* at the chelonian captive breeding centre, Ampijoroa, Madagascar. Dodo 36: 75-81.
- TIDD, S.T., PINDER III, J.E. AND FERGUSON, G.W. 2001. Deforestation and habitat loss for the Malagasy Flat-Tailed Tortoise from 1963 through 1993. Chelonian Conservation and Biology 4: 59-65.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a11p56 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This IUCN Red List assessment reprinted from *The IUCN Red List of Threatened Species*™ www.iucnredlist.org/details/8070/0 (2008)



# Erymnochelys madagascariensis

THOMAS E.J. LEUTERITZ, GERALD KUCHLING, GERARDO GARCIA, AND JULIETTE VELOSOA



## Taxonomy:

Kingdom ANIMALIA Phylum CHORDATA Class REPTILIA Order TESTUDINES Family TESTUDINIDAE Scientific Name: *Erymnochelys madagascariensis* Species Authority: (Grandidier, 1867) Common Name/s: English – Madagascar Big-headed Turtle, Madagascar Sideneck Turtle French – Podocnémide De Madagascar Synonym/s:

Dumerilia madagascariensis Grandidier, 1867 Podocnemis madagascariensis subspecies bifilaris Boettger, 1893 Podocnemis madagascariesis (Grandidier, 1867)

# **Taxonomic Notes:**

Historically placed in *Podocnemis*. No subspecies are currently recognized.

#### **Assessment Information:**

Red List Category & Criteria:

Critically Endangered A4d ver 3.1

Year Published: 2008

Date Assessed: 2008-01-15

- Assessor/s: Leuteritz, T., Kuchling, G., Garcia, G. & Velosoa, J. (Madagascar Tortoise and Freshwater Turtle Red List Workshop)
- Reviewer/s: Rhodin, A. & Mittermeier, R.A. (IUCN SSC Tortoise & Turtle Freshwater Turtle Red List Authority)

# Justification:

Overall, the species is in widespread serious decline (affecting both genetic forms equally), which was estimated as 80% over the past 75 years (three generations) and projected to continue as a further 80% decline in the next 75 years (CBSG 2001). The 2001 CAMP workshop evaluated the species as Critically Endangered under criterion A4d (CBSG 2001).

# **History:**

- 1996 Endangered
- 1994 Indeterminate (Groombridge 1994)
- 1990 Indeterminate (IUCN 1990)
- 1988 Indeterminate (IUCN Conservation Monitoring Centre 1988)

1986 – Indeterminate (IUCN Conservation Monitoring Centre 1986)

## Geographic Range:

Range Description: *Erymnochelys madagascariensis* is endemic to the western lowland river basins of Madagascar from the Mangoky River in the south to the Sambirano region in the North (Iverson 1992, Glaw and Vences 1994, CBSG 2001, Pedrono 2008).The species ranges up to about 500 m altitude (Pedrono 2008). Two genetically distinct forms have been noted. It is sympatric with *Pelomedusa subrufa* and *Pelusios castanoides*.

The species' extent of occurrence was estimated at the 2001 Conservation Assessment and Management Plan (CAMP) workshop as over 20,000 sq. km, with an area of occupancy of less than 500 sq. km. (CBSG 2001). Countries: Native: Madagascar

Range Map: See Figure.

# **Population:**

The best available information in 2001 generated an estimate of at least 10,000 animals making up some 20 subpopulations (CBSG 2001). Individual populations comprise tens to a few hundred animals based on markrecapture studies (Garcia 2006). The species is universally reported to be in widespread serious non-cyclical decline (CBSG 2001).

Population Trend: Decreasing.

# Habitat and Ecology:

- *Erymnochelys* habitat consists of slow-moving rivers, lakes, and swamps. Its preferred habitat is that of permanent open wetlands (CBSG 2001) and favours basking sites like rocks, logs, etc. (Kuchling and Garcia 2003). Garcia (1999, 2006) and Garcia and Lourenco (2007) carried out on fecal and stomach content analyses and found that juveniles feed primarily on aquatic invertebrates and adults feed on molluscs, plant material (leaves, seeds and fruit), and dead animals.
- This turtle has a carapace length of 50 cm or more (Garcia 1999, 2006). Females are sexually mature at carapace lengths of 25-30 cm (Kuchling 1988). The sex ratio in various populations varies from 1:2 to 1.7:1 (Kuchling 1988, Gracia 2006). Age at maturity and longevity are not known, but a generation time of 25 years was estimated at the 2001 CAMP workshop (CBSG 2001).

These turtles nest between September and January (most prevalent October-December) and appear to have a biennial ovarian cycle, with individual females only nesting in



alternate years. They can lay up to two or three clutches with an average of 13 eggs (range 6-29) in a reproductive season (Kuchling 1988, 1993a and b; Garcia 2006; Pedrono 2008).

Systems: Terrestrial; Freshwater.

#### **Major Threat(s):**

- *Erymnochelys* turtles are exploited for food at the local subsistence level and also taken as incidental catch in regular fishing (Kuchling 1993a, 1997; Kuchling and Mittermeier 1993; CBSG 2001; Garcia and Goodman 2003).
- The habitat is fragmented by agricultural and deforestation practices. Siltation is a problem because of the conversion of lakes to rice fields (CBSG 2001). No information is available on the predicted impacts of hydrological changes to Madagascar's rivers in the context of agricultural development, infrastructure development (dams/reservoirs) and climate change. Most populations occur outside protected areas, and even those inside protected areas are under exploitation pressure (Garcia and Goodman 2003).

#### **Conservation Actions:**

*Erymnochelys* has been listed in CITES Appendix II since 1978 (UNEP-WCMC 2007) and is fully protected by Malagasy Law (Kuchling 1993a, 1997; Kuchling and Mittermeier1993). Most major populations of *Erymnochelys madagascariensis* occur outside protected areas. Most of the small populations inside protected areas (PN Ankarafantsika 65,520 ha, PN Baie de Baly, RNI Bemaraha 152,000 ha) are also under exploitation pressure and declining or depleted or locally extirpated (CBSG 2001).

- Durrell Wildlife Conservation Trust and Conservation International have been working collaboratively on a conservation strategy for this species since 1997/98. This includes population field studies, captive breeding, and community education (Garcia 1999, 2006; Kuchling 2000; Kuchling and Garcia 2003).
- Kuchling (1997) suggested three conservation actions: an education campaign for fishermen, a captive breeding programme, and the establishment of additional protected areas. Recommendations from the 2001 CAMP workshop suggest additional measures which include enforcing protection for the species in protected areas and recovery management of depleted protected populations, establishment of monitoring and recovery strategies for the populations at Manambolomaty (a Ramsar site with the largest and most important *Erymnochelys* population), and public education range-wide (CBSG 2001).

#### **Bibliography:**

- CBSG. 2001. Evaluation et Plans de Gestion pour la Conservation (CAMP) de la Faune de Madagascar: Lémuriens, autres Mammifères, Reptiles et Amphibiens, Poissons d'eau douce et Evaluation de la Viabilité des Populations et des Habitats de *Hypogeomys antimena* (Vositse). IUCN SSC Conservation Breeding Specialist Group.
- GARCIA, G. 1999. Ecology and conservation of the Madagascan side-necked turtle *Erymnochelys madagascariensis*. Dodo 35: 172-173.
- GARCIA, G. 2006. Ecology, human impact and conservation of the Madagascan side-necked turtle at Ankarafantsika NP, Madagascar. Thesis. University of Kent, Canterbury, UK.
- GARCIA, G. AND GOODMAN, S.M. 2003. Hunting of protected animals in the Parc National d'Ankarafantsika, north-western Madagascar. Oryx 37(1): 5.
- GARCIA, G. AND LOURENCO, W. 2007. *Erymnochelys madagascariensis* diet. Herpetological Review 38(3): 330-331.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Moos Druck / FARBO, Leverkusen & Koln.
- IUCN. 2008. 2008 IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org. (Accessed: 5 October 2008).
- IVERSON, J.B. 1992. A Revised Checklist with Distribution Maps of the Turtles of the World. Private, Richmond, IN.
- KUCHLING, G. 1988. Population structure, reproductive potential, and increasing exploitation of the freshwater turtle *Erymnochelys madagascariensis*. Biological Conservation 43: 107-113.
- KUCHLING, G. 1993a. Biologie und lebensraum von Erymnochelys madagascariensis (Grandidier, 1867) und vergleich mit den anderen wasserschildkröten Madagaskars. Salamandra 28(3/4): 231-250.
- KUCHLING, G. 1993b. Possible biennial ovarian cycle of the freshwater turtle *Erymnochelys madagascariensis*. Journal of Herpetology 27(4): 470-472.
- KUCHLING, G. 1997. Patterns of exploitation, decline, and extinction of *Erymnochelys madagascariensis*: implications for conservation. In: J. van Abbema (ed.), Conservation, Restoration and Management of Tortoises and Turtles - Proceedings: of an International Conference, pp. 113-117. NYTTS, New York.

- KUCHLING, G. 2000. Concept and design of the Madagascan sidenecked turtle *Erymnochelys madagascariensis* breeding facility at Ampijoroa, Madagascar. Dodo 36: 62-74.
- KUCHLING, G. AND GARCIA, G. 2003. Pelomedusidae, Freshwater Turtles. In: S.M. Goodman and J. Benstead (eds), Natural History of Madagascar, pp. 956-960. University of Chicago Press, Chicago.
- KUCHLING, G. AND MITTERMEIER, R.A. 1993. Status and exploitation of the Madagascan big-headed turtle. Chelonian Conservation and Biology 1(1): 13-18.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Sabah, Malaysia.

# Overview of the Natural History of Madagascar's Endemic Tortoises and Freshwater Turtles: Essential Components for Effective Conservation

# MIGUEL PEDRONO<sup>1</sup> AND LORA L. SMITH<sup>2</sup>

<sup>1</sup>CIRAD, UPR AGIRs, B.P. 853, Antananarivo 101, Madagascar [miguel.pedrono@cirad.fr]; <sup>2</sup>Joseph W. Jones Ecological Research Center, 3988 Jones Center Rd., Newton, Georgia 39870 USA [lora.smith@jonesctr.org]

ABSTRACT.-Madagascar had seven endemic chelonian species, including six tortoises and one aquatic turtle. The now extinct tortoises species, *Aldabrachelys grandidieri* and *Aldabrachelys abrupta*, as well as the extant species, *Astrochelys yniphora*, *Astrochelys radiata*, *Pyxis planicauda*, and *Pyxis arachnoides*, all occurred in the arid bush and in the mosaic of dry forests and wooded savannahs from south to northwestern regions of the island. The aquatic Madagascar Big-headed Turtle, *Erymnochelys madagascariensis*, occurs in rivers and large lakes in western Madagascar. These species all have delayed maturity offset by a prolonged reproductive lifespan. They also have a moderate annual reproductive output that includes multiple small clutches of eggs within a season, thus their intrinsic population growth rates are low. The last two decades have brought an increased understanding of the demographic vulnerability of Madagascan chelonians to overexploitation.Particularly significant are the drivers of population dynamics relating to adult mortality and fecundity. The maximum level of harvest that their populations can sustain is low and is already greatly exceeded in most locations. This is the point at which the design of sound conservation strategies is crucial; increased integration of the natural history of Madagascan chelonians in conservation strategies could significantly improve their effectiveness.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, Podocnemididae, natural history, effective conservation, Madagascar

Madagascar's very diverse habitats and climates have been important evolutionary determinants of the life-history patterns of its chelonians. The island supported seven contemporary endemic species, including six tortoises and one aquatic turtle. Recent field research on Madagascan chelonians has revealed much about the ecology of the different extant species (Smith 1999; Pedrono 2000, 2008; Leuteritz 2002; O'Brien 2002; Garcia 2006). Phylogenetic analyses undertaken during the same period have added to our understanding of these species' histories (Caccone et al. 1999; Noonan 2000; Palkovacs et al. 2002; Austin et al. 2003; Le et al. 2006; Vargas-Ramirez et al. 2008). At present, we know more about Madagascan chelonians than we do about any other group of reptiles in Madagascar.

The Madagascar Big-headed Turtle (*Erymnochelys* madagascariensis), the island's one endemic aquatic chelonian, is the only Old World representative of the family Podocnemididae and is most closely related to the South American genus *Peltocephalus* (Noonan 2000; Vargas-Ramirez et al. 2008). Molecular data support a monophyletic origin of the Madagascan testudinids (Caccone et al. 1999). The ancestral testudinid probably originated from mainland Africa and later diverged into three clades: the giant tortoises (genus *Aldabrachelys*), medium-sized tortoises (genus *Astrochelys*), and small tortoises (genus *Pyxis*). Extant Madagascan tortoises occupy a range of habitats in the arid south and western portion of the island, but are totally absent from the humid eastern slopes (Pedrono 2008). The two species of extinct Madagascan giant tortoises, Aldabrachelys grandidieri and Aldabrachelys abrupta, occupied coastal areas and the colder highland region of the island and are thought to have filled an ecological role similar to that of large herbivorous mammals. Madagascar probably served as a source of dispersal for giant tortoises to most western Indian Ocean Islands (Bour 1994). Indeed, molecular analyses confirm the close relationship between extinct Madagascan Aldabrachelys spp. and the surviving lineage on the Aldabra Atoll, Aldabrachelys gigantea (Austin et al. 2003), which thus represents an unique restoration potential in parts of Madagascar (Pedrono et al. 2013). The giant chelonians did not fare well following human settlement of Madagascar, which occurred approximately 4000 years ago (Dewar et al. 2013). Giant tortoises vanished soon after human arrival, followed by the conversion of the mosaic of forests and wooded savannahs to closed canopy forests and species-depauperate grasslands (Burney et al. 2004).

The past extinctions of giant tortoises and the current threatened status of Madagascan chelonians should not be treated as separate problems. The current declines of Madagascan species are only the latest stage of a much longer-term mass extinction process (see Crowley 2010). In this context, knowledge of their natural history and response to historic threats reveals much about their vulnerability to current threats. Over the last 4000 years of human impact on Madagascar, the ranges of Madagascan chelonians have been greatly reduced, many populations have been lost and

Table 1. Biometric measurements of extant endemic Madagascan chelonians; means and ranges.

Species	Sex	Adult body mass (kg)	Adult straight-line carapace length (cm)
Astrochelys yniphora	male	10.30 (7.20–18.90)	41.5 (36.1–48.6)
	female	8.80 (5.50–12.00)	37.0 (30.7–42.6)
Astrochelys radiata	male	6.70 (4.50–10.50)	33.4 (28.5–39.5)
	female	5.50 (3.10–10.20)	30.5 (24.2–35.5)
Pyxis planicauda	male	0.36 (0.30–0.41)	12.6 (11.4–13.4)
	female	0.42 (0.34–0.67)	13.2 (12.0–14.8)
Pyxis arachnoides	male	0.19 (0.10–0.30)	11.1 (8.0–14.4)
	female	0.20 (0.08–0.40)	11.0 (8.6–15.4)
Erymnochelys madagascariensis	male	5.10 (1.75–9.80)	35.2 (27.5–45.8)
	female	4.90 (1.75–9.60)	34.5 (28.0–43.0)

fragmented, and have declined in abundance and distribution. Understanding the natural history of Madagascan chelonians is thus an essential component of any successful conservation strategy for these species.

## Natural History of Madagascan Endemic Chelonians

Body Size. — Madagascar was previously inhabited by two of the world's largest tortoises, *Aldabrachelys grandidieri* (125 cm straight line carapace length; SCL) and *Aldabrachelys abrupta* (115 cm SCL) (Bour 1994). The island also hosts one of the world's smallest tortoises, *Pyxis arachnoides* (11 cm SCL). Large body size is a preadaptive trait for long transoceanic drifting that allowed the ancestors of these tortoises to initially colonize Madagascar. It is also an adaptation to a broad range of environmental conditions. However, the selective harvest of giant tortoises by humans indicates that size indirectly confers a vulnerability to extinction (McKinney 1997). The largest extant species of Madagascan tortoise is *Astrochelys yniphora*, which can attain nearly 50 cm SCL (Pedrono and Markwell 2001) (Table 1). *Astrochelys radiata* is slightly smaller than *A. yniphora*. Interestingly, subfossil *A. radiata* from the Morondava region were larger than living members of this species (Bour 1994). Both *A. yniphora* and *A. radiata* exhibit sexual size dimorphism, with males attaining a larger body size than females (Smith et al. 2001; O'Brien 2002). Adult female *P*.



Figure 1. Radiated Tortoise, Astrochelys radiata, in its natural habitat. Photo by Miguel Pedrono.

14.8 (5.0-22.0)

Species	Maturity (years)	Incubation (days)	Clutch Size	Clutch Frequency	Egg mass (g)
Astrochelys yniphora	17–22	237(197-281)	3.2 (1-6)	2.4 (1-4)	36.2 (20.0–54.0)
Astrochelys radiata	16-21	(263-342)	2.5 (1-5)	(1-3)	39.0 (28.0-55.0)
Pyxis planicauda	9-13	(254-343)*	1	(1-3)	19.7 (15.4–22.2)
Pyxis arachnoides	9-13	(247-324)*	1	(1-3)	17.4 (11.0-22.0)

77 (58–109)

13 (6-32)

**Table 2.** Reproductive parameters of extant endemic Madagascan chelonians; means and ranges, \* = in captivity.

*planicauda* are on average larger and heavier than adult males (Bloxam and Hayes 1991; Rakotozafy 2009), whereas male and female *P. arachnoides* are about the same size. There is no difference in average SCL between the three subspecies of *P. arachnoides* (Pedrono 2008). Male and female *E. madagascariensis* are similar in body size (Kuchling 1988; Garcia 2006) (Table 1).

18 - 25

Erymnochelys madagascariensis

Reproduction. — Age at sexual maturity in Madagascan chelonians differs among species and is related to body size, and thus to individual growth rates. Like other chelonians, the medium-sized species (Astrochelys spp.) have extremely long development times; A. yniphora and A. radiata reach sexual maturity at 17–22 yrs and 16–21 yrs, respectively (Table 2). These species also have a relatively low annual reproductive potential. Mean clutch size of A. yniphora is 3.2 and the species lays an average of 2.4 clutches per year (Pedrono et al. 2001) (Table 2). Astrochelys radiata produces up to 3 clutches of 1-5 eggs per year (Leuteritz and Ravolanaivo 2005). The small Madagascan tortoise species (Pyxis spp.) are characterized by relatively early sexual maturity (9–13 yrs). However, both P. planicauda and P. arachnoides have a very limited reproductive output; each produces 1-3 clutches of a single egg per year (Razandrimamilafiniarivo et al. 2000; G. Hofstra, pers. comm.). Hence, their intrinsic population growth rate is extremely low. Female *E. madagascariensis* attain sexual maturity at 18–25 yrs (G. Kuchling, pers. comm.) and produce 2–3 clutches of 13 eggs per breeding season (Garcia 2006) (Table 2).

(2-3)

For all Madagascan chelonians, sex is determined by environmental conditions in the nest, but the sex ratio at hatching in the wild seems to approach parity. All species produce multiple clutches, which may be an adaptation to reduce the risk of nest predation. For all the Madagascan species there is variation in reproductive output among individual females, which is related to female body mass. Both clutch frequency and mean clutch mass are correlated with maternal body mass. Hatchling body mass is also strongly correlated with egg mass. On average, each reproductive female Astrochelys spp. produces around four hatchlings per year, compared to only about one hatchling per year for female Pyxis spp. Erymnochelys madagascariensis has the highest reproductive output of all the living species of Madagascan endemic chelonians, with roughly 17 hatchlings per year, although females probably only produce eggs every two years (Kuchling 1988, 1993). The length of the incubation period is variable (Table 2), and is determined by the length



Figure 2. Ploughshare Tortoise or Angonoka, Astrochelys yniphora. Photo by Lora L. Smith.



Figure 3. Flat-tailed Tortoise, Pyxis planicauda. Photo by Miguel Pedrono.

of time between oviposition and the beginning of the rainy season. Eggs of Madagascan testudinids probably undergo diapause during the cool dry season. Increasing incubation temperatures in the wet season may reverse the diapause, embryonic development is completed and hatchlings emerge from the nests during the rainy season.

Activity Patterns. — Activity in Madagascan chelonians is closely tied to seasonal rainfall. Tortoises are more active during the warm wet season (from November to May, when virtually all of the annual rainfall occurs), than during the cool dry season (from June to October). For Astrochelys spp., juveniles are largely dormant in the dry season when they stay hidden beneath leaf litter. Adults continue to feed during the dry season, although to a lesser degree than during the wet season (Smith 1999; Leuteritz 2002). Both adults and juveniles of both species of Pyxis are inactive during the extended dry season in southern Madagascar, when they seek shelter under the sandy soil, leaf litter, or preferentially, under shrubby vegetation (Bloxam and Hayes 1991; Walker et al. 2007). Thus, these tortoises conduct nearly all of their biological activities in just the 5–6 rainy months of the year. Pyxis spp. also shelter beneath leaves during the hottest part of the day during the wet season. Madagascan tortoises are particularly active on rainy days. Astrochelys radiata and P. arachnoides exhibit a bimodal activity pattern, avoiding any activity during peak temperatures, and are active only in the morning (0630-1000 hrs) and late afternoon (1500-1830 hrs) (Leuteritz 2002). The total daily activity period of P. arachnoides is short, on average 2-4 hrs a day when it is not raining (Pedrono 2008). Madagascan tortoises are often found basking in the early morning or after rain in open, sunny places. The aquatic species E. madagascariensis is

also more active during the warm wet season than during the rest of the year; however, it feeds year round (Garcia 2006).

Habitat and Home Range. — Many chelonians occur in naturally high population densities as a result of their low energy requirements. However, most populations of extant Madagascan species are allopatric and densities are artificially low due to overharvesting and poaching. Remaining habitat also is fragmented and declining from harvest of trees for firewood and charcoal production, uncontrolled bush fires, and encroachment for cultivation.

Astrochelys yniphora occurs in second growth habitat with bamboo (Perrierbambos madagascariensis), shrubs (Terminalia boivinii and Bauhinia pervillei), palm (Bismarkia nobilis) savannah, and forest edges around Baly Bay in western Madagascar (Smith 1999). Pyxis planicauda occurs in dry deciduous forests, as well as more open degraded habitat in the Menabe region north of Morondava in western Madagascar. It prefers secondary forests mixed with open areas over natural undisturbed forests (Rakotombololona, 1998). Astrochelys radiata and P. arachnoides are found in xerophytic spiny forests in southern Madagascar.

Adult tortoises of all Madagascan species are highly sedentary and exhibit some degree of site fidelity; it is common to find an individual in the same location in the same period during consecutive years. *Erymnochelys madagascariensis* occurs in rivers and lakes in western Madagascar and also is largely sedentary, although it can migrate across dry land if environmental conditions become too unfavorable. Home range size in *E. madagascariensis* varies according to sex, age, time of year, and probably also by population density (Garcia 2006).

Astrochelys yniphora is the only species of Madagascan chelonian for which detailed home range size data are available, but similar patterns are expected for other Madagascan testudinids. Male A. yniphora have a much larger home range than females and the size of the home range is greater in the wet season than in the dry season. Males have an average home range of 21 ha in the rainy season compared to 7 ha in the dry season, and females have an average home range of 13 ha in the rainy season and 4 ha in the dry season (Smith et al. 1999). Males are particularly mobile in the first rains of November and December, during which they fight with other males for access to females. Females are most active from January through May during the nesting season. Nest forays of greater than 1 km have been observed. Home range size is also strongly influenced by the size and age of individuals. Juveniles are particularly sedentary and have a home range of only 0.1–0.3 ha (Pedrono 2000).

Preliminary data on *P. planicauda* indicates that adult males and females have minimum home ranges of 0.5 ha and 0.42 ha, respectively. Juveniles of this species also are very sedentary with a minimum home range of only 0.02 ha (Rakotozafy 2009).

Diet. — Our knowledge of the diet of Madagascan chelonians is largely anecdotal. Astrochelys spp. feed on grasses (e.g., Aristida congesta and Eragrostis sp.), sedges, and some broad-leaved plants. Tortoises seem to prefer new growth rather than mature growth because of the high protein and low fiber content. The introduced cactus, *Opuntia* sp., benefits A. radiata since it is one of its preferred foods in the wild; the fruits are particularly appreciated. Occasionally, Astrochelys spp. eat droppings of other animals, pieces of bones and mollusc shells. Such items probably provide calcium and other minerals in the diet (Leuteritz 2003). Astrochelys spp. are able to drink through their nostrils instead of the mouth, although they do not possess a valvular structure like the extinct and living Aldabrachelys spp., allowing it to close its olfactory area. Such capability allows tortoises to exploit shallow, ephemeral puddles of water in arid habitats.

*Pyxis planicauda* eats nearly all types of leaves within reach on the forest floor, as well as fungi and fallen fruits. Occasionally they eat snails, slugs, and insects, and have also been observed scavenging animal corpses when they encounter them (Kuchling and Bloxam 1988). *Pyxis arachnoides* is an opportunistic browser and eats many types of plant leaves. New plant growth which develops after rain is particularly appreciated.

Juvenile *E. madagascariensis* have a diet of aquatic or terrestrial invertebrates that have fallen into the water (e.g., molluscs, Coleoptera, Trichoptera larvae, Odonata, and Ephemeroptera). Adult *E. madagascariensis* become progressively more omnivorous and consume *Ficus* and *Raphia* fruits, *Phragmites* shoots and stems, freshwater snails, *Melanoides tuberculatus*, and also scavenge dead animals such as fish. This species is principally opportunistic, with a diet dependent on the seasonal and spatial availability of resources. The proportion of animal prey eaten by adult turtles decreases significantly during the dry season (Garcia 2006). Predation and Parasitism. — As in other chelonians, the annual survival rate of Madagascan turtles and tortoises increases with body size and age. The carapace of large adults provides protection from predators. However, small juveniles, especially tortoises, are extremely vulnerable to predation by diurnal predators, as they are active and forage in open habitats in the wet season, and their shells do not harden for several years. Thus juvenile mortality is very high, with most of the offspring never reaching sexual maturity (Pedrono 2000; O'Brien 2002). The pressure from predators can vary temporally and among populations.

The African Bush Pig (*Potamochoerus larvatus*), which was probably introduced from Africa, is capable of killing juveniles of all species of Madagascan chelonians. However, nest predation by African Bush Pigs seems surprisingly low (around 3% for *A. yniphora*; Pedrono et al. 2001). Other potential predators of young tortoises include the Madagascar Buzzard (*Buteo brachypterus*), the introduced Indian Civet (*Viverricula indica*), and snakes (*Lioheterodon* spp.).

Potential predators of eggs or young *E.madagascariensis* include the African Bush Pig, the Yellowbilled Kite (*Milvus aegyptius*), the Madagascar Fish Eagle (*Haliaeetus vociferoides*), and the Nile Crocodile (*Crocodylus niloticus*); there are no known predators of large adult Madagascar Big-headed Turtles.

While disease has never been observed in wild populations, several species of ticks (i.e., *Amblyomma geochelone*, *A. chabaudi*, *Geckobia enigmatica*) have been found on *Astrochelys* and *Pyxis* spp. (Bertrand and Pedrono 1999; Durden et al. 2002). These parasites do not appear to cause significant disturbance to the tortoises.

#### Conclusions and Conservation Implications

The unique natural history of Madagascan chelonians presents equally unique challenges as well as opportunities for their conservation. Land tortoises, for example, are closely associated with dry scrub habitats, and bush fires within these habitats are one of the main conservation issues in Madagascar. Tortoises are particularly vulnerable to this threat because of their limited mobility; the long-term impact of bush fires on tortoise habitats is another concern. Bush fires will probably become more frequent in Madagascar as a result of climate change. Changes in temperature, rainfall patterns, and storm frequency and intensity may also directly impact Madagascar's ecosystems. Over the long term, new assemblages of species will form and create modified or entirely new ecosystems as a result of these changes (e.g., Seastedt et al. 2008). However, having been in existence since before the time of the dinosaurs, chelonians have already survived numerous episodes of rapid climate change in the geological past, and they are possibly less vulnerable to climate change than other animal groups in Madagascar. Although increased temperatures could potentially shift the timing of nesting in chelonians and increase egg incubation temperatures, with an increased production of females, freshwater turtles in North America have been found to have some plasticity in timing of nesting and selection of nest sites that produce optimal temperatures for a balanced sex ratio (Schwanz and Janzen 2008). Problems may arise from complex interactions associated with climatic conditions, activity budgets, and body reserves of small Madagascan tortoise species that aestivate during the long dry season. The rate of recovery of body reserves during the active wet season will depend upon climatic conditions. For example, if climate change results in a shorter wet season, female *Pyxis* spp. may find it difficult to restore their body reserves to reproduce or survive aestivation.

By far the most critical factor in conservation of Madagascan chelonians is overexploitation. The life history characteristics of chelonians render them particularly vulnerable to this threat (e.g., Congdon et al. 1994). This is particularly true of the largest remaining Madagascan species, *A. yniphora* and *A. radiata*. The fact that poachers in Madagascar specialize in these species and do not transfer their efforts to more abundant species once chelonian populations are driven to low numbers does not leave a chance for recovery. As the number of individuals decreases, a constant level of exploitation represents an increasing proportion of their populations. The moderate annual reproductive output and delayed maturity offset of these species cannot compensate for the loss of adults to poaching. It is thus easy to overexploit Madagascan chelonians, even at initially high densities.

The extinction of Madagascan giant tortoises illustrates the size-selectivity of this process, and confirms threats to surviving species that are next on the size scale (A. yniphora, A. radiata, and E. madagascariensis). Typically, highly profitable species are exploited first (McKinney 1997); the consumption of *P. arachnoides* in areas where *A. radiata* has disappeared is symptomatic of this pattern. If one accepts this hypothesis of selectivity, the current status of A. yniphora, which presents an intermediary size between the extinct giant tortoises and extant overexploited A. radiata - is not surprising. For the last few centuries A. yniphora has been in a state of near-extinction, with populations stabilized at extremely low numbers. However, collection of A. yniphora from the wild has greatly accelerated over the past 15 years, resulting in very rapid declines in the already depauperate populations and the species is now very close to total extinction in the wild (Pedrono 2008). A similar pattern of decline is occurring in A. radiata populations, although the effects have been buffered by their wide distribution and high population densities in southern Madagascar. However, the scale of exploitation of this species and the apparent extirpation of populations is alarming (Leuteritz 2002; O'Brien 2002).

Given the current threats to all of Madagascar's endemic chelonians, the design of sound conservation strategies is crucial. There is a need to rigorously assess the potential contributions of different management alternatives based on the best available science (Ferraro and Pattanayak 2006). The recognition that all individuals are not alike is fundamental to this process. The life history characteristics of most chelonians indicate that conservation of adults, and adult females in particular, is the most effective means of recovering populations (e.g., Frazer 1992; Congdon et al. 1994). This is because an adult female has a long reproductive life span in which to produce enough offspring to compensate for juveniles that do not survive into adulthood.

With critically endangered species such as A. yniphora, captive breeding to restock wild populations is an important component of a comprehensive conservation program. However, if we want to maintain wild populations, then extensive captive breeding and headstarting programs are inadequate if nothing is done to also address the threats facing the adults in the wild. Ex-situ conservation initiatives should never take priority over in-situ approaches; rather they should be used to supplement them. Ill-conceived conservation strategies may result in even further decline of populations that are already under threat. Of real concern for conservation of Madagascan chelonians is what we perceive as the continued emphasis on repatriation and rescue centers for confiscated animals and captive breeding and reintroduction, over a greater needed emphasis on conservation of wild populations. We believe that these ex-situ activities can divert attention and resources from efforts to conserve wild populations that still have a chance to recover (Pedrono 2011). They also have the potential to decrease genetic variability within species and to transmit exogenous pathogens to wild populations.

In our opinion, an increased understanding of the natural history of the Madagascan chelonians could significantly improve conservations strategies. Priority should be given to research on the two species of Pyxis for which we have little information on vital demographic parameters such as survival rate or average clutch frequency in wild populations. The same is true for E. madagascariensis, the study of which is complicated by its aquatic habitat. These parameters are needed to produce Population Viability Analysis (PVA) models, which allow the identification of parameters that influence the species' vulnerability and allow an unbiased evaluation of different conservation options (i.e., in-situ vs. ex-situ approaches) that can be used to define conservation strategies for these species (e.g., Tenhumberg et al. 2004). Ultimately, species-based conservation strategies need to be converted into focused, practical action plans to secure protection for dwindling populations of tortoises and turtles.

One of the major reasons for the long-standing debates between *in-situ* and *ex-situ* conservation approaches is the lack of empirical evidence in the definition of these species' conservation strategies. *Astrochelys yniphora* is the only Madagascan chelonian to have been the focus of a comprehensive PVA process to date (Pedrono 2000; Pedrono et al. 2004). However, its results, specifically the recommendation from population modeling to conserve wild adults, have not yet been effectively achieved, as evidenced by the fact that poaching and smuggling of wild individuals from Baly Bay National Park has unfortunately increased. And although some successes have been achieved in some programs, other aspects of conservation programs for Madagascan chelonians have been less effective. We believe that shortcomings in the definition and implementation of these species' conservation strategies may be part of the explanation. More of a focus on conservation of wild chelonians in their native habitats, along with applications of tools such as PVA that consider life history characteristics of Madagascan chelonians, is in our opinion key to preserving these unique species.

#### Résumé

Madagascar possédait sept espèces de chéloniens endémiques, dont six tortues terrestres et une tortue d'eau douce. Les espèces terrestres éteintes, Aldabrachelys grandidieri et Aldabrachelys abrupta, ainsi que les espèces survivantes, Astrochelys yniphora, Astrochelys radiata, Pyxis planicauda et Pyxis arachnoides, vivaient dans le bush aride, les forêts sèches, et les savanes arborées de la partie ouest et sud-ouest de l'île. La podocnémide de Madagascar, Erymnochelys madagascariensis, se rencontre dans les rivières et les grands lacs de l'ouest malgache. Ces espèces sont caractérisées par une maturité tardive compensée par un stade reproducteur prolongé. Elles présentent également un faible taux de reproduction annuel, reposant sur des pontes réduites. Dés lors, les taux de croissance intrinsèque de leurs populations sont faibles. Les recherches menées sur l'écologie de ces espèces durant les deux dernières décennies ont souligné la vulnérabilité démographique de leurs populations face à la surexploitation. La mortalité adulte et la fécondité constituent les deux principaux paramètres à risque pour la dynamique de leurs populations. Ces dernières présentent un seuil maximum de prélèvement très faible et il est déjà dépassé dans de nombreux endroits. C'est pourquoi il apparaît essentiel de mettre en œuvre des stratégies de conservation rigoureuses; une plus forte intégration de l'histoire naturelle des chéloniens malgaches dans la définition de leurs stratégies de conservation devrait permettre d'en accroître nettement leur efficacité.

#### LITERATURE CITED

- AUSTIN, J.J., ARNOLD, E.N., AND BOUR, R. 2003. Was there a second adaptative radiation of giant tortoises in the Indian Ocean? Using mitochondrial DNA to investigate speciation and biogeography of *Aldabrachelys* (Reptilia, Testudinidae). Molecular Ecology 12:1415–1424.
- BERTRAND, M. AND PEDRONO, M. 1999. Euryxenie et stenoxenie du genre Geckobia Megnin 1878 (Actinedida: Pterygosomatidae): récolte de Geckobia enigmatica n. sp. sur une tortue terrestre malgache (Geochelone yniphora). Acarologia 11:41–47.
- BLOXAM, Q.M.C. AND HAYES, K.T. 1991. Further field observations on the Malagasy flat tailed tortoise *Pyxis planicauda*. Dodo 27:138–145.
- BOUR, R. 1994. Recherches sur des animaux doublement disparus: les tortues géantes subfossiles de Madagascar. Mémoire et Travaux E.P.H.E. 19:1–253.
- BURNEY, D.A., BURNEY, L.P., GODFREY, L.R., JUNGERS, W.L., GOOD-MAN, S.M., WRIGHT, H.T., AND JULL, A.J.T. 2004. A chronology for late prehistoric Madagascar. Journal of Human Evolution 47:25–63.
- CACCONE, A., AMATO, G., GRATRY, O.C., BEHLER, J., AND POWELL, J.R. 1999. A molecular phylogeny of four endangered Madagascar tortoises based on MtDNA sequences. Molecular Phylogeny and Evolution 12:1–9.

- CONGDON, J.D., DUNHAM, A.E., AND VAN LOBEN SELS, R.C. 1994. Demographics of common snapping turtles (*Chelydra serpentina*): implications for conservation and management of long-lived organisms. American Zoologist 34:397-408.
- CROWLEY, B.E. 2010. A refined chronology of prehistoric Madagascar and the demise of the megafauna. Quaternary Science Reviews 29:2591–2603.
- DEWAR, R.E., RADIMILAHY, C., WRIGHT, H.T., JACOBS, Z., KELLY, G.O., AND BERNA, F. 2013. Stone tools and foraging in northern Madagascar challenge Holocene extinction models. Proceedings of the National Academy of Sciences 110:12583–12588.
- DURDEN, L.A., KEIRANS, J.E., AND SMITH, L.L. 2002. Amblyomma geochelone, a new species of tick (Acari: Ixodidae) from the Madagascan ploughshare tortoise. Journal of Medical Entomology 39:398-403.
- FERRARO, P.J. AND PATTANAYAK, S.K. 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. PLoS Biology 4:482-488.
- FRAZER, N.B. 1992. Sea turtle conservation and halfway technology. Conservation Biology 6:179-184.
- GARCIA, G. 2006. Ecology, human impact and conservation for the Madagascan side-necked turtle (*Erymnochelys madagascariensis* Grandidier, 1867) at Ankarafantsika National Park, Madagascar. Ph.D. Thesis, University of Kent, Canterbury, UK.
- KUCHLING, G. 1988. Population structure, reproductive potential and increasing exploitation of the freshwater turtle *Erymnochelys madagascariensis*. Biological Conservation 43:107–113.
- KUCHLING, G. 1993. Possible biennial ovarian cycles of the freshwater turtle *Erymnochelys madagascariensis*. Journal of Herpetology 27:470–472.
- KUCHLING, G. AND BLOXAM, Q.M.G. 1988. Field-data on the Madagascan flat tailed tortoise *Pyxis (Acinixys) planicauda*. Amphibia-Reptilia 9:175–180.
- LE, M., RAXWORTHY, C.J., MCCORD, W.P., AND MERTZ, L. 2006. A molecular phylogeny of tortoises (Testudines: Testudinidae) based on mitochondrial and nuclear genes. Molecular Phylogenetics and Evolution 40:517-531.
- LEUTERITZ, T.E. 2002. Distribution, status and reproductive biology of the radiated tortoise, *Geochelone radiata* (Shaw, 1802) in south-west Madagascar. Ph.D. Thesis, George Mason University, Fairfax, VA, USA.
- LEUTERITZ, T.E. 2003. Observations on diet and drinking behaviour of radiated tortoises (*Geochelone radiata*) in south-west Madagascar. African Journal of Herpetology 52:127–130.
- LEUTERITZ, T.E. AND RAVOLANAIVO, R. 2005. Reproductive ecology and egg production of the radiated tortoise (*Geochelone radiata*) in southern Madagascar. African Zoology 40:233–242.
- MCKINNEY, M.L. 1997. Extinction vulnerability and selectivity: combining ecological and paleontological views. Annual Review of Ecology and Systematics 28:495–516.
- NOONAN, B.P. 2000. Does the phylogeny of pelomedusoid turtles reflect vicariance due to continental drift? Journal of Biogeography 27:1245–1249.
- O'BRIEN, S. 2002. Population dynamics and exploitation of the radiated tortoise *Geochelone radiata* in Madagascar. Ph.D. Thesis, University of Cambridge, UK.
- PALKOVACS, E.P., GERLACH, J., AND CACCONE, A. 2002. The evolutionary origin of Indian Ocean tortoises (*Dipsochelys*). Molecular Phylogenetics and Evolution 24:216–227.
- PEDRONO, M. 2000. Gestion interactive entre les populations sauvages et captives: stratégie de conservation de la tortue *Astrochelys yniphora* à Madagascar. Ph.D. Thesis, University of Paris VI, France.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications, Borneo. Sabah: Kota Kinabalu, 147 pp.
- PEDRONO, M. 2011. Wasted efforts: why captivity is not the best way to conserve species. Madagascar Conservation & Development 6:57–59.

- PEDRONO, M. AND MARKWELL, T. 2001. Maximum size and mass of the ploughshare tortoise (*Geochelone yniphora*). Chelonian Conservation and Biology 4:191.
- PEDRONO M., SMITH, L.L., SAROVY, A., BOUROU, R., AND TIANDRAY, H. 2001. Reproductive ecology of the ploughshare tortoise (*Geo-chelone yniphora*). Journal of Herpetology 35:151–156.
- PEDRONO, M., SMITH, L.L., CLOBERT, J., MASSOT, M., AND SARRAZIN, F. 2004. Wild-captive metapopulation viability analysis. Biological Conservation 119:463–473.
- PEDRONO, M., GRIFFITHS, O.L., CLAUSEN, A., SMITH, L.L, GRIFFITHS, C.J., WILMÉ, L., AND BURNEY, D.A. 2013. Using a surviving lineage of Madagascar's vanished megafauna for ecological restoration. Biological Conservation 159:501–506.
- RAKOTOMBOLOLONA, W.F. 1998. Study of the distribution and density of the Madagascan flat-tailed tortoise *Pyxis planicauda* in the dry deciduous forest of Menabe. Dodo 34:172–173.
- RAKOTOZAFY, M.T.L. 2009. Biologie et estimation de la densité de la population de *Pyxis planicauda* (Grandidier, 1867) dans la forêt dense sèche et semi-caducifoliée de Menabe Antimena, Madagascar. Master's Dissertation, University of Antananarivo, Madagascar.
- RAZANDRIMAMILAFINIARIVO, O.C., REID, D., AND BEKARANY, E. 2000. Captive management and reproduction of the Madagascar flattailed tortoise *Pyxis planicauda* at the chelonian captive breeding centre, Ampijoroa, Madagascar. Dodo 36:75–81.
- SCHWANZ, L.E. AND JANZEN, F.J. 2008. Temperature change and temperature-dependent sex determination: can individual plasticity in nesting phenology prevent extreme sex ratios? Physiological

and Biochemical Zoology 81:826-834.

- SEASTEDT, T.R., HOBBS, R.J., AND SUDING, K.N. 2008. Management of novel ecosystems: are novel approaches required? Frontiers in Ecology and Environment 6:547–553.
- SMITH, L.L. 1999. The status and ecology of the angonoka tortoise (*Geochelone yniphora*) of western Madagascar. Ph.D. Thesis, University of Florida, Gainesville, FL, USA.
- SMITH, L.L., BOUROU, R., MAHATOLY, J. AND SIBO, C. 1999. Home range and microhabitat use in the angonoka (*Geochelone yniphora*) in Madagascar. Chelonian Conservation and Biology 3:393–400.
- SMITH, L.L., PEDRONO, M., DORAZIO, R.M., AND BISHKO, J. 2001. Morphometrics, sexual dimorphism and growth in the angonoka tortoise (*Geochelone yniphora*) of western Madagascar. African Journal of Herpetology 50:9–18.
- TENHUMBERG, B., TYRE, A.J., SHEA, K., AND POSSINGHAM, H.P. 2004. Linking wild and captive populations to maximize species persistence: optimal translocation strategies. Conservation Biology 18:1304–1314.
- VARGAS-RAMIREZ, M., CASTANO-MORA, O.V., AND FRITZ, U. 2008. Molecular phylogeny and divergence times of ancient South American and Malagasy river turtles (Testudines: Pleurodira: Podocnemididae). Organisms, Diversity & Evolution 8:388–398.
- WALKER, R.C.J., WOODS-BALLARD, A.J., AND RIX, C.E. 2007. Population density and seasonal activity of the threatened Madagascar spider tortoise (*Pyxis arachnoides arachnoides*) of the southern dry forests; South West Madagascar. African Journal of Ecology 46:67–73.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a13p67 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

# Troubled Times for the Radiated Tortoise (Astrochelys radiata)

# **RICK HUDSON<sup>1</sup>**

#### <sup>1</sup>Turtle Survival Alliance, 1989 Colonial Parkway, Fort Worth, Texas 76110 USA [rhudson@fortworthzoo.org]

ABSTRACT. – Wild populations of the Radiated Tortoise are under increasing pressure from poachers to supply local food markets (adults) and the international pet trade (juveniles). The species is declining rapidly and significant range contraction has been documented. The situation is compounded by severe environmental degradation and a lack of capacity for enforcement and protection at the local level. The importance of maintaining core source populations and protected areas is underscored, as well as the role of local community involvement. A comprehensive strategy to transition tortoises seized from the illegal trade back into areas of former abundance is outlined.

KEY WORDS. – Reptilia, Testudines, Testudinidae, *Astrochelys radiata*, conservation, illegal trade, Madagascar

Borrowing a quote from the late John Behler, these are indeed "troubled times for turtles." This rings especially true for Madagascar's Radiated Tortoise, *Astrochelys radiata*, widely considered as the world's most strikingly beautiful tortoise. One of four endemic tortoises on the island, *A. radiata* occupies a narrow band of xeric spiny forest along the southwestern coastline. Traditionally avoided by indigenous tribes because they were considered to be taboo (*fady*), these tortoises are now routinely and relentlessly harvested for food.

When John Behler and I first visited southern Madagascar over 20 years ago, Radiated Tortoises were abundant and one could hardly fathom as to why they were ever classified as an Endangered species. We drove to the coastal fishing village of Beheloka, and at approximately 1600 hrs, it was in John's words, "like someone threw the switch." Tortoises suddenly began to emerge in numbers, and it felt like we were stopping the vehicle every 50 yards to photograph one. As we gazed down the long, straight, red dirt road, we could see tortoise after tortoise in the distance. Upon arriving in Beheloka several hours later, shortly before dusk, we again found Radiated Tortoises in abundance, as well as numerous Spider Tortoises, Pyxis arachnoides arachnoides, in the coastal dunes around the village. We even encountered both species side by side, hunkered under the same Euphorbia bush. This day was truly one of those special moments in life that one never forgets.

But those halcyon days are long gone, with populations of Radiated Tortoises having been decimated in this area during the late 1990s for human consumption, which was followed some years later by the mass collection of Spider Tortoises for the international pet trade. Today, only a few scattered individuals of the Spider Tortoise can be found around Beheloka, mere remnants of a once thriving population. Unfortunately, this scenario is now being played out throughout southern Madagascar, and the Radiated Tortoise, once a commonly seen denizen of the spiny forest landscape, has disappeared from vast tracts of its former range. Formerly considered one of the world's most abundant tortoises, with populations conservatively estimated at 12 million (Leuteritz 2005), it is now assessed as Critically Endangered on the IUCN Red List, and unless drastic protective measures are taken, functional extinction in the wild within the next 20 years is a distinct possibility. Biologist Ryan Walker, who has been documenting range contraction in both Radiated and Spider Tortoises for the past seven years, stated in March 2011 that this prediction "may be a bit generous." According to Walker "we are witnessing the systematic extermination of these species across their range."

#### **Extinction within 20 Years**

We predicted extinction for the Radiated Tortoise in the wild within the next two decades after a visit to Madagascar in March of 2010; this projection was reported in a widely distributed press release by the Wildlife Conservation Society (WCS). The purpose of our joint Turtle Survival Alliance/ WCS expedition was to conduct health assessments on both wild and captive Radiated Tortoises, in preparation for an upcoming release of animals that had been confiscated from the illegal wildlife trade. On the second day of our trip, Brian D. Horne stumbled upon a disturbing site at the garbage dump in the village of Faux Cap. The area was littered with Radiated Tortoise shells (minimally estimated at 200 adults and subadults) from animals that were recently slaughtered for food, a grim harbinger of the carnage that we were to discover over the next two weeks (Fig. 1).

We also discovered that poaching had heavily impacted populations of the tortoise in areas that just a few years ago supported scores of individuals; we found only a handful of juveniles in these areas, and encountered adults only in close proximity to protected lands. We likened this rate of hunting to what the American Bison faced during the early 19th century, when it was nearly hunted to extinction after numbering in the 10s of millions (Dary 1974). Although a



**Figure 1.** The village of Faux Cap was littered with Radiated Tortoise shells (minimally estimated at 200 adults and subadults) from animals that were recently slaughtered for food. Photo by Rick Hudson.

limited level of subsistence hunting of Radiated Tortoises has existed for decades, generally for holiday celebrations in the cities of Tulear and Ft. Dauphin, the current rate of poaching is unsustainable. With this scale of poaching and the rate of decline in this species, which is unlike anything witnessed in modern times, functional extinction of natural populations in 20 years is not an unlikely scenario (Fig. 2). To illustrate this impact, Rafeliarisoa et al. (2013, this volume) estimate that the range of the Radiated Tortoise has contracted by approximately 65% over the past 150 years. However the numbers have decreased by roughly 47% in the past 12 years, from an estimated 12 million tortoises in the late 1990s, to around 6.3 million today. The rate of decline-the primary reason for their elevation to IUCN Critically Endangered status-is both shocking and troubling, and demands swift conservation action.

Tortoise extinctions are not new to islands, and certainly not islands in the Indian Ocean. According to the Turtle Taxonomy Working Group (2012) checklist, at least 10 species of giant tortoises have been driven to extinction by the actions of humans in relatively recent times. Those in Madagascar were the first to go, as two species were lost approximately 750 to 1050 years ago, shortly after humans arrived. Five species disappeared in the 1700s from Réunion, Mauritius, and Rodrigues, and in more recent times three went extinct in the Galapagos Islands in the eastern Pacific Ocean.

To date, the work of Sue O'Brien and colleagues (2003) had provided the most scholarly review of the current level of overexploitation of the Radiated Tortoise. These authors presented some startling conclusions, though not all were totally unexpected. They estimated that the annual take of Radiated Tortoises exceeded 50,000 animals per year, an amount they considered unsustainable based on the following salient points:

1. The geographic range of the Radiated Tortoise had contracted by ca. 20% over the previous 25 years, tortoise abundance had significantly declined close to centers of high demand, and commercial hunters were traveling increasingly farther to find sufficient densities of tortoises.

2. Tortoise density was three times lower and the size of adult tortoises was smaller in harvested populations, compared to an unharvested population.

3. Based on several important life-history characteristics (i.e., differential survival rates between adults and juveniles and the limited reproductive output of the female) and the harvest rate at that time, their population modeling predicted extinction within 2–15 yrs when starting with a hypothetical population of 10,000 tortoises.

4. The harvest at the time was at least 25 times greater than a predicted sustainable harvest. In addition, the authors detailed that the removal of juvenile tortoises rather than the adults would be much more sustainable.

Unfortunately, the Radiated Tortoise continues to be impacted by indiscriminate collection at two critical stages of its life history, with both juveniles and adults being heavily collected. Aside from the slaughter of adults for food, we have received reports of thousands of small Radiated Tortoises leaving the Antananarivo airport on direct flights to Bangkok, Thailand, from where they are distributed to markets in Asia, most notably China, Indonesia, Japan, Malaysia, Singapore, and the former Soviet Union. Recent work by TRAFFIC indicates that Radiated Tortoises are being smuggled into Southeast Asia at an alarming rate, through Thailand, and that they are now the most commonly observed chelonian in the trade (Nijman and Shepherd 2007). This "one-two harvesting punch" will almost certainly render the recovery of Radiated Tortoise populations nearly impossible without significant hands-on efforts aimed at reducing the off-take of both adults and juveniles. Additionally, programs for restocking areas of suitable habitat with tortoises seized from the illegal trade will become increasingly necessary.

Yet, the Radiated Tortoise appears to defy logic in that it has managed to sustain remarkable population numbers prior to these modern times, when other similar species have long since undergone catastrophic population declines (e.g., African Spur-thighed Tortoise and Burmese Star Tortoise). The answer to this puzzle may lie within the traditional belief known as *fady* (taboo). The dominant tribe in southwestern Madagascar, the Antandroy, do not eat tortoises and hold on to



**Figure 2.** The current rate of poaching is unsustainable. A poacher from Beloha is shown here in front of a large pile of tortoise shells. Photo by Aaron Gekoski.

a long-held belief that harming them is taboo. Unfortunately, these local customs that protected tortoises for centuries are being lost to the rapid westernization of traditional societies. In addition, this particular tradition of fady is not being respected by outside tribes, particularly the Antanosy from the north and east and the Vezo in the far west. Members of these tribes often target areas to specifically collect tortoises for sale in major cities and to meet the demand for bushmeat that is being fuelled, in part, by large-scale international mining operations in southern Madagascar. For instance, tortoise populations have been extirpated in areas surrounding large urban centers in the south (Tulear and Ft. Dauphin). Even more disturbing, recent evidence indicates that poachers are searching for tortoises in distant and remote areas that are often extremely difficult to reach, as evidenced by poaching camps discovered with the remains of hundreds of tortoises (Castellano et al. 2013, this volume). Local informants are also reporting that trucks loaded with Radiated Tortoises and/ or dried tortoise meat have been recently spotted on their way to Antananarivo. Groups of tortoise hunters are reportedly dropped off in tortoise-rich areas and are able to thoroughly



**Figure 3.** Fresh tortoise meat is being sold openly without fear of prosecution. Herilala Randriamahazo, TSA's Malagasy Tortoise Conservation Coordinator, is shown here purchasing tortoise meat at a restaurant in Tsiombe. Photo by Rick Hudson.

extract large numbers of tortoises, often taking only the dried meat, which makes concealment easier. Furthermore, in towns such as Beloha and Tsiombe, fresh tortoise meat is being sold openly without fear of prosecution (Fig. 3). Tortoise meat is offered in some restaurants daily as the "special" and the remains of discarded tortoise shells can be easily seen in these cities, piled along the roads or in vacant lots, a testament to this growing trade. Sadly, poverty-stricken and protein-starved people are not consuming tortoises; rather it is people that can afford to eat in restaurants, who simply prefer to eat something other than chicken or beef, that are consuming the majority of the tortoises. This situation is exacerbated by the following factors:

• Several years of extreme drought have led to diminished rice and agricultural production, and poverty, leading people to collect the tortoises for cash so they can purchase rice and corn.

• An arcane law dictating that wildlife laws must be enforced from afar (Antananarivo, or a regional office), and thus local officials have no legal capacity to apprehend poachers. Enforcement action is often days or weeks away, making the system easy to circumvent.

· Severe habitat degradation of the xeric spiny forest has greatly limited the amount of remaining habitat for the tortoises. This forest type is now regarded as the most endangered forest type in Madagascar (<2% remains), primarily in a limited number of protected areas. Following the burning and clearing of forests for agriculture (slash and burn) invasive plant species outcompete native species. Two species in particular, Opuntia sp. (prickly pear) and Agave sp. (sisal), dominate theses altered areas. The problem is exacerbated by an overabundance of Zebu cattle that sustain themselves on Opuntia, which facilitates the plant's dispersal through the spread of seeds in the dung. Large numbers of goats also share the habitat, and charcoal production consumes any large trees left standing after burning. Amazingly, in this highly disturbed and human-altered habitat, the Radiated Tortoise is still able to continue finding enough resources to survive and reproduce. And it is uncertain to what degree the tortoises are also utilizing Opuntia (particularly the fruits) as a substitute food source in these highly altered habitats. Yet it is obvious that the chances for long-term survival of the Radiated Tortoise are grim in light of both habitat destruction and degradation and the elevated levels of collection for human consumption.

• The recent collapse of the central government and political instability makes conservation efforts logistically difficult. In short, the government is effectively non-operational, international tourism is at a modern low, and any and all natural resources are apparently for sale in marginal efforts to keep the government solvent.

Perhaps the most troubling trend is that poachers are now entering protected areas (Special Reserves, National Parks, and World Heritage Sites) to collect tortoises. One of the largest remaining populations of Radiated Tortoises is in the Cap Ste. Marie (CSM) Special Reserve (Fig. 4), a small (17 km<sup>2</sup>) protected area with one of the highest densities of tortoises in the world (once estimated from 1905 to 2105 individuals/km2; Leuteritz 2005). But, with only a handful of guards to protect the reserve and no means of making daily patrols to deter poaching, this near pristine site remains vulnerable. The guards lack motorcycles or all-terrain vehicles to patrol the reserve; rather, they occasionally hitch a ride on an ox-cart. The only real protection the reserve has is due to the fact that the park is isolated and difficult to reach. This protection is fleeting, however, as once the population of tortoises outside the park is diminished, the poachers will eventually make their way into the park. This situation was confirmed through conversations with the CSM staff, who admit that they are aware of the looming crisis, but they are poorly prepared to deal with the impending threat. To illustrate this, in October 2011 a poaching camp was raided in the village of Tragnavaho, and the remains of 1982 slaughtered adult tortoises were uncovered. Sixty people-including women and children-were rounded up, mainly from the town of Fotadrevo in the north, where many of the poaching gangs currently hail from. Tragnavaho lies between Beloha, a major trade nexus for tortoises coming from the south and a well-known tortoise eating center, and CSM, a foreboding indication of how close to the Reserve poachers are operating. We heard similar stories from the staff at Lac Tsimanampetsotsa, Madagascar's newest National Park, where poaching has already heavily impacted tortoise populations, largely due to the park's close proximity to the city of Tulear.

Our sense of urgency is now heightened because it appears that the situation may have finally reached a tipping point. After *holding their own* despite years of harvesting for food, though on a more limited basis, the beautiful Radiated Tortoise may be on its *final legs*. Our challenge is to determine a strategy that will at least preserve *some* healthy populations; that solution will almost certainly lie at the local community level. Southern Madagascar is a vast rural region where there is little capacity for enforcement of tortoise poaching activity. Enforcement is constrained by a poor communications network, lack of transportation by officials, and a lack of knowledge of the laws.

Given the urgent nature of the present crisis, what can we do to help? How can we engender support for protecting tortoises in the face of such grinding poverty? The solutions will not be easy, because of the number of people and domestic livestock trying to eke out an existence in this harsh, desert environment. Moreover, this situation can only become worse because Madagascar has one of the fastest-growing human populations in the world, with the majority of people under the age of 12.

#### Vital Protected Areas

We believe that at least one solution begins with Madagascar National Parks (MNP), a private association that manages the protected areas network and operates under the Ministry of the Environment and Forests (MEF). With only two protected areas that support robust populations



**Figure 4.** Radiated tortoises with the iconic light house at the Cap Ste. Marie Special Reserve in the background. This Reserve supports the densest and most important tortoise population for protection in Madagascar. Photo by Aaron Gekoski.

of Radiated Tortoises, we must find ways to empower and strengthen them to meet this challenge. Given the importance of the CSM Special Reserve as a major source population of tortoises, this has to become our *line in the sand* and we must devote all possible resources to protecting this critical area. Will we be able to find the means of providing greater financial support to more effectively manage this important population, given that high dollar items such as vehicles are so desperately needed? Perhaps more importantly, do we really have a choice? If we cannot find the means to adequately defend these protected areas from poachers, it appears there may be little hope for the survival of this species in the wild.

A second but equally important solution involves the development of community-based protection programs, whereby local villagers assist the MNP staff in patrolling and monitoring tortoise populations within and around the protected areas. In order to encourage such cooperation, we need to find ways for improving the socioeconomic lives of the local people as an incentive to support protective measures. In 2011, Christina Castellano and the TSA presented a comprehensive and multifaceted plan to the World Bank for protecting the tortoise population at CSM that involved a range of actions, most of them community-based. Actions included improving capacity


**Figure 5.** The completed "signed" agreement (village leaders traced their hands) committing the community to tortoise protection is displayed for the ceremony in which TSA pledged to build a new school for Antsakoamasy. Photo by Rick Hudson.



Figure 6. Over 1200 people showed up to witness the dedication ceremony for the region's newest primary school, many having walked for days to reach Antsakoamasy. Photo by Rick Hudson.

for surveillance and enforcement, both within and outside the Reserve, establishing a communications network, biological monitoring and research, increasing capacity to properly care for confiscated tortoises, engaging the local community in Reserve management, and building a research/interpretive center, as well as a tortoise rescue center, and a public relations and marketing campaign. The three-year program totaled \$647,745, with the World Bank agreeing to provide \$485,245 in support. However, despite this approval of the proposal nearly three years ago, we have been unsuccessful in having the funds allocated as a result of the MNP bureaucracy.

In 2010 the TSA found an enthusiastic group of villagers at Antsakoamasy, a small village located on the outskirts of CSM, who are doing an admirable job of protecting tortoises. We engaged them to find out why, and what they hoped to gain by protecting the tortoises and challenging the poachers. We learned that the protective taboo or *fady*  is very strong in this village, and the tortoises are seen as the embodiment of their ancestors. We hypothesized that Antsakoamasy could become a model for community protection of a local Radiated Tortoise population. But how should TSA reward what they do, and provide incentive for continuing this custom? We asked the village elders what they wanted most for their community and they indicated a primary school. Therefore, the TSA agreed to fund the construction of a school and began raising \$15,000 toward this cause (Fig. 5). In March 2011 we formalized this agreement with a traditional zebu festival at Antsakoamasy. The festival was attended by at least 1200 people (Fig. 6), including the mayor from the nearby town of Maravato, who extolled the crowd to regard tortoises as a means of improving their lifestyle and community.

Our hope was that word of this relationship would spread rapidly throughout the rural villages of the south, and that Antsakoamasy would become a catalyst, motivat-



Figure 7. This new school house was presented by the TSA to the village of Antsakoamasy in recognition of their exceptional protection of Radiated Tortoises. Photo by Herilala Randriamahazo.

ing other villages to provide greater protection for their tortoises. In March 2012, after five months of planning and construction, that hope was realized as a huge crowd gathered to dance and celebrate, eat and drink, and cut the ribbon on their new school (Fig. 7). From all over the Androy Region they came: politicians, local officials, teachers, and of course the children-over 1000 of them. All wanted to be there to participate in the dedication ceremony for the region's newest primary school. A host of local political officials in attendance spoke enthusiastically on the irony of how one village protecting tortoises could have such a powerful impact, bringing people together to celebrate and refresh their cultural traditions and taboos, while building a partnership that resulted in a new school as a basis for the future for their children. One education official committed to provide a full-time teacher for the school, which has since happened. Clearly something special was happening at Antsakoamasy, and this community has since become a regional model that establishes a strong link between protecting tortoises and long-term benefits for the community.

To place the effectiveness of this relatively small sum of \$15,000 into a greater conservation perspective—knowing that the sale of surplus offspring from Radiated Tortoise captive breeding programs in the United States alone could easily generate these funds on a regular sustained basis—we must find a way to challenge the Radiated Tortoise captive care community to help with this cause, thus linking *ex-situ* breeding programs with the survival of wild populations of tortoises.

The important role that Antsakoamasy plays in the greater tortoise conservation strategy for the region cannot be understated. This community not only protects the vital eastern flank of CSM, but now shines as a beacon in the south, providing inspiration to communities that are willing to come to terms with tortoise poachers. The message must be clear: tolerance for poaching has no rewards and there is value in protecting tortoises.

## **Keystone Species**

If the spiny forest habitat has a keystone species, it is almost certainly the Radiated Tortoise. This species has become an icon for southern Madagascar, one that every tourist expects to see (second only to the sighting of lemurs), and if conservation groups need a landscape species to rally around, then the Radiated Tortoise is a clear choice. Surviving in both disturbed and "undisturbed" habitats, Radiated Tortoises are one of the most highly visible components of this tortured ecosystem, and losing this species to extinction due to an indulgent need for tortoise meat and pets would be a travesty.

The ongoing crisis with the Radiated Tortoise should be a call to action for all of us — a rallying cry if you will — because if we lose this durable symbol of longevity and survivorship from the spiny forest, what will be left to save? Conservation groups today often state that "we don't do single species conservation," but if we ignore the plight of the Radiated Tortoise then the question becomes, "at the end of the day, what have we really achieved in southern Madagascar?" We believe this species must become our barometer for success in this ecosystem. *If we lose the tortoise, then everything else will not be far behind*.

The TSA's goal is to develop partnerships with groups already working at the community level in the south, such as WWF Madagascar, which has an extensive education network and is able to impact conservation on a broad scale. Nearby, personnel from Henry Doorly Zoo's Madagascar Biodiversity Partnership (MBP) are working in the Lavavolo Classified Forest to find an alternative fuel source to charcoal, thereby protecting tortoise habitat from burning and agricultural conversion. In 2011, the TSA, working closely with Christina



**Figure 8.** Movie nights were the highlight of a local media campaign designed to highlight the growing poaching crisis of Radiated Tortoises. The film *Tortoises in Trouble* was shown to nine communities in March 2012. Photo by Christina Castellano.

Castellano (then with the Orianne Society, now with Utah's Hogle Zoo), launched a partnership designed to identify and protect important source populations, focusing on those with a supportive community nearby, and that practice a strong protective *fady*. Overall we aim to increase surveillance of key tortoise populations, reduce poaching, increase the number of confiscations, expand educational opportunities, and engage the communities in the management of protected areas.

#### Protect the Sokake

In 2011 the TSA launched a major media campaign designed to draw attention to the Radiated Tortoise crisis internationally and to increase pressure on the government to respond with stricter penalties and enforcement. We also wanted to "raise the awareness level" locally, particularly in areas of high tortoise consumption where a tolerance for poachers has developed. In September, noted South Africa-based wildlife film makers Moz Images traveled to Madagascar to captured this story. The film, entitled Tortoises in Trouble, was released in 2012 and tracks a group of 140 confiscated tortoises from the capital of Antananarivo to their homeland in the south. Along the way the film exposes ample evidence of massive tortoise poaching, and explores the root causes through interviews with poachers, gendarmes, and local judiciary. The film became the centerpiece of our campaign to take this message to the rural communities in key tortoise poaching areas in the south, as well as those that traditionally do not harm tortoises. During a two-week trip Team Sokake (local for tortoise), including our Malagasy colleagues Riana Rakotondrainy (University of Antananarivo), Herilala Randriamahazo (TSA), Sylvain Mahazotahy (TSA), Soary Tahafe (University of Tulear), and colleagues from Madagascar National Parks (MNP), presented the film in nine villages and communities (Fig. 8). Movie nights turned out to be wildly popular, especially with children, as we handed out thousands of arm bands and stickers with the simple message Protect the Sokake. These materials were also distributed to participants in the husbandry workshops who returned to their hometowns and began dutifully displaying the materials in prominent store locations and public places. I recall arriving in Beloha and feeling a sense of pride as we saw our materials plastered everywhere, and hundreds of kids wearing our brightly colored armbands as a symbol of solidarity. Likewise when we left the fishing village of Lavanono the morning following movie night, literally every house and shop displayed a tortoise poster.

We believe the value of the media campaign is that it helps reinforce the protective traditions among certain tribes in the south that traditionally have not harmed tortoises. This *fady* is breaking down in some areas, with poachers descending from outside regions, from tribes that do not share the local protective custom. As is becoming far too commonplace, local people are becoming complacent with tortoise killing and eating though it violates their cultural traditions. The *Protect the Sokake* message is becoming widespread and obvious now, and lets local people know that the *fady* still exists, and that people around the world care about what is happening to Madagascar's tortoises.

In response to the 2012 media blitz in the south, a tortoise council emerged in the town of Ambovombe and pushed through a community based pact or Dina, which binds villages to honor their fady and not tolerate poachers on their land. This historic agreement is now being applied throughout the south, and TSA is providing support to gendarmes to reach areas where poachers are working or have been apprehended. Dinas are an effective form of local law, and usually transcend national law in rural areas that are disconnected from national policy. A significant outcome of this Dina has been the dramatic increase in both tortoise confiscations and arrests, both in the south and at the airport in the capital city, a sign that the tide may finally be turning. For the first seven months of 2013, TSA's Madagascar office was called on to handle tortoise confiscations. As the number of tortoises requiring captive sanctuary grew, it became obvious that we needed to develop increasing capacity to handle them.

#### **Confiscation to Reintroduction Strategy**

With it becoming apparent that MNP was unlikely to release the World Bank funds, and the number of tortoises requiring sanctuary increasing, the TSA began seeking funding to develop a comprehensive strategy for responsibly transitioning tortoises caught up in the trade, back into the wild. Often, these confiscations end poorly for the tortoises involved, and we continue to see appalling levels of mortality due to improper care and inadequate holding facilities. Radiated Tortoises are increasingly becoming akin to *refugees* in need of safe sanctuary, and with populations crashing rapidly, there is an overwhelming need to ensure that as many as possible survive.

In March 2012, together with Christina Castellano and Michael Ogle (Knoxville Zoo), we conducted two tortoise husbandry workshops in Madagascar aimed at improving care and survival. The first was held in the newly dedicated school house at Antsakoamasy, the second at SOPTOM's Village des Tortues in Ifaty. The curriculum was directed at frontline personnel that were likely to handle seized tortoises; fifty people participated, representing MNP, the Forestry Department, local Gendarmes, and community leaders. Lectures and presentations covered all facets of tortoise management, and were enhanced with a printed color husbandry manual. Perhaps most encouraging were lively discussions that took place as participants exchanged views and attempted to work through the various obstacles to tortoise conservation in their regions. Primary among them are the lack of financial resources available locally to effectively deal with tortoise protection, enforcement, and the resulting confiscations. We believe that these workshops will prove catalytic because we now have organized groups of empowered and inspired advocates who, at the very least, are monitoring the illegal tortoise trade. The TSA's challenge will be to identify the resources that will now allow them have an impact on tortoise conservation.

The first step in this process is to build temporary rescue facilities where confiscated tortoises can be unpacked and immediately cared for. With grants from the Boise Zoo Conservation Fund and the Mohamed bin Zayed Species Conservation Fund, the TSA began planning a series of five such centers in the south, to be located in Ambovombe, Ampanihy, Betioky, Beloha, and Tsiombe-all well-known tortoise trafficking areas. The Center at Ambovombe was built in August 2013 and the Ampanihy facility is currently under construction. These five centers are designed for shortterm holding, where tortoises can be cared for, stabilized, and returned to health before being moved. The crown jewel in this strategy is a proposed Regional Rescue Center where tortoises will remain for longer periods of time, for processing, health and genetic screening, and preparation for release into the wild. This Center will be located east of the Menarandra River, closer to the core of the remaining Radiated Tortoise range, and will be the counterpart to SOPTOM's Village des Tortues at Ifaty (near Tulear) in the western part of their range. In recent time the Ifaty facility has been the recipient of numerous tortoise confiscations and overcrowding could soon become an issue. This second regional tortoise Center is currently being planned for the town of Maravato where the mayor is extremely supportive of our work and has offered to host the new facility. Plans are now underway to identify financial backers that will fund this Center's construction in 2014. This is an ambitious and multi-step process, but is essential if we are to properly handle the vast numbers of tortoises that we anticipate in the future as enforcement efforts improve. The TSA now has two fulltime staff members in the south that are working to make this vision a reality.

Returning confiscated tortoises to areas of former abundance, in safe and protected habitat, is the ultimate goal of this recovery program. Over the next few years the TSA will be working to identify potential release sites that have supportive communities nearby that can be mobilized as tortoise guards. One such example is the village of Ampotoka where the TSA is working to restore a depleted tortoise population in their sacred forest. Though preliminary releases occurred with limited success in 2011-2012, a TSA-sponsored research project will begin in December 2013 that will test various techniques to determine the best strategy for releasing tortoises. With a goal of improving site fidelity - the propensity of a tortoise to remain in the area where it was released-we will build enclosures of 1 ha each, where tortoises will be held for periods of six months and one year prior to a *soft* release. From previous experience we know that Radiated

Tortoises that are hard-released, without first acclimating and orienting to a novel environment, generally move away from the area where they are released. Our goal is to instill site fidelity so that tortoises remain close to the release site, which may be a limited protected area such as a sacred forest where they are safe from poaching.

Such progress provides some measure of hope and optimism, despite the grim scenario that is being played out through so much of the rural south. Radiated Tortoises will not survive unless we can encourage community support for their protection, and we are challenged to find innovative solutions that will benefit local villages. We believe that building and sustaining these relationships will be essential if we are to have a fighting chance to save this beleaguered icon of the southern spiny desert.

Acknowledgments. — Much of the work described here was supported through the generosity of the following organizations: Andrew Sabin Family Foundation, Knoxville Zoo, Boise Zoo Conservation Fund, Mohamed bin Zayed Species Conservation Fund, Columbus Zoo, World Wildlife Fund (WWF) Education for Nature grant, Utah's Hogle Zoo, Los Angeles Zoo, Phoenix Zoo, Owen Griffiths, Toronto Zoo, Natural Encounters, Turtle Conservation Fund, Radiated Tortoise SSP, and Conservation International.

### LITERATURE CITED

- CASTELLANO, C.M., DOODY, J.S., RAKOTONDRAINY, R., RONTO, W., RAKOTONDRIAMANGA, T., DUCHENE, J., AND RANDRIA, Z. 2013. Long-term monitoring and impacts of human harvest on the Radiated Tortoise (*Astrochelys radiata*). Chelonian Research Monographs 6:75–85.
- DARY, D. 1974. The Buffalo Book: The Full Saga of the American Animal. Illinois: Swallow Press, 384 pp.
- LEUTERITZ, T. 2005. Distribution, status, and conservation of Radiated Tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124:451–461.
- NIJMAN, V. AND SHEPHERD, C. 2007. Trade in non-native, CITESlisted, wildlife in Asia, as exemplified by the trade in freshwater turtles and tortoises (Chelodinae) in Thailand. Contributions to Zoology 76(3):207–212.
- O'BRIEN, S., EMAHALALA, E., BEARD, V., RAKOTONDRAINY, A., REID, A., RAHARISOA, V., AND COULSON, T. 2003. Decline of the Madagascar Radiated Tortoise, *Geochelone radiata* due to overexploitation. Oryx 37:338–343.
- RAFELIARISOA, T., WALKER, R.C. J., AND LOUIS, E.F., JR. 2013. Decline in the range and population density of Radiated Tortoises, Astrochelys radiata, in southern Madagascar. Chelonian Research Monographs 6:86–92.
- TURTLE TAXONOMY WORKING GROUP [VAN DIJK, P.P., IVERSON, J.B., SHAFFER, H.B., BOUR, R., AND RHODIN, A.G.J.]. 2012. Turtles of the world, 2012 update: annotated checklist of taxonomy, synonymy, distribution, and conservation status. Chelonian Research Monographs 5:000.243–328.

## Long-Term Monitoring and Impacts of Human Harvest on the Radiated Tortoise (*Astrochelys radiata*)

## CHRISTINA M. CASTELLANO<sup>1</sup>, J. SEAN DOODY<sup>2</sup>, RIANA RAKOTONDRAINY<sup>3</sup>, WILLIAM RONTO<sup>3</sup>, TANTELINIRINA RAKOTONDRIAMANGA<sup>3</sup>, JULIO DUCHENE<sup>4</sup>, AND ZIGZAG RANDRIA<sup>5</sup>

<sup>1</sup>Utah's Hogle Zoo, 2600 Sunnyside Avenue, Salt Lake City, Utah 84108 USA [ccastellano@hoglezoo.org]; <sup>2</sup>Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, Tennessee 37996 USA [jseandoody@gmail.com];

<sup>3</sup>Department of Animal Biology, Faculty of Sciences, University of Antananarivo, P.O. Box 906, Antananarivo 101, Madagascar

[riana\_mia@yahoo.co.uk, ronto84mananjara@yahoo.fr, ratah83@yahoo.fr];

<sup>4</sup>University of Tulear, 601 Tulear, Madagascar [djjosepha@gmail.com];

<sup>5</sup>Forestier Betioky-sud, CP612, Madagascar

ABSTRACT. - The Radiated Tortoise (Astrochelys radiata) is endemic to the spiny forest along Madagascar's southern coastline. It is listed as Critically Endangered by the IUCN Red List due to local consumption, collection for the illegal pet trade, and habitat loss. Surveys were conducted at five widespread locations to determine the current status of tortoise populations for comparisons with data collected 10-15 years earlier. Interviews were conducted at each location to better understand the factors influencing recent harvest trends—such as drought, poverty, political instability, and the erosion of protective native taboos. Tortoises occurred at high densities at the Cap Sainte Marie Special Reserve, Lavanono, Nisoa-Ambony, and Lavavolo. However, very few individuals were observed at Ankirikirika; this was coincident with the discovery of a nearby tortoise poaching camp that contained the remains of about 600 tortoises. Tortoise densities have increased at both protected locations, the Cap Sainte Marie Special Reserve and Nisoa-Ambony, and decreased at Ankirikirika and Lavavolo, when compared to previous years. Tortoise density at Lavanono was similar to earlier reports. According to interviewees, an increase in the illegal harvest was mostly associated with: 1) regional development that has attracted tortoise-eating people to the region that do not respect the local taboo against consuming this species; 2) poverty, motivating people to collect tortoises for money, or to trade for rice; 3) drought that has led to crop failure and hunger; and 4) the consumption of tortoise meat as a delicacy for special occasions and religious holidays. It was also determined that tortoise collection is mainly conducted by Antanosy people from Fotadrevo and that most of the harvesting activity is concentrated along the Menarandra River in the Marolinta, Ankirikirika, and Androka regions. Community conservation programs should target villages that drive tortoise collection, including Fotadrevo, Beloha, Tsiombe, Ft. Dauphin, and Tulear. A long-term monitoring program for the tortoise populations at the five survey locations has been established. However, these populations are extremely vulnerable to collection and require a substantial increase in protection.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, community conservation, harvest, Madagascar, population density, taboo erosion

Humans are altering biodiversity in many ways and at faster rates than generated and maintained by natural processes (IPCC 2007; Pressey et al. 2007). The most unfortunate result of biodiversity alteration is extinction and conservationists are particularly concerned with species that may be lost in the very near future. Indeed, finite resources for conservation management dictate the need for prioritizing efforts towards species that are the most imperiled (Joseph et al. 2009).

Two critical pieces of information should precede major conservation efforts to protect declining species: quantitative evidence for the decline and knowledge of the threatening processes. Evidence of declines is crucial because observations of mortality do not necessarily translate into population level losses (Houlahan et al. 2000; Doody et al. 2009). Identifying the major threatening processes is important for conservation programs aimed at eliminating, or reducing threats; and reintroducing, repatriating, or translocating individuals for conservation purposes (Griffith et al. 1989; Dodd and Seigel 1991; Lambeck 1997).

Long-term monitoring provides a robust identification of population trends using quantitative data. It is generally superior to short-term monitoring because it can capture perturbations against a background of annual variation in abundance generated by 'natural' factors that vary across years, such as rainfall amounts or food availability. Identifying potential or probable threatening processes responsible for a species' decline is often difficult; however, qualitative evidence in tandem with declines in population abundance can pinpoint a major threatening process.

The iconic tortoises of southern Madagascar are highly endangered. It has been predicted that the Radiated Tortoise (Astrochelys radiata) may go functionally extinct within the next 20 years (Hudson and Horne 2010), and the species has been listed as Critically Endangered by the IUCN Red List since 2008 due to local consumption, collection for the illegal pet trade, and habitat loss (Leuteritz and Rioux Paquette 2008). Over-collection is considered to be the main threatening process behind this decline, as tortoises are intensely harvested for local consumption by the Malagasy and also exported for the international trade (O'Brien et al. 2003). Increased poverty, prolonged drought, erosion of local taboos (fady) protecting the tortoises, and most recently, ineffective law enforcement related to political instability are thought to be driving the harvest even further (O'Brien et al. 2003; Bohannon 2009).

We examined the status of the Radiated Tortoise within its core range by assessing long-term changes in abundance at five locations that were surveyed 10–15 years prior to our surveys. We also addressed the impact of human harvest by interviewing key locals to determine their views on 1) whether the collection for human harvest has increased; and 2) what social factors underpinned any increase—including poverty, drought, and recent political instability. We also measured tortoises to investigate any effects of the harvest on size structure in each population. Our discovery of an active tortoise poaching camp near Ankirikirika provided insight into the details of the harvest. We conclude by making recommendations for the future protection of the Radiated Tortoise.

#### **METHODS**

Study Species. — The Radiated Tortoise (Astrochelys radiata) is a large terrestrial species that is endemic and restricted to the spiny forest of southwest Madagascar (Fig. 1; Leuteritz 2002; Glaw and Vences 2007; Pedrono 2008). It is the most conspicuous and iconic of the Malagasy tortoises due to its size and the attractive starred pattern on its shell. It was once very common throughout its range, but has been subject to heavy collection for many years and has now been extirpated from some areas (Lewis 1995; Leuteritz 2002; O'Brien et al. 2003). Its historic distribution extended from the area north of the village of Morombe located in the Toliara Province on the west coast, southward to the Cap Sainte Marie Special Reserve, and east nearly to Fort Dauphin (Glaw and Vences 2007). Currently, it exists south of Toliara and west of Ambovombe, which signifies an estimated range reduction of about 65% (Rafeliarisoa et al. 2013 [this volume]).

Study Locations and Historical Data. — Five widespread localities (Fig. 2; Cap Sainte Marie Special Reserve, Lavanono, Ankirikirika, Nisoa-Ambony, and Lavavolo) were surveyed for tortoises between October and November



**Figure 1.** Radiated Tortoise (*Astrochelys radiata*) at the Cap Sainte Marie Special Reserve. Photo by C. Castellano.

2009. These sites were chosen because they were surveyed previously in 1995 (Lewis 1995) and 1999 (Leuteritz 2002). A description of each survey location follows.

Cap Sainte Marie Special Reserve (CSM). — This reserve of 1750 ha is located at the southern-most tip of Madagascar, approximately 200 km west of Fort Dauphin (Fig. 2). The dominant vegetation is Alluaudia comosa, Euphorbia sp., and Fernando madagascariensis (Fig. 3) (Leuteritz 2002). Radiated Tortoise density at CSM was previously estimated at 563.0 tortoises/km<sup>2</sup> (Lewis 1995) and 653.7 tortoises/km<sup>2</sup> in 1999 (Leuteritz 2002). The mean carapace length (CL) for tortoises (n = 23) at CSM was 24.6 cm (range = 9.6-36.3) and the percentages of males:females:juveniles in the population were 39.1:8.7:52.2 (Leuteritz 2002).

Lavanono. — This area is located about 30 km west of CSM (Fig. 2). The dominant vegetation is *Euphorbia stenoclada* and *Opuntia* sp. (Leuteritz 2002). The forest



**Figure 2.** Map of survey locations in southern Madagascar (not to scale). 1 = Cap Sainte Marie Special Reserve, 2 = Lavanono, 3 = Ankirikirika, 4 = Nisoa-Ambony, and 5 = Lavavolo. Cross hatched area = historic distribution of the Radiated Tortoise (from Leuteritz and Rioux Paquette 2008).



Figure 3. Typical spiny forest vegetation at the Cap Sainte Marie Special Reserve. Photo by C. Castellano.

is degraded as a result of livestock grazing and burning for agriculture (Fig. 4). Density estimates for tortoises at Lavanono were previously 713.8 tortoises/km<sup>2</sup> (Lewis1995) and 953.1 tortoise/km<sup>2</sup> (Leuteritz 2002). The mean CL of 28 individuals was 18.5 cm (range, 6.4–33.5) and the percentages of males:females:juveniles in the population were 14.3:17.9:67.9 (Leuteritz 2002).

Ankirikirika. — This forest is located about 49 km northwest of Lavanono (Fig. 2). It is considered to be a sacred forest and a traditional ceremony must be conducted before commencing work. Alluaudia ascendens, Euphorbia stenoclada, and Obetia sp. dominate the forest (Leuteritz 2002). Ankirikirika was described by Leuteritz (2002) as having been a beautiful gallery forest in 1999. In contrast, we observed considerable evidence that timber was being illegally harvested. Large piles of wood chips were found along many of the survey transects. Density estimates for tortoises at this location were previously 1076.7 tortoises/km<sup>2</sup> (Lewis 1995) and 1884.6 tortoises/km<sup>2</sup> in 1999 (Leuteritz 2002). The mean CL for 15 tortoises was 30.9 cm (range, 4.6-36.6) and the percentages of males:females:juveniles in the population were 20.0:66.7:13.3 (Leuteritz 2002).

*Nisoa-Ambony.* — This site is located about 65 km northwest of Ankirikirika (Fig. 2). The dominant vegetation is *Alluaudia comosa, Comiphora sp., Euphorbia* sp., *Jatropha mahafaliensis*, and *Kalanchoe beharensis* (Leuteritz 2002). The forest is protected as a reserve by the local people. Tortoise density at this location was estimated to be 3484.5 tortoises/km<sup>2</sup> in 1999 (Leuteritz 2002). The mean CL for 28 tortoises measured was 25.0 cm (range, 5.3–36.7) and the percentages of males:females:juveniles in the population were 35.7:28.6:35.7 (Leuteritz 2002).

Lavavolo. — This area is located about 20 km northwest of Nisoa-Ambony (Fig. 2). The vegetation is dominated by Adansonia sp., Alluaudia ascendens, Didierea trollii, Euphorbia sp., Jatropha mahafaliensis, and Kalanchoe beharensis (Leuteritz 2002). Tortoise density was estimated



Figure 4. Degraded habitat at Lavanono dominated by large stands of non-native *Opuntia* sp. Photo by C. Castellano.

at 602.0 tortoises/km<sup>2</sup> (Lewis 1995) and 4908.3 tortoises/ km<sup>2</sup> (Leuteritz 2002). The mean CL for 38 tortoises measured was 19.2 cm (range, 4.8–34.9) and the percentages of males:females:juveniles in the population were 26.3:18.4:55.3 (Leuteritz 2002).

Data Collection in the Present Study. — Two 80 m-wide transects at least 400 m apart were surveyed for tortoises at each of the five locations between 28 October and 16 November 2009. Each transect was surveyed by 7–9 people spaced approximately 10 m apart. Transects ranged in length from 400–1000 m depending on the number of tortoises observed and the handling time required to measure them. Transects were walked once per day over two days during peak tortoise activity periods (0630–1000 and 1530–1900 hrs). Transects were alternated each day between these periods to ensure a morning and afternoon survey was completed for each site.

Time, air temperature, cloud cover, precipitation, wind speed, and GPS location were recorded at the beginning and end of each survey. Air temperature was recorded with a rapid register thermometer held in the shade at 1 m above the ground. Cloud cover was recorded as clear sky, some clouds, or no blue sky visible. Precipitation was recorded as none, light, moderate, or heavy. Wind speed was recorded as 0 = calm (smoke rises vertically), 1 = light breeze (wind felt on skin), 2 = gentle breeze (wind motion visible in leaves), 3 = moderate wind (dust raised, small branches moving), and 4 = strong wind (large branches in motion, whistling). GPS locations were recorded using a Magellan hand-held unit in the datum WGS 84.

We searched for tortoises by scanning left and right for both moving individuals and those that were inactive under bushes. Data on size, weight, age, and sex were collected for each individual tortoise encountered. Carapace and plastron lengths were measured using a 45 cm caliper rule and mass was determined using Pesola spring scales. Age was estimated by counting growth annuli, but was clearly inaccurate for older individuals with worn annuli. Sex was determined according to secondary sexual characteristics: males have thicker and longer tails, deeper anal notches, and more protruding gular scutes (Leuteritz 2002). Individuals < 26 cm CL were considered juveniles (Leuteritz 2002). In order to distinguish among individuals in future surveys, the shell of each tortoise was permanently notched with a square file using a standardized system (Cagle 1939). The five survey locations were also reflected in the notch pattern; for example, all individuals observed at CSM were notched L8 in addition to their unique code. This was done in order to be able to identify the origin of confiscated or displaced tortoises in the future. The Lincoln-Peterson method was used to estimate population size for each transect based on all original captures on day 1 and all recaptures on day 2. Density was determined based on the population estimate and the total area of the survey site (i.e., transect length and width).

Training Program. — Three Malagasy graduate-level students from the University of Antananarivo (UA) and one from the University of Tulear participated in the training program. The primary goal of the program was to teach the methods used to survey and monitor tortoises, and to provide them with the skills needed to implement a community-based tortoise monitoring program. The students that participated were selected based on their academic program and level of field experience.

Students attended a project orientation session at UA before the fieldwork was conducted. The orientation session included a presentation of the project's objectives and a demonstration of the monitoring techniques and data collection procedures that were to be employed. In addition, each student received a "conservation toolbox" with the equipment needed to conduct the surveys and collect the appropriate data (i.e., GPS, compass, file, scales, maps, notebook, etc.). Moreover, an all-day training session was conducted at the first survey location before the surveys were initiated.

*Road Surveys.* — Road surveys for tortoises were conducted opportunistically when traveling by vehicle during the hours of peak tortoise activity. Date, location, time, GPS coordinates (UTMs), weather, and speed (km/hr) were recorded at the beginning and end of each survey. Total lengths of roads traveled and numbers of tortoises observed were determined at the completion of each survey.

*Community Interviews.* — The perception of the conservation community at the time of the study was that an increase in the illegal harvesting of natural resources throughout the country had transpired due to the ousting of the former president in February 2009. The belief was that government agencies in Antananarivo were less able to regulate or monitor illegal activities. To gauge the credibility of this perception interviews were conducted with members of each of the five communities that were associated with the survey locations. Questions were asked with regards to whether the collection of tortoises had increased, and what factors may have underpinned any increase, including poverty, drought, and the lack of

law enforcement due to political instability associated with the change in government.

### RESULTS

Surveys. — Twenty-one surveys were conducted for Radiated Tortoises from 28 October to 16 November 2009. The average transect length was 515 m (range, 100-900). Transect length varied due to number of tortoises observed; for example, the high density of tortoises at Cap Sainte Marie required a large portion of the survey period to be spent processing individuals. The mean search effort (personhours) per survey was 17 hrs (range, 10-32). The mean air temperature recorded during the surveys was 26°C (range, 22-37°C). Weather conditions were mostly slightly overcast, with little or no rain. More specifically, partly cloudy skies were recorded for 42% of the surveys followed by 34% clear skies and 24% with no blue sky visible. Light precipitation was recorded for 12% of the surveys and no precipitation for 88%. Wind speed was recorded as gentle breeze for 46% of the surveys followed by 27% light breeze, 21% moderate wind, and 3% for both calm and strong winds.

The number of tortoises and the percentages of males, females, and juveniles observed at each survey location are summarized in Table 1. The mean number of individual tortoises observed across locations was 40 (range, 3–106). The greatest number of individuals were found at Nisoa-Ambony transect 1 (n = 106) and the fewest at Ankirikirika transect 2 (n = 3). The mean proportions of males, females, and juveniles captured across all locations were 28.2% (range, 0.0–53.5), 36.7% (range, 19.2–66.6), and 34.9% (range, 6.6–75.0), respectively. Females outnumbered males by a considerable margin at 7 of the 10 sites (Table 1). A contingency test revealed that sex ratios were not independent of location when the data from the two transects were pooled for each location (X<sup>2</sup> = 43.973, p < 0.001).

**Table 1.** Total numbers, sex, and age class of tortoises captured and processed during the present study in 2009, compared to those observed at the same locations in 1999 by Leuteritz (2002) (italics\*). 1,2=survey transects in the present study; T=transect from Leuteritz study. CSM = Cap Saint Marie. Nis-Am = Nisoa-Ambony.

Location	Transect	Ν	% Males	% Females	% Juveniles
CSM	1	90	12.2	24.4	63.3
CSM	2	36	5.5	19.4	75.0
CSM*	Т	23	39.1	8.7	52.2
Lavanono	1	41	14.6	19.5	65.8
Lavanono	2	26	46.1	19.2	34.6
Lavanono*	Т	28	14.3	17.9	67.9
Ankirikirika	1	13	38.4	53.8	7.6
Ankirikirika	2	3	0.0	66.6	33.3
Ankirikirika*	* T	15	20.0	66.7	13.3
Nis-Am	1	106	41.5	51.8	6.6
Nis-Am	2	34	20.5	47.0	32.3
Nis-Am*	Т	28	35.7	28.6	35.7
Lavavolo	1	30	50.0	33.3	16.6
Lavavolo	2	28	53.5	32.1	14.2
Lavavolo*	Т	38	26.3	18.4	55.3
	Mean	40	28.2	36.7	34.9

**Table 2.** Carapace lengths from transects in the present study (2009) compared to those obtained in 1999 by Leuteritz (2002) (\*). Data are means  $\pm 1$  SD.

Location	Transect	Ν	Mean CL (cm)	Range
CSM	1	90	22.6	8.6-36.6
CSM	2	36	22.5	13.2-34.5
CSM*	Т	23	24.6	9.6-36.3
Lavanono	1	41	21.6	5.6-32.0
Lavanono	2	26	26.8	2.0-37.0
Lavanono*	Т	28	18.5	6.4-33.5
Ankirikirika	1	13	31.6	20.3-34.4
Ankirikirika	2	3	20.3	10.8-27.6
Ankirikirika*	Т	15	30.9	4.6-36.3
Nisoa-Ambony	1	106	31.0	5.5-37.4
Nisoa-Ambony	2	34	25.6	2.3-36.4
Nisoa-Ambony	′* Т	28	25.0	5.3-36.7
Lavavolo	1	30	30.1	8.6-38.4
Lavavolo	2	28	30.4	6.7-37.2
Lavavolo*	Т	38	19.2	4.8-34.9

We used CL as an index of body size for comparisons among locations, transects within locations, and between transects in the present study and that of Leuteritz (2002). Mean CL differed significantly among locations (Table 2; non-parametric ANOVA on ranks: H = 132.08, p < 0.001) and between most transects (Dunn's pair-wise method, p < 0.05). The examination of CL distributions revealed considerable variation in size structure among survey locations (Fig. 5). For example, CL distributions were essentially normally distributed at both CSM transects **Table 3.** Population density estimates (tortoises/km<sup>2</sup>) at the five survey locations between transects and among years studied. CSM = Cap Sainte Marie; 1995 = study by Lewis (1995); 1999 = study by Leuteritz (2002); 2009 (T1 and T2) = transects surveyed in the present study.

Location	1995	1999	2009		
			T1	T2	Mean
CSM	563.0	653.7	23600.0	2850.0	13225.0
Lavanono	713.8	953.1	710.0	1031.0	870.5
Ankirikirika	1076.7	1884.6	870.0	60.0	465.0
Nis-Ambony	N/A	3484.5	10450.0	760.0	5605.0
Lavavolo	602.0	4908.3	925.0	970.0	947.5

and at Lavanono transect 1, while CL distributions were skewed towards larger animals at Lavanono transect 2, both transects at Nisoa-Ambony, and both transects at Lavavolo. Size structure distributions for the Ankirikirika transects are not shown due to low sample size.

*Population Densities.* — Population density estimates for tortoises varied considerably between transects at each location with the exception of Lavavolo (Table 3). The highest densities were recorded at Cap Sainte Marie (2859–23,600 tortoises/km<sup>2</sup>) and Nisoa-Ambony (760–10,450 tortoises/ km<sup>2</sup>), while the lowest density was recorded at Ankirikirika (60–879 tortoises/km<sup>2</sup>). Population density estimates also varied considerably among years (Fig. 6). Tortoise density has increased over time at the Cap Sainte Marie Special Reserve and Nisoa-Ambony and decreased at Ankirikirika



Figure 5. Carapace lengths of Radiated Tortoises at four survey locations, showing variation in the shapes of the size distributions among sites and between transects within sites.



Figure 6. Comparisons of density estimates of *A. radiata* among studies, sites, and years.

and Lavavolo, while the density of tortoises at Lavanono has remained relatively constant.

*Road Surveys.* — Six opportunistic road surveys for Radiated Tortoises were conducted during the last week of October 2009. Survey transects ranged from 5–40 km in length. The number of tortoises observed per survey ranged from 7–105. Linear densities ranged from 0.88–3.13 tortoises per road km. Two tortoises were found dead on the road between Cap Sainte Marie and Lavanono. The ruptured shells of both individuals indicated that they were struck by vehicles.

Threats to Survival. — On 4 November 2009 we encountered a poaching camp about 11 km south of Ankirikirika. The camp was within 50 m of the Menarandra River on a road that had been closed to traffic a week earlier. About 10 of the approximately 30 total poachers (estimated by the number of carry sticks) who were in the camp when we arrived fled into the forest. On the road were six large blankets covered with cooked tortoise limbs (Fig. 7). The limbs were being dried in the sun in preparation for transport. It was estimated that each blanket had approximately 170 limbs, or the meat of over 40 tortoises. Together, the meat on the six blankets represented more than 250 individuals.

When we arrived, poachers were in the process of slaughtering tortoises, cleaning shells, and removing entrails

in preparation for cooking (Fig. 8). There were dozens of small charcoal pits that were used for cooking. Cast iron pots filled with vegetables were found along with pieces of burned shells. Primitive hatchets used for slaughtering tortoises were also observed, and plastic bottles filled with tortoise liver oil were discovered in transport sacks (Fig. 9). One live tortoise was observed hanging in a tree. A rope had been sewn through a hole drilled in the carapacial edge. Three sacks filled with dried tortoise meat were also discovered. We estimated that each sack contained the meat of about 100 tortoises, which brought the total estimated number of poached tortoises to about 600. The sacks were tied to carry sticks used for transport.

At the recommendation of the government official in our group (ZR), we released the tethered tortoise and disposed of the tortoise limbs, most of the weapons, and cooking utensils by throwing them into the river. Villagers who had seen the camp told us that the poachers were from the Antanosy tribe. We filed a police report in Itampolo and submitted several hatchets and bottles of liver oil to the police as evidence (Fig. 9).

Two tortoise shells were found crushed on the road between Cap Sainte Marie and Lavanono. Tortoises were



Figure 8. Tortoises being slaughtered and entrails removed in preparation for cooking at poaching camp. Photo by C. Castellano.



Figure 7. One of six blankets covered in tortoise limbs at poaching camp near Ankirikirika. Photo by C. Castellano.



Figure 9. Primitive weapons used to slaughter tortoises and bottles of tortoise liver oil used for cooking. Photo by C. Castellano.

regularly observed crossing the road and eating cactus fruit on road edges. This behavior makes them susceptible to death or injury through collisions with vehicles. Eight burned tortoise shells were observed at Lavanono. The tortoises may have been burned to death while sheltering in vegetation. Fire is commonly used to clear vegetation. Timber has been illegally harvested from the forest at Ankirikirika and the habitat has been significantly degraded as a result. Four fire pits were also discovered while conducting surveys at this location. Each had three to four tortoise shells present. The shells had been hacked open from the top of the carapace and the plastrons were removed with visible hatchet marks on the bridge. The local villagers were aware that people enter the forest to harvest the timber, and that these harvesters eat tortoises to sustain themselves while collecting timber.

Four tortoise nests that had been destroyed by predators were discovered at transect 2 at Nisoa-Ambony. In addition, two 2-year-old tortoises were found with their heads and forelimbs missing. Both individuals had teeth and/or claw marks on their shells. Two dead hatchlings with intact heads and limbs were also found at this location. They may have been victims of ant predation. One dead juvenile with puncture wounds in its shell and one adult tortoise with a missing limb were observed along transect 1 at Lavavolo.

Interviews. — Seventeen local Malagasy people were interviewed at five locations. According to interviewees, the increase in the illegal harvest was not due to the political unrest, but was mostly associated with: 1) regional development that has attracted tortoise eating tribes to the region that do not respect the local taboo against consuming this species; 2) poverty, motivating people to collect tortoises for money, or to trade for rice; 3) drought that has led to crop failure and hunger; and 4) the consumption of tortoise meat as a delicacy for special occasions and religious holidays. It was also determined that tortoise collection is mainly conducted by the Antanosy tribe from Fotadrevo.

Interview 1. — The first interview was conducted on 29 October at the Cap Sainte Marie Special Reserve. The people interviewed included a village elder (male, 65 years old), camp cook (male, 40), and three representatives (males, 25–55) from Madagascar National Parks (MNP). It was stated that very little harvesting is occurring within the park. Tortoises are harvested for food north of Marovato, transferred to Ft. Dauphin through Beloha and Tsiombe, and sold in restaurants in Ft. Dauphin.

It was agreed that there had been no increase in the collection of tortoises since the change in government. Collection is random and mainly for local consumption. In March, one ranger chased a man with 10 tortoises tied to his bicycle. The man dropped his bicycle and fled. In July, another man was found carrying a few tortoises, but he also fled when confronted, leaving the tortoises behind.

Once tortoises were extremely abundant and could be seen throughout the area. The decline began when the lighthouse was built in 1971. With the lighthouse came people from many different tribes, including those that did not respect the local taboo (fady) against consuming tortoises. Tsiombe was mentioned as a place with a mixture of these tribes. A tortoise can be purchased in the local market for 20,000 Ariary (currently equivalent to about US \$10) in Tsiombe. Collectors that live there are asked to gather tortoises when patrons request them. (Note: Before the lighthouse was erected, people in the community built fires in stone pits to guide ships around the cape. Nevertheless, a commercial fishing boat sank and the people on board said that they saw a vision of the Virgin Mary appear above them on the cliff's edge. To honor this vision, nuns erected a statue of the Virgin Mary and named this location Cap Sainte Marie.)

Interview 2. — This interview was conducted at Lavanono on 1 November. Three male fishermen aged between 20–25 years were interviewed. There is awareness of the political situation in the capitol city Antananarivo, but it has had very little effect on their community. The people of Lavanono respect the fady and do not harm tortoises. They were unaware of any collectors entering the village since they moved there about three years ago. They were aware that collectors live in Beloha and tortoises can be found in the markets there.

Interview 3. — This was conducted at Lavanono on 1 November. The male owner of a hotel aged 50 was interviewed. Fewer tortoises are seen in the village since he and his family arrived in 2003. The forest habitat has been reduced since then. There is awareness that other tribes collect and eat tortoises. Tortoises are collected from Lavanono when people from these tribes travel through on their way to other villages or cities. One family will eat around five tortoises. The hotel owner has never seen anyone collect tortoises in large numbers, but has heard stories of tortoises being collected for restaurants in Ft. Dauphin. In 2007, he saw about 20 tortoises in the markets at Beloha. He also witnessed a politician and his companions collecting tortoises. The people in the village told them that it was forbidden, but they took them regardless.

Interview 4. - This was conducted in Beloha on 2 November. A male military commander aged 40 was interviewed. He was travelling from Tongobory to Tulear where he was stationed. He reported that the dried meat of fifty tortoises was located two weeks earlier in Androka, a place that had not been targeted previously by poachers. The poachers were Antanosy women that were camping in the forest. After collecting the tortoises they dried the meat in preparation for transport to Fotadrevo. Dried tortoise limbs are considered to be a delicacy by some tribes. The Antanosy trade the meat for rice, which they can no longer afford to buy. The people in Androka protested, but the women would not leave; although they eventually fled when the police arrived. The commander also reported that the shells of five hundred tortoises had been found near Marolinta two days before this interview. (Note: We attempted to find this site in order to document this massacre, but the river could not be crossed due to overnight flooding).

*Interview 5.* — This was conducted in Beloha on 3 November. A deputy of the former administration was interviewed (male, age 70). Tortoises have been collected around Beloha for the last 40 years, but there has been a decrease in the rate of collection over the past two. Two years ago he saw 10 oxcarts filled with tortoises in Beloha. Antanosy people from Fotadrevo collect tortoises, dry the meat, and transport it back to their village. Both live tortoises and dried meat are sent to Tulear and Ft. Dauphin. In these cities, tortoise meat is considered to be a delicacy and is served for special events and holidays, especially Christmas. Tortoises are also sent to restaurants on Reunion.

Interview 6. — This was conducted at the Sacred Forest of Ankirikirika on 3 November. The brother of the King (70 years old) and his son (35) were interviewed. Protection for the tortoises has increased since the change in the administration. The government committee that is in charge of protecting the environment is now working properly. In the past collectors were unafraid; now they are afraid and run from the police. The people who collect tortoises for food are very hungry. They have been suffering through drought for several years and have had little success with their crops. Both the prince and his son were very sympathetic because these people need food and they are very poor. They were both born in this forest and have seen a decline in tortoises over the past several years. Antanosy people have collected most of the tortoises from the forest at Ankirikirika. They also cut down the trees and the forest and tortoises are dying. There is a local law to punish collectors; it states that if someone is seen killing a tortoise they must purchase a six-year-old zebu for 200,000 Ariary (US\$ 100), spread its blood at the site where the tortoise was killed, and give the zebu meat to the villagers. The event is documented and the person's name is sent to the government. It is believed that this deters people from collecting tortoises.

Interview 7. — This was conducted at Itampolo on 6 November. Two male police officers (age 35–40) were interviewed. A sailboat had been docked in the bay for over a week and they had just returned from inspecting it. No tortoises were found on-board. Earlier that week, they located poachers with sacks of dried meat from approximately 800 tortoises and 95 live individuals between Itampolo and Androka. Eight poachers identified as Antanosy people from Fotadrevo, which included four men, three women, and one young boy, had been arrested and were currently jailed in Itampolo. The law states that the confiscated meat has to be destroyed and was therefore burned. The officers said that collection was on the rise as Christmas was approaching.

Interview 8. — This was conducted at Itampolo on 8 November. Two male farmers (age 30) were interviewed. Tortoise collection has not increased with the change in administration. Tortoises are not being collected by locals because of the fady and Antanosy do not come here because it is too close to the police station. Also, the community protects the tortoises in this area. Tortoise numbers have not declined because the forest is not harmed. If someone is caught eating, or taking a tortoise they have to kill a sixyear-old zebu, spread its blood at the site, and give the zebu meat to the villagers (same law as in Ankirikirika). People travelling through the area do collect tortoises to eat during their journey.

Interview 9. — This last interview was conducted in Itampolo on 8 November. A local man (60) was interviewed. Collection was increasing, but not because of politics. A Chinese man living in Antananarivo sends people to collect tortoises for their livers. They prefer males because they have larger livers than females. The tortoises are slaughtered and the livers are sent to Ampanihy and then to Japan. These men are very dangerous and carry guns. Tortoises are also collected during religious holidays especially around Christmas and during periods of drought when food is scarce.

## DISCUSSION

*Population Density.* — Despite the high estimates of tortoise abundance reported here, the populations at the survey locations are extremely vulnerable to collection and require immediate and substantial protection. Illegal collection of tortoises is widespread and will eventually reach these locations as other populations become depleted. Compared to historical surveys in 1995 and 1999, tortoise densities were lower at two localities (Ankirikirika and Lavavolo), higher at two sites (Cap Sainte Marie and Nisoa-Ambony), and relatively unchanged at a fifth locality (Lavanono). Tortoise density may have increased at the Cap Sainte Marie Special Reserve and the forest at Nisoa-Ambony because both locations receive protected area status. An MNP office has been erected at Cap Sainte Marie since Leuteritz completed his research in 2002. This office provides a significant law enforcement presence, which has likely limited tortoise poaching in the reserve. Similarly, the forest at Nisoa-Ambony is near to Itampolo, which is the location of the Gendarmerie (military police). As a result, there is a strong police presence in this area that may serve to deter tortoise collection. Density estimates for the population at Nisoa-Ambony may be somewhat inflated, however, as the tortoises at this location were aggregated at a communal drinking site (Doody et al. 2011). Nevertheless, our data suggest that these locations, with the exception of Ankirikirika, support dense populations of Radiated Tortoises, which makes them critical for the survival of the species and therefore require significant protection.

The tortoise population at Ankirikirika has suffered greatly from illegal harvest and possibly habitat destruction. This population remains in jeopardy because it is within an area that is being targeted by poachers. Urgent action is needed at Ankirikirika to prevent further losses. The community at Ankirikirika respects tortoises, is aware of illegal poaching, and wants to prevent further harm. This community can contribute greatly to tortoise conservation because of their strong presence in the forest, but require support from the police. At Lavavolo, habitat degradation may be contributing to a slow decline in tortoises, although this species is known to live in degraded landscapes (O'Brien et al. 2003). Livestock grazing occurs throughout the area and the survey sites were located near to settlements. Demography. — Radiated Tortoise populations at Cap Sainte Marie and Lavanono had relatively higher numbers of smaller individuals present than Nisoa-Ambony and Lavavolo. This suggests that the populations at CSM and Lavanono are expanding. The size distributions at Nisoa-Ambony and Lavavolo suggest that those populations are contracting. However, the vegetation among the survey locations was variable. The dwarf vegetation at Cap Sainte Marie and exposed sandy substrate at Lavanono may have made it easier to locate both large and small individuals. The forests at Nisoa-Ambony and Lavavolo were dense compared to the others; nevertheless, the vegetation was relatively sparse at all locations as it was the very beginning of the wet or growing season.

Leuteritz (2002) reported that the population at Cap Sainte Marie was composed mainly of small individuals. When compared to the size structure reported for this location in the present study, it appears that the juvenile tortoises observed by Leuteritz have grown into the larger size classes. This could reflect a decrease in harvesting between these study periods, or some other factor.

*Illegal Harvest.* — The perception of the people interviewed in the local communities was that there was an increase in tortoise harvest, but this increase was not associated with the political situation. The four primary reasons given for the apparent increase in collection were:

1. Development in the region has attracted peopled from tribes that do not respect the local taboo (fady) that prevents people from harming the tortoises.

2. Tortoise meat is considered to be a delicacy and is served for special occasions; consequently, collection increases before religious holidays, especially Christmas.

3. People collect tortoises in order to earn money.

4. Prolonged periods of drought has led to years of crop failure; as a result, people trade tortoise meat for rice.

Collectively, both our results and observations suggest that tortoise harvesting is primarily driven by Antanosy people from Fotadrevo. They hunt tortoises and dry the meat before transporting it back to Fotadrevo. Villages associated with the tortoise trade for local consumption include Fotadrevo, Beloha, Tsiombe, Marolinta, Androka, and Ankirikirika. Tortoises are collected for restaurants in Tulear and Ft. Dauphin. None of the people interviewed had any information on tortoises being collected for the international trade.

The apparent increase in harvest of tortoises is related to the erosion of taboos across human generations (Lingard et al. 2003). Cultural taboos play a critical role in species conservation by guiding human conduct toward the natural environment in many of the world's traditional societies (Colding and Folke 2001). A system of taboos is central to Malagasy culture and strict taboos offer undeniable protection for threatened species (e.g., lemurs and chameleons) especially where capacity to enforce external conservation laws is restricted (Tengo et al. 2007; Jones et al. 2008). Consuming or harming tortoises in southern Madagascar is considered taboo by three of the four Malagasy tribes that span their range. Historically, this has resulted in "safe havens" for these species (Lingard et al. 2003). These taboos are not respected by outside tribes (e.g., Antanosy) that travel to the safe havens to collect tortoises. Moreover, young members of the tribe respecting the taboos maintain that they mainly uphold the taboos out of respect for their elders, rather than for traditional (supernatural) reasons. Tortoise abundance is lower in areas nearest to the Antanosy and urban centers with greater ethnic mixing (Lingard et al. 2003). Recent severe drought and political instability have increased poverty and reduced law enforcement, respectively, throughout the nation (Bohannon 2009). Opinions of the locals we interviewed notwithstanding, these phenomena may be further exposing the taboo as an ever-weakening institution for conservation of tortoises even within the safe havens.

#### Recommendations

We make the following recommendations based on the findings noted.

1. Protected locations, which include a law enforcement presence, support the highest densities of Radiated Tortoises.

a) Provide support to the MNP office and the presence of Park Rangers at the Cap Sainte Marie Special Reserve to deter poaching; and,

b) Establish reserves with a law enforcement presence at Nisoa-Ambony, Lavanono, Ankirikirika, and Lavavolo.

2. Radiated Tortoises at Ankirikirika are declining drastically due to illegal collection and also potentially due to habitat loss. The community at this location can contribute to tortoise conservation.

a) Develop a community-based conservation program to be facilitated by the royal family;

b) Establish a law enforcement presence to prevent tortoise collection and timber harvesting; and,

c) Determine the impacts of poaching and timber harvesting on tortoises.

3. Current tortoise density (in 2009) has increased at Cap Sainte Marie and Nisoa-Ambony, decreased at Ankirikirika and Lavavolo, and remained stable at Lavanono, as compared to 1995 and 1999 when previous surveys were conducted.

a) Continue long-term monitoring programs at these locations in order to determine population trends through time; and,

b) Use the data provided here (including sex ratios, age class structure, size distributions, sources of mortality, potential for community-based conservation programs, etc.) to develop tailored conservation strategies for each location as these factors vary among sites.

4. Tortoise meat is considered to be a delicacy and is served for special occasions; consequently, collection increases before religious holidays, especially Christmas.

a) Develop a conservation campaign to raise awareness about overharvesting that can be implemented throughout the year, but especially during the months that precede religious holidays. Target villages that contribute to the demand for tortoise meat, including Fotadrevo, Beloha, Tsiombe, Tulear, and Ft. Dauphin.

5. Development in the south and southwest has attracted people from outside tribes that do not respect the local fady to move into villages within the tortoise's range, including Beloha and Tsiombe.

a) Conduct surveys to establish the status of tortoises at these and surrounding locations;

b) Use these data to identify and develop areas of protection for the remaining populations; and,

c) Identify barriers to tortoise conservation at these and surrounding locations and develop community-based conservation program to eliminate those barriers.

6. People are very poor and collect tortoises for money, or trade the meat for rice. The ongoing drought has led to years of crop failure; as a result, people collect tortoises to eat because they are starving.

a) Develop partnership with USAID, or similar organizations, to develop alternate food sources for villagers that respect the fady and those that do not, particularly in the region between Faux Cap and Ft. Dauphin.

7. The Antanosy people from Fotadrevo are driving the illegal harvest. They hunt tortoises and dry the meat before transporting it back to Fotadrevo.

a) Target Fotadrevo for a community-based conservation program; and,

b) Develop and implement an awareness and education campaign at this location.

Acknowledgments. — This study was funded by the Andrew Sabin Family Foundation, Wildlife Conservation Society (WCS), American Zoo and Aquarium Conservation Endowment Fund, Conservation International, and Healesville Sanctuary. We sincerely appreciate the logistical support provided by the team at WCS/Madagascar. We are also truly thankful to Andy Sabin and Russel Traher for their interest and dedication to Madagascar tortoise conservation.

### Résumé

La tortue radiée (Astrochelys radiata) occupe naturellement les forêts épineuses de la zone littorale du sud de Madagascar. L'espèce est classée En Danger Critique d'Extinction conséquemment à non seulement une consommation locale accrue, mais aussi aux collectes que ses populations subissent pour le marché des animaux exotiques et de compagnie, ainsi que la perte de son habitat originel. Des inventaires ont été effectués dans cinq localités éparses pour réévaluer le statut des populations naturelles de tortues radiées, en comparaison avec des données datant de 10 à 15 ans. Des interviews ont été réalisées dans chaque localité pour mieux comprendre les facteurs à l'origine des récentes tendances de collecte de tortues comme la sécheresse, la pauvreté, l'instabilité politique et la perte progressive des tabous ancestraux. La tortue radiée se trouve encore en grand nombre dans

la Réserve Spéciale de Cap Sainte-Marie, de même qu'à Lavanono, Nisoa-Ambony, et Lavavolo. Toutefois, très peu d'individus ont pu être observés à Ankirikirika. Ceci est probablement lié à la découverte par la suite d'un campement de braconniers à proximité. Les restes d'environ 600 tortues y ont été constatés. Comparée aux données antérieures, la densité des tortues a augmenté dans les zones protégées que sont Cap Sainte-Marie et Nisoa-Ambony et elle a diminué à Ankirikirika et Lavavolo. La densité trouvée à Lavanono était similaire à celle évoquée dans de précédents rapports. D'après les personnes interviewées, l'augmentation de la collecte illicite de tortues était principalement due à: 1) un développement local qui a attiré des personnes de tribus différentes et pour lesquelles consommer la tortue n'est pas tabou; 2) une pauvreté croissante qui pousse les gens à vendre des tortues ou à les échanger contre du riz; 3) la sécheresse qui a corrompu les récoltes et ramené la famine; et 4) la viande de tortue est toujours considérée comme un mets des grandes occasions. La collecte des tortues est souvent effectuée par les Antanosy venant de Fotadrevo et les «foyers» des collectes se situent le long de la rivière Menarandra dans les environs de Marolinta, Ankirikirika, et Androka. Les programmes de conservation mis en place avec les communautés locales devraient cibler les localités qui dirigent les collectes de tortues, comprenant Fotadrevo, Beloha, Tsiombe, Ft-Dauphin, et Toliara. Un programme de suivi à long terme des populations de tortues dans les cinq sites inventoriés a été mis en place. Toutefois, ces populations sont extrêmement vulnérables par rapport à la collecte. De ce fait, une accentuation des mesures de protection est requise.

### LITERATURE CITED

- BOHANNON, J. 2009. Madagascar's coup endangers science and scientists. Science 323:1654–1655.
- CAGLE, F.R. 1939. A system of marking turtles for future identification. Copeia 1939:170–173.
- COLDING, J. AND FOLKE, C. 2001. Social taboos: invisible systems of local resource management and biodiversity conservation. Ecological Applications 11:584–600.
- DODD, C.K., JR. AND SEIGEL, R. 1991. Relocation, repatriation, and translocation of amphibians and reptiles: are they conservation strategies that work? Herpetologica 47:336–356.
- DOODY, J.S., CASTELLANO, C.M., RAKOTODRAINY, R., RONTO, W., RAKOTODRIAMANGA, T., DUCHENE, J.J., AND RANDRIA, Z. 2011. Aggregating drinking behaviour of radiated tortoises (*Astrochelys radiata*) in arid Madagascar. Chelonian Conservation and Biology 10:145–146.
- ERNST, C. H. AND BARBOUR, R.W. 1989. Turtles of the World. Washington DC: Smithsonian Institution Press, 313 pp.
- GLAW, F. AND VENCES, M. 2007. A Field Guide to the Amphibians and Reptiles of Madagascar (Third Edition). Cologne: Vences and Glaw Verlag, 496 pp.
- GRIFFITH, B., SCOTT, J., CARPENTER, J., AND REED, C. 1989. Translocation as a species conservation tool: status and strategy. Science 24:477–480.
- HOULAHAN, J.E., FINDLAY, C.S., SCHMIDT, B.R., MEYER, A.H., AND KUZMIN, S.L. 2000. Quantitative evidence for global amphibian population declines. Nature 404:752–755.

- IPCC. 2007. Impacts, adaptation and vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). Cambridge: Cambridge University Press, 976 pp.
- JONES, J.P.G., ANDRIAMAROVOLOLONA, M.M., AND HOCKLEY, N. 2008. The importance of taboos and social norms to conservation in Madagascar. Conservation Biology 22:976–986.
- JOSEPH, L.N., MALONEY, R.F. AND POSSINGHAM, H.P. 2009. Optimal allocation of resource among threatened species: a project prioritization protocol. Conservation Biology 23:328–338.
- LAMBECK, R.J. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11:849–856.
- LEUTERITZ, T. 2002. Distribution, status, and reproductive biology of the radiated tortoise, *Geochelone radiata* (Shaw, 1802) in southwest Madagascar. Ph.D. Thesis, George Mason University, Fairfax, VA, USA.
- LEUTERITZ, T. AND RIOUX PAQUETTE, S. 2008. Astrochelys radiata. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. www.iucnredlist.org/details/9014/0.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). Unpublished Report, World Wildlife Fund, Madagascar Country Office.
- LINGARD, M.L., RAHARISON, N., RABAKONANDRIANINA, E., RAKO-

TOARISOA, J.A., AND ELMQVIST, T. 2003. The role of local taboos in the conservation and management of species: the Radiated Tortoise of southern Madagascar. Conservation and Society 1:223–246.

- O'BRIEN, S., EMAHALALA, E.R., BEARD, V., RAKOTONDRAINY, R.M., REID, A., RAHARISOA, V., AND COULSON, T. 2003. Decline of the Madagascar radiated tortoise *Geochelone radiata* due to overexploitation. Oryx 37:338–343.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu: Natural History Publications (Borneo), 147 pp.
- PRESSEY, R.L., CABEZA, M., WATTS, M.E., COWLING, R.M., AND WILSON, K.A. 2007. Conservation planning in a changing world. Trends in Ecology and Evolution 22:583–592.
- PRITCHARD, P.C.H. 1979. Encyclopedia of Turtles. New Jersey: TFH Publications, 895 pp.
- RAFELIARISOA, T.H., WALKER, R.C.J., AND LOUIS, E.E., JR. 2013. Decline in the range and density of the radiated tortoise, *Astrochelys radiata*, in southern Madagascar. Chelonian Research Monographs 6:86–92.
- TENGO, M., JOHANSSON, K., RAKOTONDRASOA, F., LUNDBERG, J., ANDRIAMAHERILALA, J. A., RAKOTOARISOA, J.A., AND ELMQVIST, T. 2007. Taboos and forest governance: informal protection of hot spot dry forest in southern Madagascar. Ambio 36:683.

## Decline in the Range and Population Density of Radiated Tortoises, Astrochelys radiata, in Southern Madagascar

TSILAVO H. RAFELIARISOA<sup>1,2,3</sup>, RYAN C.J. WALKER<sup>4,5</sup>, AND EDWARD E. LOUIS, JR.<sup>2,3\*</sup>

<sup>1</sup>Département de Biologie Animale, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar [rafelykely@hotmail.com]; <sup>2</sup>Madagascar Biodiversity Partnership, ONG, VO 12 Bis A, Manakambahiny, Antananarivo 101, Madagascar [mbp.dg.mbbp10@gmail.com];

Ananana ivo 101, inaa gascar [mop ag moop10@gnat.com],

<sup>3</sup>Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, Nebraska 68107 USA [genetics@omahazoo.com]; <sup>4</sup>Nautilus Ecology, Oak House, Pond Lane, Greetham, Rutland, LE15 7NW, United Kingdom [ryan@nautilusecology.org];

<sup>5</sup>Department of Life Sciences, The Open University, Milton Keynes, MK7 6AA, United Kingdom;

\*corresponding author

ABSTRACT. – The Critically Endangered Radiated Tortoise, *Astrochelys radiata*, is endemic to the dry forests of south and southwest Madagascar. The remaining populations are facing a significant threat of extinction due to habitat loss and extensive illegal harvesting for the local bush meat and international pet trades. We utilized a presence/absence and line-transect DISTANCE sampling survey method and systematically applied this approach across the species' extent of occurrence to establish current range, population density, and population size. We found that *A. radiata* has undergone a contraction of extent of occurrence by approximately 65% since 1865. The current study estimates that the wild population has declined by 47% during the last 12 years, leaving approximately 6.3 million tortoises remaining at a density of 420 individuals/km<sup>2</sup>. The rapid decline of *A. radiata* emphasizes the need for a swift and effective conservation strategy, one that will likely make use of community-based conservation and poverty alleviation programs already active within the region.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, conservation, population density, range decline, abundance, Madagascar

Madagascar, the fourth largest island on Earth, sustains one of the world's highest priority biodiversity hotspots (Myers et al. 2000) with outstanding species diversity due to 165 million years of isolation (Rabinowitz et al. 1983). The highly unique bio-ecological regions existing throughout the island support a complex pattern of microendemism among taxa (Goodman and Benstead 2005; Wilmé et al. 2006), including four species of tortoises (Pedrono 2008). Several factors, including illegal harvesting, habitat degradation, increasing poverty levels, unstable political and economic situations, and an inadequate educational system, have brought a number of these endemic species to the brink of extinction. These factors have played a role in the present conservation status of Madagascar's Radiated Tortoise, Astrochelys radiata, or sokake, which is recognized as Critically Endangered on the IUCN Red List (IUCN 2011) and in dire need of conservation intervention.

Radiated tortoises are collected for food and the pet trade at the local, national, and international levels (O'Brien et al. 2003). Furthermore, habitat degradation occurs where this tortoise is endemic. The xerophytic spiny forest of southwest coastal Madagascar, a habitat extremely important for biodiversity (Seddon et al. 2000), has been converted for agricultural use and firewood (Harper et al. 2007) within many areas. Harper et al. (2007) estimated an overall reduction of spiny forest cover from 30,298 km<sup>2</sup> to 21,322 km<sup>2</sup> from 1970–2000 with an annual rate of loss of 1.2%. Unfortunately, this spiny forest eco-region represents the smallest proportion of designated protected area of any region in Madagascar (Du Puy and Moat 2003).

In order to develop a suitable conservation strategy and management plan for the Radiated Tortoise, an accurate estimate of the species' range and population density is essential (Gelatt and Siniff 1999). The first estimate of its original geographic range was inferred from subfossil specimens and shipping records of tortoise exports in 1865 (Vinson 1865; Bour 1994; Nussbaum and Raxworthy 2000). This suspected historical extent of occurrence for A. radiata included an uninterrupted band of 550 km of coast from Morombe to Tolagnaro (Decary 1950) (Fig. 1 A). More recently, several authors have established that the species' extent of occurrence has seriously declined over the last 200 years due to anthropogenic pressures (Juvik 1975; Lewis 1995; O'Brien 2002; Leuteritz et al. 2005) (Fig. 1). Our study applies a detailed range-wide presence/absence survey to establish the current extent of occurrence and incorporates a DISTANCE sampling methodology to estimate the current wild population size and density of A. radiata.

## METHODS

*Field Techniques.* — Field work was undertaken during January and February of 2010 and 2011, coinciding with the rainy season and annual period of heightened tortoise



Figure 1. Historical extent of occurrence of A. radiata; A = Decary (1950), B = Juvik (1975), C = Lewis (1995), D = Leuteritz et al. (2005).

activity (Leuteritz 2003). The species is crepuscular (O'Brien 2002; Leuteritz 2003); therefore, surveying was limited from 0630–1030 and 1530–1830 hrs during the cooler parts of the day when the tortoises are most active. We surveyed 64 areas within the historical extent of occurrence (Leuteritz et al. 2005) of the Radiated Tortoise between the area north of Toliara and the Anosy region, east of Tolagnaro (Fig. 1) spanning the Mahafaly and Karimbola plateaus.

Within each survey area, two observers traversed a 1 km transect line by walking side by side, following an easterly bearing, roughly in a linear direction, using the tracking function of a handheld GPS to measure the distance covered. Each surveyor carefully searched for tortoises on their respective side of the transect line and directly in front of the surveyor. Transects took 29.6 to 39.8 minutes to transverse, depending upon terrain and density of the vegetation. For each encountered tortoise, the perpendicular distance from the center of the transect line was measured in cm to the middle of the carapace at first detection for each individual, using a 15 m steel retractable tape measure. In addition, the curved

carapace length (CCL) was measured for all tortoises as a means of estimating the age of each individual and to obtain population demographics. We defined an adult tortoise as having a CCL larger than 330 mm, while smaller tortoises were reported as juvenile. Males were differentiated from females by the presence of a concave plastron. Each tortoise was marked using a small dot of nail polish on the top of the carapace, to avoid repetitive counts.

Walker (2012) has demonstrated that linear transect sampling can miss smaller individuals. To account for the cryptic nature of juvenile Radiated Tortoises (Pedrono 2008), a concurrent timed search survey was conducted by a two-person team. This presence/absence survey allowed for an estimation of the current extent of occurrence for the species (Gaston and Fuller 2009). These surveyors thoroughly searched for additional tortoises maintaining an approximate distance of 10 m from the transect line in order to eliminate duplicate detection between the two survey teams, as described by Walker (2012). The timed searchers focused their attention on the base of low lying



**Figure 2.** Current extent of occurrence of the *A. radiata* population in southern Madagascar, resulting from a two-year (2010 and 2011) survey across the historical extent of occurrence of the species. Black dots indicate sampling locations.

vegetation; a microhabitat favored by the species (Pedrono 2008).

Data Analysis. — Using the program ArcMap (ArcGIS 9.0), scanned historical range maps for the species were geo-referenced and the boundaries of the described extent of occurrences were digitized to form polygons for ranges described in 1865, 1975, 1995, and 2000 (Decary 1950; Juvik 1975; Lewis 1995; O'Brien et al. 2003; Leuteritz et al. 2005). Using the area calculation function in ArcMap, the areas of these respective polygons could be calculated in km<sup>2</sup> (Table 1). Following this, the waypoints marking the 64 survey sites visited during the present study were plotted

onto a base map of southern Madagascar from a Geographical Information System (GIS) database within ArcMap. Each waypoint was coded as either having a presence or absence of tortoises recorded within each of the respective study sites. Based on these data, the perimeter of the current extent of occurrence could be digitized to form a polygon and the area calculated for the current extent of occurrence and then added to the GIS. The final layer added to the GIS included the four polygons representing the suspected historical extent of occurrence of the species based on the studies noted above.

Transect data were analyzed using DISTANCE 5.0 software to determine tortoise density and population size (Thomas et al. 2010). The statistical methodology used for line transect analysis is based on Fourier analysis (Burnham et al. 1980; Akin 1998). The accuracy of the analysis depended on four assumptions: 1) objects directly on the line will not be missed; 2) objects are fixed at the initial sighting position (i.e., they do not move and are not counted more than once); 3) distances are measured exactly; and 4) all sightings are independent (Burnham et al. 1980). A Conventional Distance Sampling (CDS) engine was used to provide a design-based analysis of the line transect data comprised of object records (tortoises detected) across all transects within the species' current extent of occurrence, using the approach described by Buckland et al. (2001). Probability of detection was modeled as a function of observed distance from the transect line, using robust, semi-parametric methods. To investigate any responsive movement to the observer and clumping of observations (Laake 1978), a histogram of 13 intervals of equal width representing the perpendicular distance data were examined for the 152 tortoises detected during the line transect surveys, but no strong evidence of evasive movement was detected. However, distances further from the center line appeared to be denser (101-400 cm) and data close to 0 cm distance (< 100 cm) appeared to cluster to some degree (Fig. 3). To improve model robustness, we truncated (w = 1000 cm) and transformed the data into automatically adjusted intervals (200 cm) using the data filter function to gain a buffer at 0 cm distance (Buckland et al. 2001) (Fig. 4).



**Figure 3.** Raw distance data grouped into 100 cm intervals showing heaping (101–400 cm), and a spike at 0 cm distance as a result of varying detection probability further from the center line due to variation in habitat complexity.



**Figure 4.** Data detection probability g(y) of *A. radiata* after truncation and transformation of data to intervals using DISTANCE 5.0.

**Table 1.** Survey site identification, location (latitude and longitude), number of tortoises observed in each site, and population demographics detailing the percentage of adults (A) and juveniles (J) per site.

	GPS Co	ordinates	Tortoises	Detected	Popu	lation
Site #	Lat.	Long.	Transect	Timed	Demog	graphics
				Search	%A	% J
T062	75 595	45 1507	5	1	667	22.2
T062	-23.363	45.1597	5	1	57.1	33.3 42.0
T064	-25.565	45.1058	25	1	27.1 80.8	42.9
T065	-25.557	45 1568	10	0	30.8 70	30
T066	-25.500	45 2069	15	0	267	733
T067	-25 541	45 1672	14	ŏ	57.1	42.9
T068	-25.399	44.9571	2	3	60	40
T069	-25.352	44.6773	7	5	33.3	66.7
T070	-25.215	44.6647	3	1	75	25
T071	-25.063	44.6827	1	0	100	0
T072	-25.096	44.6047	1	2	100	0
T073	-25.139	44.5421	1	2	66.7	33.3
T074	-24.990	44.1600	1	5	66.7	33.3
T075	-25.021	44.1688	1	1	0	100
10/6	-25.002	44.1665	l	1	50	50
10//	-25.038	44.1380	2	1	66.6	33.3
1078 T070	-24.981	44.148/	10	2	22.4	66 7
1079 T080	-23.104	44.5054	12	5	22.2	16.7
T080	-24.397	43.9515	2	2	100	10.7
T082	-24.840	44 0785	1	$\frac{2}{4}$	60	40
T083	-24.000	43 9463	6	1	714	28.6
T084	-24.638	43.9480	7	1	87.5	12.5
T085	-24.471	43.8483	2	Ō	0	100
T086	-24.361	43.6859	1	0	0	100
T087	-24.442	43.7727	1	1	50	50
T088	-24.246	43.6905	0	0	0	0
T089	-24.308	43.7504	1	0	0	100
T090	-24.059	43.7235	2	0	100	0
T091	-24.031	43.7250	1	1	50	50
T092	-24.079	43.7308	0	l	100	0
T093	-24.093	43.7362	0	0	0	0
1094 T005	-24.064	43.0/80	0	0	0	0
T095 T006	-24.094	43.0711	0	0	0	0
T090	-23.942	43.7073	0	0	0	0
T098	-23.711	43 6516	ŏ	0	Ő	0
T099	-23.689	43.6499	ŏ	ŏ	ŏ	Ő
T100	-23.601	43.6901	ŏ	ŏ	Ŏ	ŏ
T107	-25.568	45.4608	1	1	100	0
T108	-25.572	45.4863	1	3	75	25
T109	-25.560	45.5431	0	0	0	0
T110	-25.439	45.7396	1	5	66.7	33.3
T111	-25.425	45.6968	1	1	100	0
T112	-25.402	45.8114	2	6	62.5	37.5
T113	-25.333	45.9321	0	5	40	60
1114 T115	-25.316	45.9669	0	2	100	0
T115	-25.292	46.0228	0	0	0	0
T110 T117	-23.197	40.2741	0	0	0	0
T117 T118	-25.195	40.2941	0	0	0	0
T110	-25.104	46 5724	Ő	0	0	0
T120	-25.148	46.4503	ŏ	ŏ	ŏ	Ő
T121	-24.819	46.1170	Ő	Ŏ	Õ	ŏ
T122	-24.826	46.1198	0	0	0	Ō
T123	-24.780	45.1033	1	1	50	50
T124	-24.784	45.0988	1	3	75	25
T125	-24.658	45.3221	0	0	0	0
T126	-24.659	45.3223	0	0	0	0
T127	-24.703	44.6907	0	1	100	0
T128	-24.655	44.6575	1	0	0	100
T129	-24.676	44.8106	0	0	0	0
T130 T121	-24.158	44.45/4	0	0	0	0
1131	-24.221	44.1042	0	0	0	0
		Subtotal	152	68	61	30
		Total	22	20	01	100

The following models, considered general and robust (Buckland et al. 2001; Leuteritz et al. 2005) were utilized: uniform/cosine (Burnham et al. 1980), uniform/simple polynomial (Anderson and Pospahala 1970), half-normal/hermite polynomial and hazard-rate/simple polynomial models (Buckland 1985). The fit of each model was assessed using Akaike's Information Criterion (AIC) values, which trade-off the bias of simple models against the higher variance of more complex models (Burnham et al. 2002). Subsequently, the fit of the model was tested using Chi squared ( $\chi^2$ ) Goodness of Fit test.

## RESULTS

Of the 64 areas surveyed in 2010 and 2011 for this study, 220 Radiated Tortoises were detected. The line transect method detected a total of 152 tortoises at 44 sites, while the timed search method found an additional 68 individuals at 31 sites (Fig. 2; Table 1). Of the 64 sites surveyed, 23 were devoid of tortoises. Of the 220 individuals detected, 86 were determined to be juveniles and 134 adults, of which 56 were males and 78 females. We recorded mean CCL of 480.3 ( $\pm$  77.6) mm and 423.8 ( $\pm$  59.2) mm, respectively, for males and females. Juvenile individuals had a mean CCL of 179.5 ( $\pm$  71.1) mm. The number of tortoises observed at each site, and proportion of adults and juveniles, are listed in Table 1.

The region located just north of Tsimanampetsotsa National Park appears to be the most northern area of current occurrence of Radiated Tortoises, where the number of individuals observed in a 1 km line transect varied from 0 to 1. Moderate to high tortoise numbers (2-12 individuals/ transect) were found south of Tsimanampetsotsa and north of the Linta River. The area between the Linta and the Menarandra River, which is farther to the south, appeared to have a lower abundance of Radiated Tortoises. with 2-5 individuals/transect. The highest concentration of tortoises was found in the region south of the Menarandra River to Cap Sainte Marie Special Reserve, where we recorded 5–26 individuals/transect. The region of Ambovombe, west of Mandrare River, is the most eastern area where Radiated Tortoises can be found, and where we only recorded 0-2 individuals/transect. The current extent of occurrence of the Radiated Tortoise is now limited to an area of 15,020 km<sup>2</sup> (Fig. 2; Table 2). This current extent of occurrence represents an approximately 65% decline in what was considered to be the species' original historic geographic range (Decary 1950) (Table 2).

The half normal/hermite polynomial model proved a good fit for the data ( $\chi^2 = 2.54$ , df = 3.00, p = 0.468), supporting the lowest D AIC values (Buckland et al. 2001). The model's percent coefficient of variation was 22.5% and fell slightly above the target level of precision (< 20%), probably as a result of varying detection functions across the range. This model recorded a total population size of 6,307,900 tortoises (95% CI 4,028,500–9,877,000) with a mean tortoise density of 419.9/km<sup>2</sup> (95% CI 268.2–657.6)

 
 Table 2. Historical and current extent of occurrence of A. radiata.

Author	Year	Range (km2)	% change in range compared to 1865
Decary 1950 Juvik 1975 Lewis 1995	1865 1975 1995	42,883 23,335 30,649	-45.6 -28.5
Leuteritz et al. 2003; Present study	2000 2011	17,684 15,020	-58.8 -65.0

across the range (Table 3). Detection function fell quickly with the data displaying an effective strip width of 460 cm (ESW) (Fig. 4).

## DISCUSSION

The extent of occurrence of the Radiated Tortoise has undergone a substantial decrease over the last 150 years (Fig. 1; Table 2). Historical records suggest that the original range of the tortoise extended further north than Toliara, probably as far as Morombe (Decary 1950). The extent of occurrence is now confined between Tsimanampetsotsa and Ambovombe, east of Cap Sainte Marie. Furthermore, within this extent of occurrence there are pockets that appear to be totally depleted of tortoises, probably as a result of over-harvesting. Further intensive surveying within the areas missed by the current field operations will mostly likely reveal that the actual area of occupancy of the species is much smaller than the extent of occurrence described here.

The sharp decline in detection function (Fig. 4) was likely a result of the cryptic nature of the species and the varying density of vegetation throughout much of the habitat (Harper et al. 2007). Low ESW within distance sampling studies using tortoises is typical, with the Flat-tailed Tortoise (*Pyxis planicauda*) in the forest of Kirindy-Menabe supporting an ESW of 341 cm as a result of the typically dense understory vegetation existing in that area (Young et al. 2008).

Illegal harvesting for the bush meat trade in southern Madagascar preferentially targets mature individuals and has led to the collection of an average of 14,130 (2,430–46,500) adult tortoises annually (O'Brien et al. 2003; Rioux-Paquette 2008), however, this figure is probably conservative with the true figure more likely being hundreds of thousands (Walker and Rafeliarsoa 2012). This collection strategy skews the composition of wild populations, where juvenile tortoises become the dominant cohort within the population. Rioux-Paquette (2008) asserted that harvested tortoise populations tend to have a predominance of juveniles due to this size selection by poachers; adults are favored as they provide more meat. Young tortoises are preferred by international pet traders, due to their small size making the animals easier to conceal at security checks and customs controls (Pedrono 2008).

During recent years, there have been numerous confiscations of juvenile tortoises, including Radiated Tortoises, on local, national, and international levels (TSA 2010; Lowe 2011). The ongoing unstable political situation in Madagascar since 2009 has only exacerbated the problem of weak regulations and security measures. Overall, our data show a high proportion of adults (61%) compared to juveniles (39%) in the 41 sites where tortoises were detected (Table 1). These proportional differences contrast to findings from O'Brien (2003) and Rioux Paquette (2008) that, currently, juveniles are also targeted by poachers. Unlike adults, which are mostly used for local bush meat, juveniles are destined for export. Leuteritz et al. (2005) reported that Cap Sainte Marie, Lavanono, and Lavavolo populations had high juvenile proportions compared to adults of 52, 68, and 55%, respectively, while our results documented 40, 40, and 13% juveniles in these same regions, respectively.

Our results corroborate the findings reported by Leuteritz et al. (2005) that Cap Sainte Marie supports one of the highest concentrations of Radiated Tortoises, along with Lavanono and Lavavolo. However, our density estimate of 419.9 tortoises/km<sup>2</sup> is noticeably lower compared to the density of 2522.2 tortoises/km<sup>2</sup> that Leuteritz et al. (2005) estimated. They undertook their distance sampling work across seven sites known to support high abundance of Radiated Tortoises, resulting in what may be considered an artificially high abundance estimate of 25 million (95% CI: 12–54) Radiated Tortoises when modeled across the whole range.

Our current estimation of ca. 6.3 million tortoises, obtained from 64 survey sites, when compared to the lower end of the 95% confidence interval (12 million) of the Leuteritz et al. (2005) estimate, implies a 47% reduction in population size from an estimated 12 million in 2000. This dramatic decline suggests that the annual harvesting estimated by O'Brien et al. (2003) was either significantly underestimated, or illegal tortoise poaching has increased considerably over the last ten years. Further to this, our estimate of ca. 6.3 million tortoises represents the most comprehensive population assessment for the species, with the high intensity of survey effort able to provide a more precise population estimation. This study also introduces more robust range data for the species which in turn improves precision when producing a population estimate. However, given the ongoing tortoise poaching in southern Madagascar, we realize that these data

**Table 3.** Mean density (D per km<sup>2</sup>) with upper and lower 95% confidence intervals (CI) per km<sup>2</sup> and mean abundance (A) with upper and lower 95% CI. Delta Akaike's Information Criterion (D AIC) and density per hectare are also displayed for the population of Radiated Tortoises.

Model	ΔΑΙΟ	D per km <sup>2</sup>	95% Density CI	Α	95% Abundance CI	D per ha
uniform+cosine	0.07	384.9	249.3–594.2	5,781,100	3,744,700–8,924,900	3.8
uniform+simple polynormal	2.01	432.4	271.6–688.4	6,494,700	4,079,500–10,340,000	4.3
half normal+hermite polynormal	0.00	419.9	268.2–657.6	6,307,900	4,028,500–9,877,000	4.2
hazard rate+simple polynomial	1.45	474.2	237.4–947.5	7,122,800	3,565,100–14,231,000	4.7

will rapidly be outdated, thus we recommend further study related to distribution and density of *A. radiata* in the next five years, in order to update and provide regular "real time" information.

Currently, illegal collection for both local food subsistence and pet trade is the main factor responsible for the decline of Radiated Tortoise populations (Juvik 1975; Lewis 1995; O'Brien 2002; Leuteritz et al. 2005). Northern local communities near the west coast in the Itampolo region report poaching pressure for both consumption and illegal export, where poachers arrive by boat from Toliara, the major port city north of the tortoise's range (Rafeliarisoa, unpubl. data). Similarly, tortoise populations in the eastern region are subject to massive collection for consumption by the Antanosy tribe and loss of habitat from conversion into crop lands and sisal concessions. It now appears that this region has been totally depleted of tortoises except the very small area located within Andohahela National Park; however, the number of tortoises remaining within the park probably amount to only a few tens of animals. Ambovombe stands as the eastern-most region where Radiated Tortoises can still be found; however, it is also renowned as one of the major towns for people consuming tortoise meat as part of their daily meal. Taking this information into account, we would expect the range to decrease further westward towards the area of Cap Sainte Marie within the next few years.

The majority of the present-day range coincides with the area inhabited by the Mahafaly and Antandroy tribes that respect the local taboo, or *fady*, against eating or harming tortoises (Rioux-Paquette et al. 2008). However, other tribes that immigrate into the region do not recognize the *fady* and continue to illegally harvest tortoises (Lingard et al. 2003), thus intense pressure remains on the species within this critical region

Poaching of Radiated Tortoises increasingly threatens the long-term survival of the species, and with the international recognition of the species as Critically Endangered (IUCN 2011), the threat of extinction is of growing concern. Congdon et al. (1993) documented that even a minimal increase in the mortality of adults of a turtle population could cause serious declines for the population, amplified by the fact that turtles exhibit late sexual maturity and high hatchling and juvenile mortality (Gibbs and Amato 2000). Although no specific data regarding the illegal poaching and mortality rates of Radiated Tortoises are provided in our results, we suspect that poaching stands as the major factor responsible for the population decline.

Several key points need to be addressed in order to deal with the rapid declines facing this species, with the most challenging task focusing on the socioeconomic and cultural issues that drive local communities into tortoise-based trade. Local *fady* alone will not protect the Radiated Tortoise from poachers: however, an initiative to draw communities away from their heavy reliance and overexploitation of natural resources can be achieved through a targeted education and community based program approach. A number of NGOs in the region are engaged in livelihood generation projects, habitat restoration and direct, community-based tortoise conservation projects (WWF 2010; Rafeliarisoa et al. 2010; McGuire et al. 2013, this volume). However, these projects need to be geographically wide ranging if they are to prevent the Radiated Tortoise from becoming extinct in the wild within the next decade.

Acknowledgments. - This work was supported financially by the following organizations: Turtle Conservation Fund, Turtle Survival Alliance, British Chelonia Group. Mohamed bin Zayed Species Conservation Fund, Leicester Tortoise Society, and Chelonian Research Foundation. Logistical support and assistance with field work were provided by A. Ramsay, A. Harris, B. Horne, J. Bréchard, R. Razafimanatsoa, J.C. Rakotoniaina, H. Randriamahazo, Blue Ventures Conservation, Madagascar Biodiversity Partnership, Madagascar Institut pour la Conservations des Ecosystèmes Tropicaux, Ministere de l'Environnement et de Forets, Madagascar National Parks, the University of Antananarivo, and the whole crew members of the Genetics Department of Omaha's Henry Doorly Zoo's Center for Conservation and Research, Shannon E. Engberg, Carolyn A. Bailey, Mindy L. Wood, Gary D. Shore, Runhua Lei, and Rick A. Brenneman.

#### Résumé

La Tortue radiée, Astrochelys radiata, une espèce Gravement Menacée (selon l'UICN), est endémique de la forêt épineuse du sud et sud-ouest de Madagascar. Les populations restantes font face à une menace d'extinction significative, causée en majeure partie par une collecte illégale intensive à des fins de consommation locale et pour le commerce international d'animaux domestiques. Une méthode de suivi basé sur l'échantillonnage par DISTANCE, combinée à une approche par présence/absence a été systématiquement utilisée à travers l'étendue de la zone d'occurrence de l'espèce afin d'en établir la distribution, la densité et la taille actuelle de la population. Nous avons trouvé que A. radiata a subi une réduction de sa zone d'occurrence d'approximativement 65% depuis 1865. Cette étude estime que la population sauvage a diminuée de 47% au cours des 12 dernières années, donnant un total approximatif de 6.3 millions de tortues restantes, soit une densité de 420 individus/km<sup>2</sup>. Ce déclin rapide de A. radiata accentue le besoin d'une stratégie de conservation rapide et effective, qui sera fondée sur les communautés locales et qui tiendra compte des programmes d'appui à la pauvreté active dans la région.

#### LITERATURE CITED

- AKIN, J.A. 1998. Fourier series estimation of ground skink population density. Copeia 1998:519–522.
- ANDERSON, D.R. AND POSPAHALA, R.S. 1970. Correction of bias in belt transects of immotile objects. Journal of Wildlife Management 34:141–146.
- BEST, L.B. 1981. Seasonal changes in detection of individual bird species. Studies in Avian Biology 6:252–261.

- BOUR, R. 1981. Etude systématique du genre endémique Malagache Pyxis Bell, 1827 (Reptilia, Chelonii). Bulletin Mensuel de la Société Linnéenne de Lyon 50:154–176.
- BOUR, R. 1994. Recherches sur des animaux doublement disparus: les tortues geantes subfossiles de Madagascar. Memoire EPHE 19:1–253.
- BUCKLAND, S.T. 1985. Perpendicular distance models for the line transect sampling. Biometrics 41:177–195.
- BURNHAM, K.P., ANDERSON, D.R., AND LAAKE, J.L. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1–202.
- BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., AND LAAKE, J.L. 2001. Distance Sampling: Estimating Abundance of Biological Populations. London: Chapman and Hall, 446 pp.
- CONGDON, J.D., DUNHAM, A.E., AND VAN LOBEN SELS, R.C. 1993. Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of longlived organisms. Conservation Biology 4:826–833.
- COULSON, T. 2003. Decline of the Madagascar radiated tortoise (*Geochelone radiata*) due to overexploitation. Oryx 37:338–343.
- DECARY, R. 1950. La Faune Malgache. Paris: Payot, 236 pp.
- DU PUY, D.J. AND MOAT, J. 2003. Using geological substrate to identify and map primary vegetation types in Madagascar and the implications for planning biodiversity conservation. In: Goodman S.M. and Benstead, J.P. (Eds.). The Natural History of Madagascar. Chicago: University of Chicago Press, pp. 51–67.
- GASTON, K.J AND FULLER, R.A. 2009. The size of species geographic ranges. Journal of Applied Ecology 46:1–9.
- GELATT, S. AND SINIFF, B. 1999. Line transect survey of crabeater seals in the Amundsen-Bellingshausen Seas, 1994. Wildlife Society Bulletin 27:330–336.
- GIBBS, J.P. AND AMATO, G.D. 2000. Genetics and demography in turtle conservation. In: Klemens, M.W. (Ed.). Turtle Conservation. Washington, DC: Smithsonian Institution Press, pp. 207–217.
- GOODMAN, S.M. AND BENSTEAD, J.P. 2005. Updated estimates of biotic diversity and endemism for Madagascar. Oryx 39:73–78.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D., AND HAWKINS, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34:325–333.
- IUCN. 2011. IUCN Red List of Threatened Species. Version 2011.1. www.iucnredlist.org. Downloaded on 16 September 2011.
- JUVIK, J.O. 1975. The radiated tortoise of Madagascar. Oryx 13:145–148.
- LAAKE, P. 1978. An evaluation of synthetic estimates of employment. Scandinavian Journal of Statistics 5:57–60.
- LEUTERITZ, T.E.J. 2003. Geochelone radiata (radiated tortoise). Nocturnal activity. Herpetological Review 34:240.
- LEUTERITZ, T.E.J., LAMB, T., AND LIMBERAZA, J.C. 2005. Distribution, status and conservation of radiated tortoises (*Geochelone radiata*). Madagascar. Biological Conservation 124:451–461.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). Unpublished Report, World Wildlife Fund, Madagascar Country Office.
- LINGARD, M., RAHARISON, N., RABAKONANDRIANINA, E., RAKOTOARISOA, J.A., AND ELMQVIST, T. 2003. The role of local taboos in conservation and management of species: the radiated tortoise in southern Madagascar. Conservation and Society 1:223–246.
- Lowe, H.2011. Tortoises seized in Madagascar. Turtle Survival Alliance website. http://www.turtlesurvival.org/blog/1-blog/149-tortoisesseized-in-madagascar
- McGuire, S., Rafeliarisoa, T.H., Randriamanantenasoa, H., Randrianindrina, V.R.A., Shore, G.D., and Louis, E.E., Jr. 2013. Community outreach and education promoting the conservation of the Radiated Tortoise, *Astrochelys radiata*, in Lavavolo, Mada-

gascar. Chelonian Research Monographs 6:97-104.

- MYERS, N., MITTERMEIER, R.A., MITTERMEIER, C.G., FONSECA, G.A.B. DA, AND KENT, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853–858.
- NUSSBAUM, R.A. AND RAXWORTHY, C.J. 2000. Commentary on conservation of "Sokatra", the radiated tortoise (*Geochelone radiata*) of Madagascar. Amphibian and Reptile Conservation 2:6–14.
- O'BRIEN, S.H. 2002. Population dynamics and exploitation of the radiated tortoise *Geochelone radiata* in Madagascar. Ph.D. Thesis, Darwin College, University of Cambridge and Institute of Zoology, Zoological Society of London.
- O'BRIEN, S., EMAHALALA, E.R., BEARD, V., RAKOTONDRAINY, R.M., REID, A., RAHARISOA, V., AND COULSON, T. 2003. Decline of the Madagascar radiated tortoise (*Geochelone radiata*) due to overexploitation. Oryx 37:338–343.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu, Malaysia: Natural History Publications (Borneo), 147 pp.
- RABINOWITZ, P.D., COFFIN, M.F., AND FALVEY, B. 1983. The separation of Madagascar and Africa. Science 220:67–69.
- RAFELIARISOA, T.H., SHORE, G.D., MCGUIRE, S.M., AND LOUIS JR., E.E. 2010. Innovative solutions to conservation challenges for the radiated tortoise (*Astrochelys radiata*) project at Lavavolo Classified Forest, Madagascar. Turtle Survival Magazine 2010:64-66.
- RALPH, C.J. 1981. An investigation of the effect of seasonal activity levels on avian censusing. In: Ralph, C.J. and Scott, J.M. (Eds.). Studies in Avian Biology. Cooper Ornithological Society, pp. 265–270.
- RIOUX PAQUETTE, S.R. 2008. La génétique au service de la conservation d'une espèce menacée endémique à Madagascar, la tortue radiée Astrochelys radiata. Ph.D. Thesis, Département de sciences biologiques, Faculté des Arts et Sciences, Université de Montréal, Canada.
- SHAW, G. 1802. Amphibia. Herpetological section from the first world summary of amphibians and reptiles in English. General Zoology 3:1014.
- SEDDON, N., TOBIAS, J., YOUNT, J.W., RAMANAMPAMONIY, J.R., BUTCHART, S., AND RANDRIANIZAHANA, H. 2000. Conservation issues and priorities in the Mikea Forest of south-west Madagascar. Oryx 34:287–304.
- THOMAS, L., BUCKLAND, S.T., REXSTAD, E.A., LAAKE, J.L., STRINDBERG, S., HEDLEY, S.L., BISHOP, J.R., MARQUES, T.A., AND BURNHAM, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5–14.
- TURTLE SURVIVAL ALLIANCE. 2010. TSA assisting with illegal turtle shipment seized in Hong Kong. Turtle Survival Alliance website. http://turtlesurvival.org/blog/1-blog/73-tsa-assisting-with-illegalturtle-shipment-seized-in-hong-kong

VINSON, A. 1865. Voyage à Madagascar. Paris, France: Roret.

- WALKER, R.C. J. 2012. A critical evaluation of field survey methods for establishing the range of a small, cryptic tortoise (*Pyxis arachnoides*). Herpetological Journal 22:7–12.
- WALKER, R.C.J. AND RAFELIARISOA, T.H. 2012. Distribution of Radiated Tortoise (*Astrochelys radiata*) bush meat poaching effort. Chelonian Conservation and Biology 11(2):223–226.
- WILMÉ, L., GOODMAN, S.M., AND GANZHORN, J.U. 2006. Biogeographic evolution of Madagascar's microendemic biota. Science 312:1063–1065.
- WWF. 2010. Programme d'actions de WWF sur les tortues terrestres endémiques du sud-ouest de Madagascar: Astrochelys radiata et Pyxis arachnoides 2010-2015. WWF Madagascar p. 61.
- YOUNG, R.P., TOTO VOLAHY, A., BOUROU, R., LEWIS, R., DURBIN, J., AND FA, J.E. 2008. Estimating the population of the endangered flat-tailed tortoise *Pyxis planicauda* in the deciduous, dry forest of western Madagascar: a monitoring baseline. Oryx 42:252–258.

## The SOKAKE Project:

## Conservation of Radiated Tortoises, Astrochelys radiata, in Southern Madagascar

## BERNARD DEVAUX<sup>1</sup>

<sup>1</sup>SOPTOM - Turtle Village, P.O. Box 24, 83590 Gonfaron, France [soptom@wanadoo.fr]

ABSTRACT. – The French association SOPTOM was created in 1986 with a goal of studying and protecting turtles. It developed an original concept in tortoise and turtle protection called the Village des Tortues (Turtle Village) and established a center at Gonfaron in southern France. In the late 1990s it became interested in the tortoises of Madagascar, and in 1999 launched the "SOKAKE project" in conjunction with the Association de Sauvegarde de l'Environnement and established a Turtle Village at Mangily-Ifaty, near Toliara in southwest Madagascar. The goal of the center has been to receive tortoises confiscated by the authorities, to participate in the conservation of *Astrochelys radiata* and *Pyxis arachnoides*, and to help develop ecotourism in the region and community outreach and awareness programs to help stem local tortoise poaching.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, Astrochelys radiata, Radiated Tortoise, confiscations, poachers, Turtle Village, Mangily-Ifaty, Madagascar

The Radiated Tortoise (*Astrochelys radiata*) is a beautiful terrestrial tortoise that can grow to 18 kg and lives in prickly savannah regions amongst the cacti and baobab trees. Once very common in southern Madagascar, its area of distribution has been reduced considerably over the last 150 years. The cause of its decline is first and foremost a result of poaching for trafficking and local consumption as certain ethnic groups still eat this tortoise. Its liver is considered a delicacy and is consumed throughout the country during celebrations on special occasions such as Easter and Christmas. The destruction of its habitat through urbanization and desertification due to charcoal production and fires is also responsible for its decline.

According to our studies, which are detailed in a recently published monograph in conjunction with Roger Bour from the Natural History Museum in Paris (Devaux 2010), the residual area inhabited by *A. radiata* is now reduced to a coastal strip between Itampolo and Tsiombe, and the maximum density of the species, previously 60 tortoises/ha, has fallen to between 10 and 30 tortoises/ha at the best sites. Bearing in mind that between 20,000 and 50,000 tortoises are removed from their natural habitat each year, it is clear that this species is in serious decline.

The French association SOPTOM (Station d'Observation et de Protection des Tortues des Maures) was created in 1986 by English and French naturalists and biologists. In 1988, it began to develop an original concept in tortoise and turtle protection called the Village des Tortues (Turtle Village). The concept was as follows: to carry out field conservation projects, it takes financial resources, but unfortunately, individual states do not always have the necessary finances, and at the Rio Congress in 1992 it was stated that "*as far as possible, associations should*  *take responsibility for protecting species*". Consequently, our idea was therefore to open a rescue center for tortoises and turtles that would be open to the public and financed by our visitors. This concept, which was first applied to our facility in Gonfaron, southern France, in 1988, has been a great success, as today we welcome 110,000 visitors a year who finance our protection programs. As a result, we created other Turtle Villages at Moltifao on the island of Corsica (France) and Noflaye in Senegal. In the late 1990s we developed an interest in the tortoises of southern Madagascar, and in 1999 we established a Turtle Village at Ifaty in southern Madagascar. We are also trying to create others in Australia and perhaps in Florida.

This concept has also been applied in Italy, Spain, Costa Rica, Vietnam, South Africa, Australia, and Malaysia by other organizations. At the same time, several new associations devoted to protecting tortoises have also arisen. There are currently several young researchers, students, and enthusiasts dedicated to studying and protecting tortoises all over the world. The first naturalists and researchers who inspired us to protect tortoises were Archie Carr, followed by Peter Pritchard, Jacques Fretey, Lee Durrell, Indraneil Das, Gerald Kuchling, John Behler, and many more. Today, we are both optimistic and pessimistic in equal measures. The herpetology world has now taken action to "save the turtles" as shown by the excellent work carried out by the Turtle Survival Alliance (TSA), but some of this action is a little late. Action was needed already 30 years ago because today most tortoises and turtles are in serious decline and the future is very worrying.

In 1999 SOPTOM launched the "SOKAKE project" (*sokake* is the local name for the Radiated Tortoise) in con-



Figure 1. Entrance to the Village des Tortues (Turtle Village) at Ifaty. Photo by B. Devaux.

junction with a local association, the A.S.E. (Association de Sauvegarde de l'Environnement - the Environmental Safeguard Association) that is chaired by Professor Daniel Ramampiherika and monitored by a group of Scientific Advisers, including Roger Bour, Gerald Kuchling, and Peter Pritchard. It comprises several initiatives, including first and foremost the establishment of a Turtle Village at Mangily-Ifaty, located 35 km north of Toliara in a natural biotope where the Spider Tortoise, Pyxis arachnoides, can still be found. The team at the center currently consists of six people: three keepers and three wardens. SOPTOM ensures financial support for the Village at Ifaty, but assistance is also provided by the Turtle Survival Alliance, Amneville Zoo, and Salamandre-Nature. The Village encompasses 15 ha and is situated 500 m from the Ifaty lagoon, a savannah with baobab and umbrella trees. It includes approximately 24 enclosures and is equipped with quarantine space, hatching areas, and nurseries for juvenile tortoises. There are currently (2013) about 2200 Radiated and Spider Tortoises at the Village.

A special enclosure for *P. arachnoides* was created by the TSA in order to study all three subspecies of *Pyxis* at the same site. There is also a large information room, accommodation for permanent staff and eco-volunteers, a reception room for schools, and in 2010 we opened a Tortoise Clinic, which allows us to carry out biological and pathological studies.

The center was created to house tortoises seized by authorities during poaching checks and to raise awareness amongst the local Malagasy people, as well as foreigners. In 2009, we received 300 Radiated Tortoises that were transferred by the Madagascar Fauna Group from a holding facility at Ivoloïna located on the eastern coast of Madagascar, and in 2010, 400 Radiated Tortoises were transferred from Malaysia, where they had been confiscated from the illegal international pet trade. The Turtle Village also aims to create jobs, improve the local economy, and form an impressive tourist destination in southern Madagascar. Importantly, we work closely with the Minister of the Environment, Madagascar National Parks (previously ANGAP), and the Departement de l'Environnement des Eaux et Forêts.

The SOKAKE project includes other objectives, of which the most important is to reduce trafficking of southern Madagascar tortoises. With this in mind we carry out programs to raise awareness in schools and villages, and we conduct "information patrols" with 4x4 vehicles across the entire south to distribute information. We also organize conferences, congresses, and meetings between specialists and the authorities. An important initiative is arranging meetings with traffickers to try and convert them into craftsmen, fishermen, or farmers. Over the past 14 years we have managed to change mentalities in a sensitive way by raising awareness; for example, in Toliara there are fewer women selling turtle soup and fewer men cutting up sea turtles in the markets. Plus, there are fewer traffickers and the number of tortoises being poached appears to be much reduced. Representatives from the State have increased their efficiency on the ground and the number of initiatives to stop poaching. Surveillance for poachers in the tortoises' natural habitat is the most efficient method to stop poaching, and as a result of increased surveillance efforts, the sale of tortoises to the capital city (Antananarivo) and certain civil servants has almost disappeared. The situation is of course far from perfect, but has definitely improved when compared to the 1990s.

The SOKAKE project includes a "reintroduction" phase because the tortoises at Ifaty are not intended to stay there permanently. We are not a zoo, but rather a confiscation and transition center. The villagers in the south do not understand why the tortoises stay in Ifaty and are not placed immediately back into nature. For the past



**Figure 2.** Marked Radiated Tortoises at the Village des Tortues (Turtle Village) at Ifaty. Photo by B. Devaux.

10 years, we have been looking for suitable release sites so that these tortoises can be put back into their original biotope with favorable conditions. Finding a release site is difficult because of the continued threat posed by poachers. We do not want the tortoises to be poached again.

We have examined several areas, but few have been adequate because they are too close to villages with herds of cattle and goats passing through, damaging habitat. Ultimately, we chose the Lake Tsimanampetsotsa Reserve (now a National Park) that is located about 150 km south of Toliara. This Reserve is 250,000 ha and includes a remarkable natural biotope situated between the sea and the Mahafaly Plateau. This program is being conducted with the support of the public authorities, Madagascar National Parks, and the Departement de l'Environnement des Eaux et Forêts. A student from Germany worked on a study at the Reserve on the reproduction of A. radiata (Hammer 2013, this volume). Although a few native wild tortoises still remain at the Reserve, our Scientific Advisers and the authorities still consider this to be the ideal location to release previously confiscated tortoises.

Therefore Antoine Cadi, the SOKAKE Project Mission Coordinator, will lead the necessary local initiatives over the next few years in preparation for the release. From 2010 to 2011, two students worked on an inven-



Figure 3. Three caretakers at the Village des Tortues (Turtle Village) at Ifaty, Daniel, Mamie, and Jean. Photo by B. Devaux.

tory of the flora and fauna of the Lake Tsimanampetsotsa Reserve. We have placed 100 A. radiata in quarantine at Ifaty that will be subject to health testing before they are returned to the wild at the Reserve. Over the coming year, in collaboration with TSA Madagascar, we hope to release 50–100 of these tortoises fitted with tracking devices and plan to follow them over two years to study how they adapt to this biotope. To ensure that this release is successful, we are encouraging the local villagers to participate. A "Mr. Tortoise" will be selected from each village to oversee the tortoises at the Reserve. The animals will also be monitored by National Park Officers, because the biggest threat is still from traffickers coming from the capital. This release is therefore experimental; if the results are good we will look for other sites and will continue to release tortoises from Ifaty.

The World Wildlife Fund Madagascar has also suggested other areas for release that are located towards the eastern edge of the tortoise's range. Releases are symbolic and can send a strong message to the people through the media. It is essential to inform the local people, as well as the whole of the Madagascan population, that these tortoises are now monitored and protected and that this natural heritage must be conserved for everybody's benefit. By protecting the tortoises, the local economy also benefits through tourism. Despite all this it is still difficult to make people understand, not just in Madagascar, that animals are more valuable alive than dead. In our project, there is a strong emphasis on raising awareness amongst the villagers and getting them involved in the program.

We have several initiatives involved in tortoise conservation in the south with the main principle being to change ways of thinking through sharing information, conducting local initiatives, and media involvement. We support research and zoo techniques, including pathology, biology and husbandry; foster visitor relations and support the regional economy by creating jobs and developing tourism; and we build contacts and collaborations with other associations, both in Madagascar and abroad, and with public authorities. Reducing trafficking and poaching is the most urgent concern, to achieve this we need to raise awareness amongst the villagers and the authorities, and encourage more stringent checks and controls.

However, the real problem is poverty and the economic situation in Madagascar, which is currently suffering from political instability and a lack of tourists. If there were more visitors to Madagascar, particularly to the south that offers marvelous places to visit, there would be a better economy. Developing tourism opportunities that foster a respect for nature would improve the situation of the island's fauna, which would then be less subject to poaching.

If we want to help Madagascar, we need to visit in fairly large numbers, so that we can improve the standard of living of the villagers in the south and avoid the temptation for them to sell the local wildlife. Finally, trade in these species remains the biggest problem because it is fueled not only by the high local and regional demand for tortoise meat for



Figure 4. Turtle collectors, nearly always very poor, usually carry poached tortoises on poles on their shoulders—this one was near Cap Sainte Marie. Photo by B. Devaux.

consumption, but also by the demand of overseas collectors and enthusiasts that keep creatures in tanks and who are prepared to pay "any price" to have an A. radiata in their house. To halt the depletion of exotic wildlife, including tortoises, we must refuse to trade in these creatures. Internet sites are part of the problem, with hundreds of them offering tortoises for sale, including some of the rarest species, such as A. yniphora and A. radiata. So it is clear that Madagascans themselves are not solely responsible for all the problems regarding tortoises. The pet trade problem stems mainly from rich countries and individuals that are willing to pay astronomical prices for several species (e.g., over \$10,000 USD for A. yniphora). This demand explains why soughtafter wildlife is poached, trafficked, and depleted. We must face up to these problems if we are to safeguard the endemic Madagascan wildlife that is so extraordinary.

## Résumé

L'association française, SOPTOM, a été crée en 1986 dans le but d'étudier et de protéger les tortues. Installée dans le Sud de la France, elle a réalisé un centre d'accueil et d'information à Gonfaron nommé "Village des Tortues." Dans les années 1990, elle s'est intéressée aux tortues de Madagascar, et en 1999, avec une association de Toliara, l'Association de Sauvegarde de l'Environnement elle a créé un "programme SOKAKE" et un Village des Tortues à Mangily-Ifaty. Le but de cette centre est de recevoir les tortues saisies par les autorités, de participer à la conservation des *Astrochelys radiata* et *Pyxis arachnoides*, et de favoriser le développement éco-touristique de la région, tout en réprimant les trafics de tortues.

## LITERATURE CITED

- DEVAUX, B. 2010. Astrochelys radiata: une "star" très menacée: taxonomie, histoire naturelle, biologie, répartition, pathologie, ethnozoologie, conservation. Gonfaron, France: Editions SOP-TOM, Chelonii no. 8, 158 pp.
- HAMMER, J.M. 2013. Do bigger females produce bigger eggs? The influence of female body mass on egg mass in Astrochelys radiata. Chelonian Research Monographs 6:119–123.

# Community Outreach and Education Promoting the Conservation of the Radiated Tortoise, *Astrochelys radiata*, in Lavavolo, Madagascar

# SUSIE MCGUIRE<sup>1</sup>, TSILAVO H. RAFELIARISOA<sup>2,3</sup>, HERILALAINA RANDRIAMANANTENASOA<sup>1</sup>, VELOARIVONY R.A. RANDRIANINDRINA<sup>3,4</sup>, GARY D. SHORE<sup>5</sup>, AND EDWARD E. LOUIS, JR.<sup>3,5\*</sup>

<sup>1</sup>Conservation Fusion, Inc., 5820 Spring St., Omaha, Nebraska 68106 USA [conservationfusion@gmail.com]; <sup>2</sup>Département de Biologie Animale, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar [rafelykely@hotmail.com]; <sup>3</sup>Madagascar Biodiversity Partnership, ONG, VO 12 Bis A, Manakambahiny, Antananarivo 101, Madagascar [mbp.dg.mbbp10@gmail.com];

<sup>4</sup>Département de Biologie et Ecologie Végétales, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar [renceaimee@yahoo.fr];

<sup>5</sup>Omaha's Henry Doorly Zoo, 3701 South 10th Street, Omaha, Nebraska 68107 USA [genetics@omahazoo.com]; \*Corresponding Author

ABSTRACT. – The Radiated Tortoise, *Astrochelys radiata*, was once abundant in the southern region of Madagascar, however, its original range distribution has decreased by more than 40% over the past decade. This rapid decline is a result of habitat loss, poaching for both local consumption and illegal sale in international markets, and the degradation of local taboos or beliefs that once protected these endemic creatures. One of the last remaining strongholds of Radiated Tortoise populations identified is the Lavavolo Classified Forest located in the Toliara region of southwestern Madagascar. The community of Lavavolo is made up primarily (99.5%) of fishermen and subsistence farmers, depending upon the surrounding environment for survival. This region is dry and xeric, therefore deficient of resources, clean water, and lacks basic education. As humans are undeniably a major threat to these tortoise populations, they must also be an integral part of the solution. Here, we present the successful implementation of community-based outreach and education engaging local Malagasy as stakeholders in tortoise conservation, as both humans and animals coexist and thrive as a result of conservation initiatives.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, Astrochelys radiata, Radiated Tortoise, conservation education, community outreach, Madagascar

One of the emblematic species of the dry spiny forests of southern and southwestern Madagascar (Fig. 1) is the Critically Endangered Radiated Tortoise (*Astrochelys radiata*; IUCN 2011). This tortoise species, known as *sokake* or *kotroky* in Malagasy, is threatened by illegal pet trade, collection for international food markets, habitat destruction, and harvesting for domestic consumption (Durrell et al. 1989; Nussbaum and Raxworthy 1998; O'Brien et al. 2003; Leuteritz et al. 2005). Illegal hunting camps that harvest Radiated Tortoises operate as a year-round business, and confiscations of hundreds of individuals are reported annually in Madagascar and Asia (Rioux-Paquette et al. 2009).

Loss of tortoise habitat is driven predominantly by deforestation for agricultural land and charcoal production (Nussbaum and Raxworthy 1998; Harper et al. 2007). Even though the spiny forest produces an extremely poor quality wood, it continues to be sacrificed for the production of charcoal, and subsequently overgrown with invasive prickly pear cactus (genus *Opuntia*). Harper et al. (2007) estimated an overall reduction of spiny forest cover from 30,298 km<sup>2</sup> to 21,322 km<sup>2</sup> during the period between 1970 and 2000, with an annual rate of loss of 1.2%. Unfortunately, these

spiny forests represent the smallest designated proportion of protected area of any region in Madagascar (Du Puy and Moat 2003). As with all of Madagascar's tortoises, the decline of the Radiated Tortoise has been exacerbated by the current political and economic crisis that began in January 2009, compounding living conditions in what is considered the poorest region of Madagascar.

The combination of threats from illegal harvesting and habitat loss has led to a declining population trend. Although the Radiated Tortoise was once abundant, with an estimated total population of over 12 million individuals in 2000, it is rapidly nearing extinction with approximately 6 million individuals remaining in 2011 (Rafeliarisoa et al., 2013, this volume). These authors found that *A. radiata* has undergone a range contraction to 15,019.8 km<sup>2</sup> since 1865. This drastic decline has been intensified by the highest poverty rates in the country, and is compounded by Madagascar's current political instability. At the current rate, wildlife authorities predict the *sokake* may become extirpated from the wild within the next 5 years.

In response, in 2008, the Madagascar Biodiversity Partnership (MBP), a national Malagasy NGO and its founding partner, Omaha's Henry Doorly Zoo (OHDZ), initiated



Figure 1. The Radiated Tortoise derives its name from the radiating pattern of lines on its carapace. It is known locally in Madagascar as the *sokake* or *kotroky*. Photo by Tsilavo Rafeliarisoa.

the Radiated Tortoise Project (RTP) at Lavavolo Classified Forest, located in the Toliara region of southwestern Madagascar. The Lavavolo region (S24°38'27.4" E043°56'39.6; Fig. 1) was specifically chosen in collaboration with the Radiated Tortoise Species Survival Plan (SSP), the Turtle Survival Alliance (TSA), Turtle Conservation Fund (TCF), and OHDZ. Two criteria influenced the selection of the site for this long-term conservation effort. Using extensive field work and molecular genetic data accumulated between 2000 and 2007 on the Radiated Tortoise, the MBP documented evolutionarily significant units (ESUs) for this species and



**Figure 2.** Xeric conditions in southern Madagascar require innovative solutions to provide basic needs, such as water, to local people. The water hippo roller can transport more than eight times the amount of water, in less than half the time, versus the traditional bucket method. Photo by Tsilavo Rafeliarisoa.

concluded that the Lavavolo population called for priority action (Rioux-Paquette et al. 2010). Moreover, the people of this community, mainly from the Mahafaly ethnic group, traditionally maintain the local *fady* (taboo) against eating or harming the Radiated Tortoises. In recent times, however, this *fady* has not been respected by outsiders that have immigrated into southern Madagascar (Rafeliarisoa 2009).

In an effort to ease human pressure on an ecosystem at the local level, this project emphasizes a multifaceted approach including Radiated Tortoise field research, education, community involvement, and the development of transferable technology that secures the long term conservation of *A*. *radiata* and its habitat in southern Madagascar. Successful conservation initiatives require diverse collaborations to maximize resources and talents to achieve common goals. While the MBP focuses on the research component of the RTP, Conservation Fusion Inc. (CF) addresses the community education aspect. CF is an international educationbased non-profit engaging communities in education about unique biodiversity to instill knowledge, understanding, and ownership, all of which ultimately lead to responsible actions for a sustainable future.

Few Malagasy children and adults are aware of their own rare and unique endemic flora and fauna, including flagship species (Dolins et al. 2009). Using the Radiated Tortoise as the flagship species, the RTP, MBP, and CF modeled a program based on the philosophy of combining community development and conservation goals in an effort to connect the local people with the wildlife and habitat. This approach is twofold, both educating and creating an awareness that this species is found only in the dry, xeric southern portion of the island, and instilling pride and ownership in this emblematic species.

### METHODS

The daily monitoring and evaluation of the Radiated Tortoises in this region provided baseline data on populations and additional protection against poaching activities. The employment of local people collecting this data results in a beneficial coexistence between humans and endangered biodiversity and was highlighted in the CF educational outreach programs. To affect local ownership and sustainability brought on by environmental conditions and long term poverty, the RTP initiated scientific and community based pilot programs and assessments that included the following concerns: habitat evaluation and restoration, Radiated Tortoise diet in pristine vs. impacted habitat, and the potential development of economic engines. Complementary to these pilot programs were efforts to evaluate the effectiveness of desalination technologies and water acquisition and transport, potential for cash and food crops, and biofuel methodology of local resources. These activities were reinforced with CF educational activities to include teacher training, movie nights, conservation camps, school programs, and community outreach with villages to include a festival



Figure 3. More than 600 children participated in the tortoise festival "Kotroky-O-Rama", along with teachers, village elders, government representatives, and local law enforcement. Presentations were given by school children to include original poems and songs about conservation and taking responsible action towards protecting Radiated Tortoises. Photos by Tsilavo Rafeliarisoa.

engaging children, teachers, government officials, elders, and local law enforcement.

## RESULTS

Rocket Stoves and Biofuel Briquettes. — To build upon established, long-term relationships with community members and government officials, multiple outreach programs have been launched in the Lavavolo region. One of the initial programs initiated by the MBP included community workshops presenting alternatives to habitat destruction through the use of fuel efficient rocket stoves and the use of biofuel briquettes. These alternative biofuel efficient technologies lessen pressure upon the environment and reduce cook time, fuel wood collection and use, and provide health benefits in lieu of the harmful emissions and smoke produced from traditional open fires used for cooking (Bruce et al. 1998). The MBP has been testing new, innovative designs for the stoves and has adopted a formula that has been rigorously field-tested over the past two years at Kianjavato, Madagascar (Bryden et al. 2005). Additionally, the MBP has shown that this stove can be produced with local materials at an affordable price to local Malagasy.

A great deal of the remaining tortoise habitat has been overrun with the prickly pear cactus, genus *Opuntia*, an invasive species introduced into the southern Madagascar in 1769 (Kaufman 2001, 2004). *Opuntia* opportunistically takes over the habitat following "tavy", the traditional slash-and-burn agricultural practice for clearing the land. Furthermore, the plant is often planted as a hedge as a precursor to acquiring land. To establish a method that disposes of this non-native plant, the MBP has incorporated it in a recipe for biofuel briquettes, thus eliminating *Opuntia* from the landscape, providing an alternate to fuel wood from the spiny forest and a fuel source for the rocket stove (Fig. 2).

Currently, emissions testing of these biofuel briquettes are being conducted alongside traditional charcoal Malagasy briquettes through a collaboration with the Massachusetts Institute of Technology (MIT) D-lab and Dr. Amy Banzaert. D-lab is a program at MIT which fosters the development



Figure 4. More than 700 local students participated in conservation education games, art projects, and songs to create a sense of pride and ownership in the Radiated Tortoise. By learning the treasures their country possesses, they are more likely to protect them. Photos by Megan McGuire.



Figure 5. During conservation camp, children and teachers accompanied MBP researchers and CF staff into the spiny forests to learn more about the biodiversity in their own backyard. Children utilized tools such as magnifying glasses and binoculars to experience how scientists and Malagasy students collect data about the tortoises and their environment. Local children do not touch the tortoises due to a local taboo, however, they are committed to protecting them from poachers. Photos by Megan McGuire.

of appropriate technologies and sustainable solutions within the framework of international development, and Dr. Banzaert will verify the health benefits to local Malagasy. Furthermore, the local production of these biofuel briquettes has the potential to empower local people by creating economic engines through the sale of briquettes in the open market.

*Reforestation.* — A grassroots forest restoration program began with the construction of a new nursery in Lavavolo, following the restoration of the fence at the Itampolo nursery. Community members participated in the construction activities, including the village elder, which is of great significance in the local culture of the region. In July 2011, MBP Malagasy graduate student, Rence Randrianindrina, along with the local guide and MBP staff, conducted a habitat evaluation to both provide recommendations for the forest restoration project, and to collect important data regarding the Radiated Tortoise diet in pristine versus impacted habitat. This novel approach to restoration will be applied to reforestation efforts as community members learn the proper techniques associated with the germination of specific trees and care for seedlings in the nursery. Upon maturation, the trees will be planted systematically, and subsequently managed and monitored by local people. This information will be utilized using innovative technology such as the Groasis boxes to establish *in situ* seedlings produced in the nursery.

*Transportation of Clean Water.* — Another challenge in southern Madagascar is the lack of access and transport of clean water. To address this task, the Lavavolo com-



Figure 6. Movie nights, powered by a generator, provide community members a rare glimpse of themselves participating in education programs, with images of themselves being projected larger than life as conservation heroes. Photo by Dave Stock.

munity is field-testing a Hippo Water Roller (Fig. 2). The practical and durable design of these drums enables more water to be transported more efficiently than traditional methods. With its large drum capacity holding eight times the amount of water in one bucket, the Hippo Water Roller frees women and children from having to spend a large portion of every day dedicated to collecting water for their households, requiring far less effort rolling the water along the ground than it does carrying it on the head. Therefore, the Hippo Water Roller acts as a catalyst for conservation and education.

Education. — Education is lacking in the region, particularly the Lavavolo area, which does not have a school building or a teacher. Students must travel 20 km each day in extreme heat to attend classes. Most children cannot physically make the journey until they are adolescents, at which time they are required to contribute to the family livelihood of fishing, farming, cooking, and gathering water. Therefore, few Malagasy children or adults are aware of the rare and unique biodiversity with which they share a home. In fact, survey results show 4 out of 5 children and adults in the Lavavolo region did not realize the Radiated Tortoise exists only in Madagascar, and is restricted to the southern region where they live. Simple educational messages contribute to the protection and preservation of local biodiversity. By learning the treasures their country possesses, they are more inclined to protect it.

Through CF education projects, local children, teachers, adults, and government officials became aware of the plight of the Radiated Tortoise and were immediately pledging and planning ways to protect this unique species. Several conservation education programs have been implemented by CF, including teacher training workshops, innovative conservation-based educational materials, lessons for primary school children to participate in hands-on activities promoting the conservation, and a conservation camp engaging kids to explore the biodiversity in their own backyard. Finally, in July 2011, CF concluded educational activities with a "festival of tortoises" involving the local community called "Kotroky-O-Rama" (see below).

Network of Conservation Educators. — To strengthen environmental awareness, a network of core conservation educators (Teacher Network) was established across Madagascar to disperse local messages utilizing "flagship" species to promote sustainable actions to benefit both local people and biodiversity. Linking teachers from multiple eco-regions of the island was one of the first steps in creating this network of teachers. Therefore, CF coupled the Lavavolo project with its program in the eastern rainforests of Kianjavato, where strong ties with the teachers and education officials have been established through multiple years of educational programs. This approach provides the ideal complement to Lavavolo, since the MBP has a long term presence at both sites, with established community-based monitoring programs centered on critically endangered species. Additionally, the MBP has already launched community outreach and training, promoting sustainable enterprises and grassroots reforestation programs.

Educational Activities. — In July 2011, CF initiated its second Conservation Festival in Lavavolo, engaging the entire community in the protection of the Radiated Tortoise. CF and the novel Teacher Network formed from both regions spearheaded the festival of tortoises "Kotroky-O-Rama". The festival was a creative assemblage of students and teachers that encouraged all community members to celebrate their appreciation for conservation benefits and communicate their ideas regarding means to deter regional poaching of Radiated Tortoises. About 150 Malagasy students from Itampolo Elementary school wore original Radiated Tortoise costumes to participate in the parade at "Kotroky-O-Rama" (Fig. 3). The event was attended by over 700 students, 100% of local teachers, government officials, village elders, and law enforcement agencies, all of whom committed enthusiastically to taking responsibility for protecting the Radiated Tortoises in the Itampolo and Lavavolo region. Other activities at this event included a parade through the marketplace and the presentation of original conservation songs about protecting their natural heritage and poems written and presented to the community by the students.

School-based education programs consisted of four sessions at the Itampolo primary school in mornings and afternoons for two consecutive days to include multiple hands-on activities, including tortoise puppet painting. Provided through a grant from Turtle Conservation Fund and the Madagascar Biodiversity Partnership, 250 two-finger puppets, along with 10 hand puppets, were transformed by CF paints and inspiration from North American desert tortoises into Malagasy radiated tortoises (Fig. 4). More than 60 "tambourine tortoises" were colored and assembled by Malagasy youth to celebrate tortoise conservation through song at Kotroky-O-Rama. High school students from Omaha and former Korean refugees painted the plates yellow at the University of Nebraska for a Service Project prior to their journey to Madagascar, thus creating a global link.

Implemented initially in 2009 by CF in Kianjavato, "Conservation Camp", a field-based adventure for teachers and students (Fig. 5), allowed them to connect with flora and fauna endemic to their region. More than 35 youth from Itampolo joined MBP researchers and CF staff in the spiny forests to learn more about the endangered biodiversity in their own backyard. Children utilized tools such as magnifying glasses and binoculars as they learned how scientists and Malagasy students collect data about the tortoises and their environment. Students were given the task of performing a transect to count the number of tortoises they saw in a given section of forest. GPS coordinates collected by the MBP helped identify an area abundant with tortoises. The students and teachers also learned about the important conservation work the MBP has been conducting in the region since 2007. Students learned how to calculate the age of Radiated Tortoises by counting the rings on the scutes. Local children attending camp did not touch the tortoises because of the taboo; however, they were committed to protecting them from poachers.

Wildlife films can help promote positive conservation behavior. "Movie nights" serve as a popular way to disseminate conservation messages to large groups of people (Fig. 6). These pictorial presentations of the children and community members engaging in the previous conservation outreach and education initiatives portray them as local conservation "heroes" and highlight the benefits of conservation to both humans and wildlife. Community members were in awe of the photos of both themselves and the local biodiversity shown, and requested more presentations to learn more about the importance of local flora and fauna, especially in the Lavavolo region.

Conservation must include the local people and their basic needs. CF held multiple training workshops with the entire village of Lavavolo to educate them about clean water and sanitation. Often these challenges underpin conservation initiatives and must be addressed to improve the lives of the Malagasy people at the local level. Workshops were attended by approximately 200 local men, women, and children. Activities included lessons about the water cycle, the spread of germs and diseases, hand washing, cleanliness, and improved sanitation practices.

#### DISCUSSION

Our novel programs support a respect and appreciation for Radiated Tortoises while developing long-term relationships on a local level, resulting in behavioral changes to benefit both the community and wildlife, through a variety of educational and outreach activities. When these efforts are implemented concurrently with long-term research programs, relationships are established which empower local community members and government officials to build and strengthen conservation objectives.

The RTP, MBP, and CF have made important advances in establishing long-term connections with local teachers, children, community members, and government officials to support conservation. Meetings facilitated by the MBP amongst neighboring villages initiated an opportunity to mitigate conflicts over land use prior to spiny forest restoration. For example, MBP rebuilt the fence in Itampolo and then subsequently built a new nursery in Lavavolo community. When users are genuinely engaged in decisions regarding rules affecting their use, the likelihood of them following the rules and monitoring others is much greater than when an authority simply imposes rules (Ostrom 2006). The dialogue between the regional communities helps evaluate the current situation and how the land and environment are viewed by local communities and village leaders, in addition to government officials. Moreover, these discussions offer a means of including local people in future decisions as to what actions will be taken to address

specific conservation challenges, such as illicit trade, consumption, and habitat loss.

Over 60% of all teachers in Madagascar receive no formal training. By investing in teachers, we can reach far greater numbers of students with environmental messages. The field trip transporting Kianjavato teachers to Lavavolo presented numerous advantages. By experiencing new and different ecosystems in Madagascar, teachers from Kianjavato developed a greater appreciation for the unique biodiversity of their region, in addition to creating an opportunity to practice skills, knowledge, and new teaching methods acquired in the previous teacher workshops, by sharing best practices with the educators from Lavavolo. Moreover, the success of this program can be used as a foundation for regional programs to incorporate biodiversity and conservation education into the school curriculum. The Teacher Network provides the framework for instant relationships and empowers local Malagasy teachers as leaders as new ideas are exchanged and establishes best practices through simple education messages. Efforts to mitigate negative impacts of deforestation are often hampered by limited communications.

The Teacher Network establishes strong lines of communications and bridges the gap to improve the likelihood of positive outcomes. In this capacity, the local people become the experts through a learning process that displays a genuine understanding of the importance of education lessons and how it affects their lives. The festival is empowering local ideas and providing insight into future conservation initiatives to be run by local people. Festivals engage and include entire communities in education to reach a far greater audience. This helps to reinforce conservation messages children receive at school, and establishes trust with parents to strengthen the relationship between NGO's and the local community. The multiple training workshops and education programs by MBP and CF follow a view that successful conservation education initiatives must be consistently reinforced.

Providing Hippo Water Rollers to local community members in Madagascar is a life-changing solution to the lack of water available in specific regions, while allowing women and children an opportunity to free up time spent collecting water. Additionally, branding along with multifaceted education programs to accompany the Hippo roller will help to reinforce conservation messages and act as a daily reminder of the benefits of conservation. By joining Hippo Water Rollers to local garden initiatives, communities can improve nutrition, offer alternative food sources, and limit habitat loss to cassava production. Furthermore, by educating local people about clean water and sanitation, they are more likely to make informed decisions and actively make behavioral changes to improve their livelihood.

The Lavavolo reforestation project has numerous objectives: 1) to restore native forest trees of value to local people while expanding habitat for *A. radiata*, and to ultimately design a strategy for future sustainable harvest

and use of these trees, 2) utilize the scientific method to research the process of reforestation, and 3) to educate children and adults on the benefits of and the science behind native tree reforestation.

Current school curriculum is often based upon domestic animals such as chickens, pigs, and zebu. Furthermore, few Malagasy children realize how unique their regional biodiversity is in relationship to the rest of the world, or do not often get to see it firsthand.

The current decline of the Radiated Tortoise will not be stemmed unless conservation and wildlife agencies increase leadership and expand upon conservation education initiatives, maximizing the number of individuals engaging in programs such as those initiated by CF. Successful implementation of conservation projects affecting local communities is effective on a long-term basis only when there is collaboration and consent from local people. It is important to communicate simply the link between animals, people, and natural resources. If communities understand the "why" behind their actions, they are more likely to follow through long term.

Outreach workshops should also emphasize the effects of deforestation that directly affect people's daily lives, such as reduced water, drought, erosion, and poor crop production. Furthermore, studies confirm when local people realize the benefits forest resources provide, such as food, shelter, medicine, clean air, and water, they are motivated to change behaviors to conserve it. Additionally, community-based research often provides the foundation for building a longterm relationship with local communities.

Conservation camps have proven to be an effective tool. CF will continue this with a junior researcher program, "kely matansika", which means small but strong. Providing an opportunity to participate hands-on in field research and data collection allows children to connect with flora and fauna endemic to their region. This knowledge of the unique biodiversity instills compassion and ultimately, action to protect and preserve these important species. The children will observe how conservation provides income and opportunities to local Malagasy researchers. Exploring the natural world up-close is one of the most effective ways to create an understanding of the environment, so conservation camps can reinforce local customs and taboos.

Supporting communities in their efforts to achieve more sustainable lifestyles is not only possible, but extremely important in bringing change for themselves and achieving global environmental benefits to critically endangered species such as the Radiated Tortoise.

Acknowledgments. — We would like to acknowledge the Ministère de l'Environnement des Eaux et Forêts of Madagascar and officials and citizens of the commune of Itampolo for their support and participation in this project. This project would not have been possible without the support of the staff of Omaha's Henry Doorly Zoo's Madagascar Biodiversity Biogeography Project (MBP-HDZ) and the staff, guides, and drivers of Madagascar Biodiversity Partnership, ONG. Financial support was provided by Zoos and Aquariums Committed to Conservation (ZACC) and the Margot Marsh Biodiversity Foundation. Educational materials were the result of countless volunteer hours through our partnership with the University of Nebraska's Student Community Leadership and Service Department. We would also like to acknowledge the Turtle Survival Alliance, Turtle Conservation Fund, and the Radiated Tortoise Species Survival Plan Fund for their enthusiastic and financial support for seeing this project through to completion. Finally, we appreciate the reviewers' constructive criticism, comments, and suggestions.

## Résumé

La Tortue Radiée, Astrochelys radiata, était autrefois abondante dans la partie sud de Madagascar. Toutefois, son aire initiale de distribution a diminué de plus de 40% au cours de la dernière décennie. Ce déclin rapide est la conséquence d'une perte d'habitat, du braconnage pour la consommation locale et pour les ventes illicites sur le marché international, ainsi que de la perte des tabous et croyances locaux qui protégeaient auparavant ces créatures endémiques. Une des dernières forteresses connues pour les populations de Tortues Radiées est la Forêt Classée de Lavavolo située dans la région de Toliara dans le sud-ouest de Madagascar. La communauté de Lavavolo est majoritairement (99.5%) composée de pêcheurs et de petits cultivateurs, dépendant de l'environnement qui les entoure pour survivre. Cette région est sèche et xérique, donc manquant de ressources, d'eau potable, et l'éducation de base est absente. Puisque les hommes constituent indéniablement la plus grande menace pour ces populations de tortues, ils doivent faire partie intégrante de la solution. Nous présentons ici la mise en œuvre réussie de sensibilisation et d'éducation à base communautaire impliquant des Malgaches locaux comme parties prenantes dans la conservation des tortues. En effet, humains et animaux coexistent tous deux et s'épanouissent grâce aux initiatives de conservation.

#### LITERATURE CITED

- BRUCE, N., NEUFELD, L., BOY, E., AND WEST, C. 1998. Indoor biofuel air pollution and respiratory health: the role of confounding factors among women in highland Guatemala. International Journal of Epidemiology 27:454–458.
- BRYDEN, M., STILL, D., SCOTT, P., HOFFA, G., OGLE, D., BAILIS, R., AND GOYER, K. 2005. Design principles for wood burning cook stoves. Aprovecho Research Center, Cottage Grove, OR.
- DU PUY, D. J. AND MOAT, J. 2003. Using geological substrate to identify and map primary vegetation types in Madagascar and the implications for planning biodiversity conservation. In: Goodman, S.M. and Benstead, J.P. (Eds.). The Natural History of Madagascar. Chicago: University of Chicago Press, pp. 51–74.
- DOLINS, F.L., JOLLY, A., RASAMIMANANA, H., RATSIMBAZAFY, J., FEISTNER, A.T., AND RAVOAVY, F. 2009. Conservation education in Madagascar: three case studies in the biologically diverse island continent. American Journal of Primatology 71:1–16.
- DURRELL, L., GROOMBRIDGE, B., TONGE, S., AND BLOXAM, Q. 1989. Pyxis arachnoides: Madagascar spider tortoise; Tsakafy, Kapila. In: Swing-

land, I.R. and Klemens, M.K. (Eds.). The Conservation Biology of Tortoises. Gland, Switzerland: IUCN Publications, pp. 96–98.

- HARPER, G.J., STEININGER, M.C., TUCKER, C.J., JUHN, D., AND HAWKINS, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34:325–333.
- IUCN. 2011. IUCN Red List of Threatened Species. Version 2011.1. www.iucnredlist.org Downloaded on 15 September 2011.
- KAUFMANN, J.C. 2001. La question des raketa: colonial struggles in Madagascar with prickly pear cactus, 1900-1923. Ethnohistory 48½:87–121.
- KAUFMANN, J.C. 2004. Prickly pear cactus and pastoralism in Southwest Madagascar. Ethnology 43:345–361.
- LEUTERITZ, T.E.J. 2003. Observations on the diet and drinking behaviour of radiated tortoises (*Geochelone radiata*) in southwest Madagascar. African Journal of Herpetology 52:127–130.
- LEUTERITZ, T.E.J., LAMB, T., AND LIMBERAZA, J.C. 2005. Distribution, status and conservation of radiated tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124:451–461.
- NUSSBAUM, R.A. AND RAXWORTHY, C.J. 1998. Revision of the genus *Ebenavia* Boettger (Reptilia: Squamata: Gekkonidae). Herpetologica 54:18–34.

- O'BRIEN, S., EMAHALALA, E.R., BEARD, V., RAKOTONDRAINY, R.M., RIED, A., RAHARISOA, V., AND COULSON, T. 2003. Decline of the Madagascar radiated tortoise (*Geochelone radiata*) due to overexploitation. Oryx 37:338–343.
- RAFELIARISOA, T.H. 2009. Preliminary results of community based monitoring of the radiated tortoise at Lavavolo Classified Forest, Madagascar. Turtle Survival Alliance 2009:76–77.
- RAFELIARISOA, T.H., WALKER, R.C.J., AND LOUIS, E.E., JR. 2013. Decline in the range and density of Radiated Tortoises, *Astrochelys radiata*, in southern Madagascar. Chelonian Research Monographs No. 6, pp. 83–89.
- RIOUX-PAQUETTE, S., FERGUSON, B.H., LAPOINTE, F.-J., AND LOUIS, E.E., JR. 2009. Conservation genetics of the radiated tortoise (*Astrochelys radiata*) population from Andohahela National Park, Southeast Madagascar, with a discussion on the conservation of this declining species. Chelonian Conservation and Biology 8:84–93.
- RIOUX-PAQUETTE, S., LOUIS, E.E., JR., AND LAPOINTE, F.-J. 2010. Microsatellite analyses provide the first evidence of sex-biased dispersal in tortoises (Chelonia: Testudinidae). Journal of Heredity, doi:10.1093/JHered/es020.

## Sexual Dimorphism in Radiated Tortoises (Astrochelys radiata)

## THOMAS E.J. LEUTERITZ<sup>1,2</sup> AND DONALD T. GANTZ<sup>3</sup>

<sup>1</sup>Department of Biology, George Mason University, Fairfax, Virginia 22030 USA; <sup>2</sup>Present Address: U.S. Fish and Wildlife Service, Division of Scientific Authority, 4401 N Fairfax Dr., Arlington, Virginia 22203 USA [thomas\_leuteritz@fws.gov]; <sup>3</sup>Department of Applied Information Technology, George Mason University, Fairfax, Virginia 22030 USA [dgantz@gmu.edu]

Abstract. - Turtles exhibit a wide variety of size differences between the sexes. In addition to body size, a suite of other divergent characters exist that have often been used to determine the sex of turtles. The visual determination of sex in radiated tortoises can often be subjective and misleading, especially for tortoises around the size of sexual maturity or somewhat smaller. The purpose of this paper was to: 1) quantify and evaluate morphological characteristics that may be sexually dimorphic in the radiated tortoise, Astrochelys radiata; 2) develop a discriminant function that can accurately identify the sex of individual A. radiata based on these characteristics; and, 3) provide this function as a tool to help sex juvenile tortoises in captive breeding conservation programs. Two linear discriminant function equations were developed using morphological variables as raw or size corrected (ratio) values based on known-sex animals and comparing them to other tortoises in a population at Cap Sainte Marie (CSM), Madagascar. Although both equations are equal at classifying males, the raw + ratio variables equation did a better job of predicting females in the test data set from the CSM population. Incorporating data based on known-sex juveniles would be the next step in developing a more comprehensive discriminant function. Male radiated tortoises were found to be the same size, or slightly larger than females. The data fit Berry and Shine's mating system model, in which male combat or forcible insemination is used to explain why males are as large, or larger than females. Although male-male combat did occur at CSM, its frequency was low. It is unlikely that a significantly smaller male radiated tortoise could successfully copulate with a larger female because of the physical strength needed to restrain her and their sheer size disparity. Forced insemination is therefore a plausible explanation for equal or larger size in male radiated tortoises.

## KEY WORDS. – Reptilia, Testudines, Testudinidae, body size, morphological characteristics, discriminant function analysis, *Astrochelys radiata*, Madagascar, forced insemination

A difference in mean body size between males and females occurs in many species (e.g., seals, walrus, moose, accipiter hawks, turkeys, turtles, and iguanas). The development of external (e.g., elongate tail, bright colors, elongate claws, weapons, etc.), or internal (e.g., biochemical and brain structure) characters between the sexes is also common (Bonnet et al. 2001; Harvey and Bradbury 1991). These differences in size and special characters are referred to as sexual size dimorphisms (SSD) (Harvey and Bradbury 1991). Two major theories have been put forth to explain SSD. One theory is based on sexual selection, which was originally proposed by Darwin (1871). This states that sexual selection can result from either intra- or intersexual selection. In intrasexual selection, selection acts on traits that give an advantage to the possessor in competition among members of the same sex. In intersexual selection, selection acts on traits that make the possessor more likely to be chosen by the opposite sex (e.g., female choice and the Zahavi handicap model) (Berry and Shine 1980; Gibbons and Lovich 1990; Harvey and Bradbury 1991; Lovich and Gibbons 1992). The second theory to explain SSD is that it is derived through natural selection (Darwin 1859). Differences in size can be attributed to differential interactions of each sex with its environment as the result of natural selection, or ecological forces alone (e.g., competitive displacement) (Slatkin 1984; Lovich and Gibbons 1992).

Turtles exhibit a wide variety of size differences between the sexes (Berry and Shine 1980). For example, male Graptemys spp. and Malaclemys terrapin, North American aquatic species, are significantly smaller than the females (Ernst and Barbour 1989; Ernst and Lovich 2009). The same is true of Psammobates tortoises in Africa; however, in other African tortoises such as Geochelone sulcata and Chersina angulata, males are significantly larger than females (Lambert 1993; Boycott and Bourquin 2000). Berry and Shine (1980) suggested that female optimal body size may depend primarily on the number of eggs she lays, and secondarily on the degree of nest predation occurring. These factors may be similar between females of closely related species, but are of course different than the factors affecting male body size. This suggests that the mating system of males is responsible for the variability in direction and degree of interspecific SSD. Although the selective advantage of small versus large male body size is not fully understood, Berry



Figure 1. Male (left) and female (right) Radiated Tortoises (*Astrochelys radiata*) showing sexual dimorphism in the posterior opening of the plastron and carapace. Note the plastral concavity of the male visible at the abdominal and femoral scutes. Photo by Thomas E.J. Leuteritz.

and Shine (1980) showed that in species with male combat, or forcible insemination, males are often as large, or larger, than females. The larger the male the stronger he may be and presumably the better his ability to fight with rival males, or to overpower females during mating. Conversely, in species with female choice, males are usually smaller. Males of this type often exhibit elaborate precoital behavior (*liebespiel*) and have pronounced nuptial structures (e.g., elongate foreclaws). Small size increases mobility (i.e., males may be able to move greater distances), which may aid in the ability to search for females and thus be an adaptation for dispersal (Berry and Shine 1980; Bonnet et al. 2010). Phylogenetic analysis by Gosnell et al. (2009) of SSD indices indicated that the basal state of SSD in turtles is female-biased (i.e., body size of females > males).

In addition to body size, a suite of other divergent characters exist that have often been used to determine the sex of turtles, including shell morphology, claw length, eye color, tail size, and distance of cloacal vent to posterior body margin (Gibbons and Lovich 1990; Bonnet et al. 2010). The presence of a plastral concavity located at the abdominal and femoral scutes is indicative of males in many species (Carr 1952; Ernst and Barbour 1989; Ernst and Lovich 2009). Plastral concavity facilitates the mounting of females for terrestrial copulation and is most pronounced in terrestrial domed-shelled genera such as *Geochelone*, *Gopherus*, and *Terrapene*. Males in some tortoise species have an elongate gular scute, none so pronounced as the Madagascar Ploughshare Tortoise (*Astrochelys yniphora*), which is used in combat and courtship rituals (Juvik et al. 1981; Pedrono 2008).

The dimensions of the posterior opening of the plastron and carapace (i.e., anal width and anal notch) vary between the sexes (Lambert 1993; Smith 1999; Bonnet et al. 2001). Males of *Gopherus polyphemus* have a wider anal width, presumably for the positioning of the penis during copulation (McRae et al. 1981). As an adaptation for copulation many male turtles also have longer, thicker tails with the cloacal vent located more distally as compared to females (Carr 1952; Ernst and Barbour 1989). A larger posterior opening in males also allows for better mobility (i.e., less weight and more room to move limbs) to search for mates and increased stability during combat (Bonnet et al. 2001, 2010). A larger anal notch in female *G. polyphemus* has been attributed to aiding in breeding and allowing for the passage of large eggs (McRae et al. 1981; Smith 1999).

The purpose of this paper is to: 1) quantify and evaluate morphological characteristics that may be sexually dimorphic in the radiated tortoise, *Astrochelys radiata*; 2) develop a discriminant function (McRae et al. 1981; Burke et al. 1994) that can accurately identify the sex of individual *A. radiata* based on these characteristics; and 3) provide this function as a tool to help sex juvenile tortoises in captive breeding conservation programs. This should help to reduce misidentification of males and females, especially those approaching sexual maturity.

## **METHODS**

We used 69 known-sex adult Radiated Tortoises, *A. radiata* (37 females and 32 males), to model sexual dimorphism. Sex of the females was determined by the presence of eggs, which was determined either by x-ray, or direct nesting observations; sex of the males was determined by the observation of an extruded penis. These animals were a subset of the 1438 tortoises from which data were gathered at the Cap Sainte Marie Special Reserve (CSM), Madagascar, and


**Figure 2.** Measurements of shell dimensions used to quantify sexual dimorphism of Radiated Tortoises (*Astrochelys radiata*). Carapace length (CL), plastron length (PL), width (WDTH), height (HT), domed carapace length (DCL), gular length (GUL), anal notch length (CPGAP), and anal fork width (ASTT).

includes all animals for which sex could be confirmed using these methods. Out of these 1438 tortoises, we established a test data subset of 317 tortoises (154 females and 163 males) whose sex could be identified with fairly high certainty using visual external secondary sexual characteristics in the field at CSM (Fig. 1).

Straight-line carapace length (CL), plastron length (PL), carapace width (WDTH), shell height (HT), anal fork width (ASTT), anal notch/posterior opening between carapace and plastron (CPGAP), gular scute length (GUL), domed carapace length (DCL), anal scute length (ASL), anal scute width (ASWDTH), weight (WT), and annuli count (Fig. 2) measurements were recorded using a 50 cm Haglof Mantax aluminum caliper, a 150 mm metric hand caliper, a 100 cm flexible tape measure, and a Pesola spring scale. Several of these variables were corrected for body-size by dividing them by volume (VOL =  $CL \times WDTH \times HT$ ), or by CL. These size-corrected variables included ASTT/CPGAP, ASTT/VOL, CPGAP/VOL, DCL/VOL, GULL/VOL, PL/ CL, PL/VOL, WDTH/CL, WDTH/HT, ASL/ASWDTH, and (ASL x ASWDTH)/VOL. The plastral concavity in males was not used as a character in this study because we wanted to use as many characters as possible with the aim of including juvenile tortoises (i.e., characters visible prior to maturity).

SAS Linear Discriminant Analysis procedures were used to statistically analyze the morphological data (SAS Institute 1994). All variables (raw and size-corrected) from the data set were entered into the SAS Stepdisc Procedure with an entry and a removal significance level of 0.20 and 0.15, respectively. The Stepdisc Procedure performs a stepwise linear discriminant analysis through forward selection and backward elimination, or stepwise selection to find a subset of quantitative variables that best indicate interclass differences, which in this case is between males and females (SAS Institute 1994). Once the subset of quantitative variables was found, the SAS Discrim Procedure with cross-validation was used to determine which model would best classify all males and females in the known-sex data set. The final step of the analysis was to run the variables through a SAS Candisc Procedure. The Candisc Procedure performs a canonical analysis to find linear combinations of quantitative variables that best summarize the difference between the sexes (SAS Institute 1994). The entire procedure was repeated a second time using only raw values (no ratios).

## RESULTS

Following the steps described above, the four variables ASTT, ASTT/CPGAP, WDTH/HT, and PL/CL were found to best quantify sexual dimorphism in *A. radiata* at CSM. To illustrate this point using the 69 known-sex observations, ASTT is plotted against CPGAP to show the high degree of separation of this character between the sexes (Fig. 3). The vertical reference line in Fig. 3 passes through CPGAP = 3.6 cm. Only two females have a CPGAP measurement less than 3.6 cm. In Figs. 4 and 5 we refer to the test data subset of tortoises (n = 317) whose sex could be identified





Figure 3. Anal fork width (ASTT) and anal notch length (CPGAP) plotted against each other for known-sex adults (n = 69) used to construct the model.

8 A S T T 7 6 ( 5 ١ з 2 1 Ĥ 2 з 5 6 CPGAP (cm)

Test Data Set: 317 obs

Plot of ASTT v. CPGAP vmbol is Identified Sex

Sex = Identified Sex

Symbol Predicted

**Figure 4.** Subset of the test data (n = 317) where the sex predicted by the model agrees with the sex that was determined through observations of secondary sexual characteristics in the field.

using secondary sexual characteristics in the field. In Fig. 4, ASTT is plotted against CPGAP for those observations (107 females and 154 males) in the Test Data Set whose identified sex matches the predicted sex from the model generated through the Discrim Procedure. The plot in Fig. 4 extrapolates the modeled relationship for females beyond the CPGAP range of females observed in the known-sex data used for modeling. However, Fig. 4 illustrates that a large number of identified females in the Test Data Set do



**Figure 5**. Subset of the test data (n = 317) where the sex predicted by the model does not agree with the sex that was determined through observations of secondary sexual characteristics in the field.

follow the extrapolated model. In Fig. 5, ASTT is plotted against CPGAP for those observations (47 females and 9 males) in the Test Data Set whose identified sex does not match the predicted sex from the model generated through the Discrim Procedure. A total of 45 of the 47 females in Fig. 5 have CPGAP measurements less than 3.6 cm; these 45 females are outside of the range of females observed in the known-sex data used for modeling and are predicted to be males by the model.

**Table 1.** Percent of known-sex male and female Radiated Tortoises (*Astrochelys radiata*) classified correctly when removing variables from the known-sex model discriminant functions (n = 69); (**a**) Raw Variables (*Equation 2*) and (**b**) Raw + Ratio Variables (*Equation 1*).

(a) Raw Variables [Y = 2.1529988 + (1.224483100 x ASTT) - (0.743065049 x HT) - (0.963243602 x CPGAP) + (0.389531641 x PL) - (0.753023230 x ASL)] [*Equation 2*])

Number Variabl	of Variables Removed	Females	Males	
5	None	97.4% (37/38)	96.8% (30/31)	
4	ASL	97.4% (37/38)	96.8% (30/31)	
3	ASL,PL	97.4% (37/38)	100% (31/31)	
2	ASL,PL,CPGAP	97.4% (37/38)	94.6% (29/31)	
1	ASL,PL,CPGAP, HT	94.7% (36/38)	74.2% (23/31)	

(b) Raw + Ratio Variables [Y = -23.85200875 + (0.41025401 x ASTT) + (2.49780705 x ASTT/CPGAP) + (5.98881903 x WDTH/HT) + (10.14986962 x PL/CL)] [*Equation 1*])

	Number of Variables	Variables Removed	Females	Males
-	4	None	97.4% (37/38)	96.8% (30/31)
	3	PL/CL	100.0% (38/38)	96.8% (30/31)
	2	PL/CL,WDTH/HT	97.4% (37/38)	93.6% (29/31)
	1	PL/CL,WDTH/HT, ASTT/CPGAP	94.8% (36/38)	74.2% (23/31)

12

11

10

9



**Figure 6.** Relationship between weight (gm) and CL (cm) showing sexual size dimorphism in adult Radiated Tortoises (*Astrochelys radiata*) from Cap Sainte Marie, Madagascar. Three graphs show: (a) test data subset (n = 317), (b) known-sex tortoises (n = 69), and (c) unknown/uncertain and juvenile tortoises.

The linear discriminant function Y = -23.85200875+ (0.41025401x ASTT) + (2.49780705x ASTT/CPGAP) + (5.98881903x WDTH/HT) + (10.14986962x PL/CL) [Equation 1] correctly classified 97.4% of the females and 96.8% of the males in the known-sex data set used for modeling, with only one misclassified female and one misclassified male (Table 1b). A positive value of Y predicts a male and a negative value predicts a female radiated tortoise. A regression analysis of numerator and denominator of the three ratios using the 69 known-sex observations showed a significant relationship between the variables (slope = -0.616, 0.649, 0.789;  $R^2 = 0.102$ , 0.746, 0.880; P < 0.05 respectively). A second linear discriminant function containing only raw variables (no ratios) was also developed. The five variables ASTT, HT, CPGAP, PL, and ASL were found to best quantify sexual dimorphism. The linear discriminant function Y = 2.1529988+ (1.224483100 x ASTT) - (0.743065049

x HT) -  $(0.963243602 \times CPGAP) + (0.389531641 \times PL) - (0.753023230 \times ASL)$  [*Equation 2*] correctly classified 97.4% of the females and 96.8% of the males in the known-sex data set used for modeling with only one misclassified female and one misclassified male (Table 1a). Again, a positive value of Y predicts a male and a negative value predicts a female radiated tortoise.

In the known-sex data set, male radiated tortoises had sexually dimorphic characteristics such as a well-defined plastral concavity, a broader thicker anal scute, and a smaller posterior opening between the plastron and the carapace. Female tortoises ranged in CL from 28–35.6 cm (mean = 31.9 cm) and weighed from 4.3–8.4 kg (mean = 6.3 kg). Male tortoises ranged in CL from 25.8–37.7 cm (mean = 31.2 cm) and weighed from 2.5–8.8 kg (mean = 5.2 kg). There was no significant difference in body size (CL) between males and females (t = 1.19, df = 48, P > 0.05) (Fig. 6b).

Based on all 1438 tortoises at CSM, males generally first exhibit distinct secondary sexual characteristics at a CL of 26 cm (mean = 16 annuli) or greater. The smallest male observed mating had a CL of 29.6 cm (20 annuli). Based on known females (nesting or radiography, n = 39), the smallest sexually mature female had a CL of 28 cm (annuli worn) (Fig. 6abc).

The linear discriminant function models developed from the known-sex tortoises were applied, using the SAS Discrim Procedure, to a test data set composed of 317 adult radiated tortoises (154 females, 163 males) at CSM, whose sex had been identified based on visual observation of secondary sexual characteristics. The raw and ratio variable linear discriminant function model [*Equation 1*] correctly matched 94.5% of the males and 69.5% of the females in the test set. When all tortoises under 26 cm CL (those under the size of sexual maturity) (40 females, 6 males) where excluded from the Test Data Set, the model was able to correctly match 95.5% of the males and 77.2% of the females in the test set (Table 2).

#### DISCUSSION

The visual determination of sex in Radiated Tortoises can often be subjective and misleading, especially for tortoises around the size of sexual maturity (i.e., 25-27 cm CL), or somewhat smaller (Fig. 6c). The lack or absence of secondary sexual characteristics, in particular plastral concavity and size differences, often determines the sex of the female. However, juvenile males, or males about to mature, also lack these characteristics and are therefore easily misclassified as female. The difference in sexing techniques between known-sex male and female tortoises leads to a larger size bias for females because the verification of male tortoises was the extrusion of the penis, smaller tortoises (not sexually mature) can still be identified as males, since the penis is present prior to sexual maturity. However, the female characteristic for verification of sex was the presence of eggs, which excluded immature females **Table 2.** A comparison of two discriminant functions for adult tortoises (*Astrochelys radiata*) using raw variables only and raw + ratio variables. The discriminant function was developed based on known-sex tortoises (model, n = 69). The function was then applied to 2 test data sets (n = 317, n = 271) in which tortoises were sexed on secondary sexual characteristics only. Y = -23.85200875 + (0.41025401x ASTT) + (2.49780705x ASTT/CPGAP) + (5.98881903x WDTH/HT) + (10.14986962xPL/CL)[*Equation 1*]; <math>Y = 2.1529988 + (1.224483100 x ASTT) - (0.743065049 x HT) - (0.963243602 x CPGAP) + (0.389531641 x PL) - (0.753023230 x ASL)) [*Equation 2*].

	Raw V (Equ	Variables ation 2)	Raw and Ratio Variables (Equation 1)		
	Model	Test	Model	Test	
Correctly Classifies Males – Total Adults	96.8% (30/31)	94.5% (154/163)	96.8% (31/32)	94.5% (154/163)	
Correctly Classifies Females – Total Adults	97.4% (37/38)	50.7% (78/154)	97.4% (37/38)	69.5% (107/154)	
Correctly Classifies Males – $CL \ge 26$ cm		94.9% (149/157)	—	95.5% (150/157)	
Correctly Classifies Females – $CL \ge 26$ cm		60.5% (69/114)	—	77.2% (88/114)	

who had not yet reached sexual maturity and who had a smaller body size.

If we assume the model is correct in its classification of sex, then the model applied to the test data indicates that there is observer misclassification of younger tortoises taking place, especially the misidentification of young males as females as noted relative to Fig. 5. This risk was the purpose for developing a linear discriminant function. Unfortunately, the best way to truly verify if the model has made correct predictions is by returning to Madagascar and positively identifying the sex of these questionable younger individuals. A more feasible alternative is to examine captive tortoises in the USA. The model could be applied to these individuals to learn how well it matches.

The use of ratios in statistical analysis is common-place in the biological literature (McRae et al. 1981; Burke et al. 1994; Mushinsky et al. 1994; Baard 1995; Sokal and Rohlf 1995; Ernst et al. 1998; Bonnet et al. 2001), however, this use has been challenged (Kronmal 1993; Allison et al. 1995; Goran et al. 1995; Poehlman and Toth 1995) based on a lack of data normalization that can exist for some ratios (i.e., there is not necessarily a relationship between the denominator and the numerator). It may be best to avoid ratios in regression analysis altogether (Kronmal 1993). For this reason a second linear discriminant function [Equation 2] based only on raw variables was developed for the known-sex tortoises (n = 69). However, when this model was applied to the test data set it correctly matched 94.5% of the males, but only 50.7% of the females. Again when all tortoises less than 26 cm CL were excluded from the Test Data Set, the model was able to correctly match 94.9% of the males and 60.5% of the females in the test set (Table 2). Although both Equations are equal at classifying males, Equation 1 (raw + ratio variables) did a better job of predicting females in the test data set (Table 2). The only true way to determine the linear discriminant function that is better at discerning males and females is to apply them both to known-sex tortoises.

Why use four or five variables in the discriminant functions? Table 1 shows the percent of known-sex male and female tortoises correctly classified when removing variables from the two linear discriminant functions. The percentage correctly classified decreases slightly as one removes variables from the equations, but is this slight change important enough to warrant four or five variables in the equations? We believe it is, because 1) the original purpose of creating the linear discriminant functions was to remove the observer subjectivity in sexing tortoises, and 2) the analysis used cross-validation to optimize the modeling performance of the equation. Cross-validation classifies each observation in the data set using the linear discriminant function computed from each observation in the data set, not including the observation being classified (SAS Institute 1994). This helps to remove bias by limiting the ability of outlying data to skew the resulting linear discriminant function.

Incorporating data based on known-sex juveniles would be the next step in developing a more comprehensive discriminant function. Identification of sex in juveniles can be done by laparoscopy in order to examine gonads to determine sex without sacrificing the tortoises (Wood et al. 1983; Cree et al. 1991; and see Kuchling et al. in this volume). Again, juvenile Radiated Tortoises from a facility in the United States, or from captive populations in Madagascar, such as the Berenty Reserve, or the Ivoloina Zoo, could be used to obtain these data. Private breeders and zoological institutions raising juveniles could collect the same data for animals as young as possible and repeatedly as the tortoises grow to adulthood. This process would help to identify the ontogeny of these differences and may lead to a more definitive way to identify sex in juveniles.

Despite the fact that there was no significant difference in size (CL) between males and females in the known-sex animals, there was a distinct size difference at CSM as a whole (Fig. 6a), with mean male CL larger. Upon examining 317 adult tortoises (test data subset) based only on secondary sexual characteristics (i.e., sex not confirmed), males tended to be slightly larger than females. All tortoises over 34.5 cm CL were distinctly male. Mature tortoises between 28–34 cm CL, although highly variable in size between the sexes, had sufficiently developed secondary sexual characteristics to predict their sex with a high level of confidence (Fig. 6b).

If male Radiated Tortoises are considered to be the same size, or slightly larger than females, the data fit Berry and Shine's (1980) mating system model, in which male combat or forcible insemination is used to explain why males are as large, or larger than females. There were eight recorded incidences of male-male interaction between 1999 and 2000 at CSM. Seven of these involved behaviors very similar to those displayed during mating (i.e., sniffing, circling, biting, ramming, lifting, and mounting). True male combat was seen only on one occasion in February 2000, which lasted 12 minutes. It was similar to the other male-male/malefemale interactions, with the exception that there was head to head gular fork pushing, or ramming, and more severe, or intense, shell lifting. Although male-male combat did occur, its frequency seemed low. Given that the tortoise densities in general were quite high (Leuteritz et al. 2005), this could explain a reduction in combat behavior since females were not in limited supply.

Berry and Shine (1980) reported that forced insemination is questionable in the Testudinidae, but it is quite prevalent in the Kinosternidae and some Emydidae. Female Radiated Tortoises, in general, did not seem to be receptive to copulation. Males would often use vegetation to trap, or block, female escape and then pin them down for copulation. On only two occasions (6.5%; n = 31) slightly smaller males were observed mating with larger females (Leuteritz and Ravolanaivo 2005). It is unlikely that a significantly smaller male Radiated Tortoise could successfully copulate with a larger female because of the physical strength needed to restrain her and their sheer size disparity. Forced insemination is therefore a plausible explanation for equal or larger size in male Radiated Tortoises.

Acknowledgments. — We would like to thank Russell A. Mittermeier (Conservation International), Gerard Arnhold (FOCAL), Claudia Hamblin-Katnick and the Department of Biology, George Mason University, John L. Behler (Wildlife Conservation Society), and Anders G.J. Rhodin (Chelonian Research Foundation) for their financial support of this project. Thanks to Serge Rajaobelina (FANAMBY) for providing a research vehicle and a driver. The following committee of professors at George Mason University and Hofstra University were instrumental in reviewing proposals and offering feedback: Carl H. Ernst, Russell L. Burke, Lee M. Talbot, and Geoffrey F. Birchard. Many thanks to R. Ravolanaivo, TEJL's research assistant, for her countless hours of walking when the Range Rover was yet again not working or not there. We especially would like to thank Jean Claude Limberaza, Andry William, and Serge Randrianandrasana for their hard work and enthusiasm with this research ('nothing ventured nothing gained'). Much logistic and technical help was provided in Madagascar by Martin Nicoll (ANGAP), Mark

Fenn (WWF), Steven Lellelid (LWFDMD), Jean Gabriel Ratalata (Engineer), Brigitte Randrianaridera, the late Herman Petignat (Aboretumd'Antsokay), Maud Plancheneau and Philippe Chorier (AFVP), and Herilala Randriamahazo and Matthew Hatchwell (WCS). Special thanks to Russ Burke for providing comments on this manuscript.

### Résumé

Les tortues montrent une large variété de différences de taille entre les sexes. En plus de la taille du corps, une suite d'autres caractères divergents existe et a souvent été utilisée pour déterminer le sexe des tortues. La détermination visuelle du sexe chez les tortues radiées peut souvent être subjective et trompeuse, surtout pour les tortues proches de la taille de maturité sexuelle ou un peu plus petites. L'objectif de cet article a été de : 1) quantifier et évaluer les caractéristiques morphologiques qui peuvent être sexuellement dimorphiques chez la tortue radiée, Astrochelys radiata; 2) développer une fonction discriminante qui peut, avec précision, identifier le sexe d'individus A. radiata en se basant sur ces caractéristiques ; et 3) offrir cette fonction comme un outil pour déterminer le sexe des tortues juvéniles dans les programmes d'élevage en captivité pour la conservation. Deux équations linéaires de fonction de discrimination ont été développées en utilisant des variables morphologiques comme valeurs brutes ou ajustées (ratio) en se basant sur des animaux dont le sexe est déjà connu, et en les comparant ensuite avec d'autres tortues d'une population de Cap Sainte-Marie (CSM), Madagascar. Bien que les deux équations soient égales pour classer les mâles, l'équation variables brutes + ratio a mieux prédit les femelles dans la série de données test pour la population de CSM. L'incorporation de données basées sur des juvéniles de sexe connu devrait être l'étape suivante dans le développement d'une fonction de discrimination plus complète. Les mâles de tortues radiées apparaissent de même taille, ou légèrement plus grands que les femelles. Les données s'accordent avec le modèle du système d'accouplement de Berry et Shine dans lequel le combat du mâle ou l'insémination de force est utilisé pour expliquer pourquoi les mâles sont aussi, voire plus, larges que les femelles. Bien que des combats entre mâles aient eu lieu à CSM, leur fréquence était faible. Il est peu probable qu'une tortue radiée mâle de taille sensiblement plus petite puisse s'accoupler avec succès avec une femelle plus large à cause de la force physique nécessaire pour la maîtriser et de leur différence de taille pure et simple. Une insémination forcée s'avère alors être l'explication la plus plausible de la taille identique ou plus grande chez les tortues radiées mâles.

#### LITERATURE CITED

- ALLISON, D.B., PAULTRE, F., GORAN, M.I., POEHLMAN, E.T., AND HEYMS-FIELD, S.B. 1995. Statistical considerations regarding the use of ratios to adjust data. International Journal of Obesity 19:644–652.
- BAARD, E.H.W. 1995. Growth, age at maturity and sexual dimorphism in geometric tortoise, *Psammobates geometricus*. Herpetological Association of Africa 44:10–15.

BERRY, J.F. AND SHINE, R. 1980. Sexual size dimorphism and sexual selection in turtles (Order Testudines).Oecologia 44:185–191.

- BONNET, X., DELMAS, V., EL-MOUDEN, H., SLIMANI, T., STERIJOVSKI, B., AND KUCHLING, G. 2010. Is sexual body shape dimorphism consistent in aquatic and terrestrial chelonians? Zoology 113:213–220.
- BONNET, X., LAGARDE, F., HENEN, B.T., CORBIN, J., NAGY, K.A., NAUL-LEAU, G., BALHOUL, K., CHASTEL, O., LEGRAND, A., AND CAMBAG, R. 2001. Sexual dimorphism in steppe tortoises (*Testudo horsfieldii*): influence of the environment and sexual selection on body shape and mobility. Biological Journal of the Linnean Society 72:357–372.
- BOYCOTT, R.C. AND BOURQUIN, O. 2000. The Southern African Tortoise Book: AGuide to Southern African Tortoises, Turtles, and Terrapins. South Africa: Bourquin Publication, 228 pp.
- BURKE, R.L., JACOBSON, E.R, GRIFFITH, M.J., AND GUILLETTE, L.J. 1994. Non-invasive sex identification of juvenile gopher and desert tortoises (genus *Gopherus*). Amphibia-Reptilia 15:183–189.
- CARR, A. 1952. Handbook of Turtles: The Turtles of the United States, Canada, and Baja California. New York: Cornell University Press, 542 pp.
- CREE,A.,COCKREM,J.F.,BROWN,M.A.,WATSON,P.R.,GUILLETTE JR.,L.J., NEWMAN, D.G., AND CHAMBERS, G.K. 1991. Laparoscopy, radiography, and blood analyses as techniques for identifying the reproductive condition of female tuatara. Herpetologica 47:238–249.
- DARWIN, C. 1859. The Origin of Species by means of natural selection or the preservation of favored races in the struggle for life. New York: Random House, 386 pp.
- DARWIN, C. 1871. The Descent of Man and selection in relation to sex. New York: Random House, 1000 pp.
- ERNST, C.H. AND BARBOUR, R.W. 1989. Turtles of the World. Washington DC: Smithsonian Institution Press, 313 pp.
- ERNST, C.H. AND LOVICH, J.E. 2009. Turtles of the United States and Canada. Baltimore, Maryland: Johns Hopkins University Press, 827 pp.
- ERNST, C.H., WILGENBUSCH, J.C., BOUCHER, T.P., AND SEKSCIENSKI, S.W. 1998. Growth, allometry, and sexual dimorphism in the Florida box turtle, *Terrapene carolina bauri*. Journal of Herpetology 8:72–78.
- GIBBONS, J.W. AND LOVICH, J.E. 1990. Sexual dimorphism in turtles with emphasis on the slider turtle (*Trachemys scripta*). Herpetological Monographs 4:1–29.
- GORAN, M.I., ALLISON, D.B., AND POEHLMAN, E.T. 1995. Issues relating to normalization of body fat content in men and women. International Journal of Obesity 19:638–643.
- GOSNELL, J.S., RIVERA, G., AND BLOB, R.W. 2009. Aphylogenetic analysis of sexual size dimorphism in turtles. Herpetologica 65:70–81.
- HARVEY, P.H. AND BRADBURY, J.W. 1991. Sexual selection. In: Krebs, J.R. and Davies, N.B. (Eds.). Behavioural Ecology: An Evolutionary

Approach. London: Blackwell Science Publication, pp. 203–232. JUVIK, J.O., ANDRIANARIVO, A.J., AND BLANC, C.P. 1981. The ecology and

- status of *Geochelone yniphora*: a critically endangered tortoise in northwestern Madagascar. Biological Conservation 19:297–316. KRONMAL, R.A. 1993. Spurious correlation and the fallacy of the ratio
- standard revisited. Journal of the Royal Statistical Society: Series A 156:379–392.
- LAMBERT, M.R.K. 1993. On growth, sexual dimorphism, and the general ecology of the African spurred tortoise, *Geochelone sulcata*, in Mali. Chelonian Conservation and Biology 1:37–46.
- LEUTERITZ, T.E.J. AND RAVOLANAIVO, R. 2005. Reproductive ecology and egg production of the radiated tortoise (*Geochelone radiata*) in southern Madagascar. African Journal of Zoology 40:233–242.
- LEUTERITZ, T.E.J., LAMB, T., AND LIMBERAZA, J.C. 2005. Distribution, status, and conservation of radiated tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124:451–461.
- LOVICH, J.E. AND GIBBONS, J.W. 1992. A review of techniques for quantifying sexual size dimorphism. Growth, Development, and Aging 56:269–281.
- MCRAE, W.A., LANDERS, J.L., AND CLEVELAND, G.D. 1981. Sexual dimorphism in the gopher tortoise (*Gopherus polyphemus*). Herpetologica 37:46–52.
- MUSHINSKY, H.R., WILSON, D.S., AND MCCOY, E.D. 1994. Growth and sexual dimorphism of *Gopherus polyphemus* in central Florida. Herpetologica 50:119–128.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Borneo: Natural History Publications, 147 pp.
- POEHLMAN, E.T. AND TOTH, M.J. 1995. Mathematical ratios lead to spurious conclusions regarding age- and sex-related differences in resting metabolic rate. American Journal of Clininical Nutrition 61:482–485.
- SAS INSTITUTE. 1994. SAS User's Guide: Statistics. Statistical Analysis System Institute (Ed.). Carry, North Carolina, 360 pp.
- SLATKIN, M. 1984. Ecological causes of sexual dimorphism. Evolution 38:622–630.
- SMITH, L.L. 1999. The status and ecology of the angonoka tortoise (*Geochelone yniphora*) of western Madagascar. Ph.D. Thesis, University of Florida, Gainesville, USA..
- SOKAL, R.R. AND ROHLF, F.J. 1995. Biometry: The Principles and Practice of Statistics in Biological Research. New York: W.H. Freeman and Company, 887 pp.
- SYSTAT. 1992. SYSTAT: Statistics, Version 5.2 Edition. Evanston, IL: SYSTAT, Inc., 724 pp.
- WOOD, J.R., WOOD, F.E., CRITCHLEY, K.H., WILDT, D.E., AND BUSH, M. 1983. Laparoscopy of the green sea turtle, *Chelonia mydas*. British Journal of Herpetology 6:323–327.

# Endoscopic Imaging of Gonads, Sex Ratio, and Temperature-Dependent Sex Determination in Juvenile Captive-Bred Radiated Tortoises, *Astrochelys radiata*

GERALD KUCHLING<sup>1,2</sup>, ERIC V. GOODE<sup>3,4</sup>, AND PETER PRASCHAG<sup>4,5</sup>

 <sup>1</sup>Chelonia Enterprises, 28 Tokay Lane, The Vines, Western Australia 6069, Australia;
<sup>2</sup>School of Animal Biology, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6008, Australia [Gerald.Kuchling@uwa.edu.au];
<sup>3</sup>Turtle Conservancy, 49 Bleecker Street, Suite 601, New York, New York 10012 USA [eric@turtleconservancy.org];
<sup>4</sup>Behler Chelonian Center, Ojai, California 93024 USA;
<sup>5</sup>Present Address: Am Katzelbach 98, 8054 Graz, Austria [peter@praschag.at]

ABSTRACT. – Evaluation of offspring sex ratio is important in any large scale threatened species breeding program if temperature-dependent sex determination (TSD) is a possibility. We assessed the sex ratio of juvenile Radiated Tortoises, Astrochelys radiata, by direct observation of their gonads using an endoscope as part of the captive breeding program for this species at the Behler Chelonian Center (BCC). The gonads of small juvenile A. radiata are thin, elongate, and fixed to the dorsal part of the body cavity, with ovaries appearing as transparent sheaths with some oocytes visible and testes appearing as small, transparent, thin, sausage-like structures with a net of fine blood vessels on the surface. With growth, ovaries expand and masses of pre-vitellogenic follicles appear on the surface. Testes are transparent in small juveniles and, with growth, turn pinkish-white and then yellowish, with tubular structures visible through a thin, transparent theca containing a network of fine blood vessels, but no melanocytes. The breeding program produced a female-biased sex ratio with a male to female ratio of 1:8.4 (n = 75), suggesting that A. radiata exhibits TSD, with cooler incubation temperatures producing males and warmer incubation temperatures producing females. Unfortunately, incubation conditions were not monitored rigorously enough to allow a precise determination of the pivotal temperature, but a preliminary estimate is that the pivotal temperature of A. radiata is between 28.0 and 28.9°C and the upper limit of the transitional range of temperatures (i.e., above which only females are produced) is between 28.9 and 30.0°C.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, captive breeding, endoscopy, testis, ovary, sex ratio, temperature-dependent sex determination, *Astrochelys radiata*, Madagascar

The Radiated Tortoise, Astrochelys radiata, was once widespread and common in the spiny forest of southern and southwestern Madagascar. Today, it is gravely imperiled by human exploitation and habitat destruction (Pedrono 2008; Devaux 2010). Since this decline is ongoing, ex-situ assurance colonies and captive breeding operations have become increasingly important for the conservation of A. radiata; therefore, it is imperative that breeding programs use best practice management techniques. One area of concern is the production of skewed sex ratios, or potentially only one sex, for species that exhibit temperature-dependent sex determination (TSD). While offspring sex in most vertebrates depends on genotypic sex determination (GSD, i.e., sex is determined by maternal and paternal genes and/or sex chromosomes), temperature-dependent sex determination seems to be the most common form of sex determination in turtles, especially tortoises (family Testudinidae). As a general rule for TSD in turtles, lower incubation temperatures produce males and higher temperatures females (TSD Ia), although in some species very low temperatures can also produce females (TSD II) (Ewert et al. 2004). However, little information is currently available on the mode of sex determination in the critically endangered tortoises of Madagascar. Only a short note exists that describes the female-skewed sex ratio observed in the captive breeding project for *Astrochelys yniphora* at Ampijoroa (Kuchling and López 2000), which suggests that TSD does occur in this species.

Most tortoises have a prolonged juvenile phase and take many years or decades before they reach maturity and can be sexed externally. Traditionally TSD studies in turtles have sacrificed hatchlings to determine their sex (Ewert et al. 2004), which is prohibitive in studies regarding critically endangered species for which information on sex determination mechanisms is most urgently needed. Determining sex ratios in captive breeding projects using non-lethal sexing techniques for juveniles has become increasingly important. Endoscopy is currently the only 100% accurate non-lethal method available to sex juvenile turtles and tortoises that do not show external sexual dimorphism (Kuchling 1999, 2006; Kuchling and López 2000; Wibbels et al. 2000; Kuchling and Kitimasak 2009). This paper presents data on the endoscopic imaging of gonads and accessory ducts and on sex ratios in captive-bred juvenile A. radiata at the Behler Chelonian Center (BCC).

#### **METHODS**

Study Location and Breeding Group. - The BCC, which is administered by the Turtle Conservancy, is a captive breeding and management facility located in southern California, USA. The facility, certified by the Association of Zoos and Aquariums (AZA), houses some of the world's most critically endangered turtle and tortoise species. The A. radiata breeding program at the BCC is the largest and oldest of its kind in the United States. The program was initiated by the Wildlife Conservation Society (WCS) in the 1980s on St. Catherine's Island, Georgia, with individuals collected by Robert Baudy from Madagascar in the 1960s. When WCS discontinued their program in 2003, over 200 turtles and tortoises were transported from the island to the BCC campus. The group of A. radiata, which included founder animals belonging to the AZA Species Survival Plan program, continues to propagate at the BCC.

Maintenance of Breeding Stock. — The tortoises are maintained in two different breeding groups at the BCC, from which the captive-bred tortoises reported on in this study originated. The first group consists of older, wild caught specimens and is managed to meet the requirements of the SSP, with specific individuals paired to ensure healthy and genetically diverse progeny. The second group consists mainly of captive born specimens that hatched in the 1980s and are maintained in a herd. The tortoises in this group freely choose their mates. In both groups, males are separated from females for some period of time in order to maintain their interest in mating when paired again.

Tortoises have year-round access to both indoor and outdoor enclosures. They are fed a varied diet that includes natural graze cuttings, *Opuntia* cactus pads, dandelion, radicchio, endive, parsley, squash, zucchini, apples, and carrots. When outdoors, they are able to forage on natural vegetation, which includes Bermuda grass, flowering mallows, mulberry trees, *Opuntia* cacti, and autumn joy. They are also offered cuttlefish bone for calcium supplementation.

Egg Incubation. — Female A. radiata deposit eggs year-round. We do not have details of the incubation temperatures of eggs incubated on St. Catherine's Island prior to 2004. The eggs at the BCC used in this study were artificially incubated in modified wine coolers at the nominally constant temperature of 28.9°C up through 2007 and about  $30.0^{\circ}$ C from 2008 and on. Eggs are incubated in chunky vermiculite in a vermiculite:water ratio of 2:1 by weight. Hatchlings emerged in 90–120 days. Date of hatching was recorded for all juveniles, which were marked with small tags used for honey bees that were glued to their carapacial scutes.

*Maintenance of Hatchlings and Juveniles.* — Hatchlings are maintained on tables (0.9 x 1.8 m and 0.9 x 2.4 m) with 100 mm of substrate that consists of rice hulls, sand, and peat moss. The tables are planted with succulents, grasses, and other natural graze items, and a water dish is present at all times. The southern California climate allows for the tables to remain outdoors for about six to seven months (weather permitting), and in temperature and humidity controlled green houses for the rest of the year. Once the hatchlings reach an appropriate size of 100–130 mm they are transferred from the tables to larger enclosures and are fed a similar diet to that of the adults.

*Endoscopy.* — Sex was determined endoscopically in 75 juvenile A. radiata that had an average body mass of 322 g (range = 21-1333 g) during March 2010. The tortoises did not receive food for 24 to 48 hrs prior to being endoscoped. Tortoises were anesthetized by intravenous injection (carpal sinus) of ketamine hydrochloride (20-30 mg/kg body mass). Optimum anesthetic depth was achieved after about 15 minutes. Both hind legs were pulled backwards and fastened together. The left inguinal pocket and neighboring skin, shell, and leg were scrubbed with antiseptic soap and povidone-iodine. A 2.7 mm diameter rigid Storz Hopkins endoscope was inserted into the abdominal cavity through a small stab incision in the lower anterior part of the inguinal pocket. The abdominal cavity was not insufflated. A Storz cold-light fountain 482B was used as a light source. Gonads and accessory ducts were visualized, usually behind intestinal loops, and their appearance, color, and texture noted. A digital camera with macro function (Nikon Coolpix 995) was used for photo documentation. The eyepiece of the endoscope was custom-adapted to fit into the protective ring of the camera lens and photos were taken by holding the camera against the eyepiece. After completion of the endoscopy procedure the skin wound was sutured using two 4/0 vicryl stitches. The surgical procedures took between 2-10 min, depending on whether photos were taken or not. The tortoises recovered from anesthesia 1-2 hrs after the surgical procedure and were kept under observation for 24 hrs before being returned to their nursery enclosures.

### RESULTS

Appearance of Gonads and Accessory Ducts. — The gonads of small juvenile A. radiata are thin, elongate, and fixed to the dorsal part of the body cavity, very close to the kidneys, adrenal glands, and lungs. The gonads and other organs (oviduct, kidney, adrenal, lung) can generally be viewed directly or sometimes through translucent peritoneal membranes such as the mesentery. Despite being attached to the dorsal coelomic wall by various membranes, gonads and reproductive tracts move and can change their position relative to the kidneys, adrenals, and lungs (which have more or less fixed positions), for example, when turtles are tilted from one side to the other during endoscopy.

Testes of small tortoises appear as small, transparent, thin, half-roundish sausage-like structures, bound to the kidneys by the mesorchium and with a net of fine blood vessels on the surface (Fig. 1A). With growth testes become thicker, but remain half-roundish sausage-like structures ventral to the kidneys, turning first pinkish-white and then yellowish (Fig. 1B) with, in close-up, tubular structures visible through a thin, transparent theca containing a network of fine blood vessels (Fig. 1C), but no melanocytes. Epididymes and vas



**Figure 1.** Endoscopic images of gonads and accessory ducts in juvenile *Astrochelys radiata*: a: adrenal; d: oviduct; g: outgrowth of testis reminiscent of ovarian tissue; k: kidney; l: lung; o: ovary; t: testis. **A:** male 3-yr-old, 212 g body mass; **B:** male 8-year-old, 1148 g body mass; **C:** close-up of testis, same male as in B; **D:** female 8-mo-old, 43 g body mass; **E:** female 2-yr-old, 128 g body mass; **F:** female 3-yr-old, 214 g body mass; **G:** female 8-yr-old, 975 g body mass. **H:** male 7-yr-old, 529 g, protruding outgrowth reminiscent of ovarian tissue on testis. **I:** close-up of protruding outgrowth on testis, same animal as in Fig. 1H.

deferens in small juveniles are thin and translucent, difficult to locate, and not discernible in the photographs.

Ovaries are attached by a transparent peritoneum to the dorsal wall of the coelomic cavity or to a membrane that separates them from the lungs. Ovaries of small tortoises appear as transparent flat sheaths ventral to the kidneys, with some oocytes and primary follicles visible (Fig. 1D,E). With growth ovaries expand along the dorsal wall of the coelomic cavity ventrally to the lungs, increase in thickness, and masses of pre-vitellogenic follicles appear on the surface (Fig. 1F,G). The oviducts extend further cranially than the

ovaries and are ventral or lateral to the ovaries. They often cross ventrally over the posterior part of the ovary on the way to the cloaca. Oviducts of small females are relatively thin, transparent-whitish, straight bands (Fig. 1D,E). With growth oviducts become wider and thicker and more whitish (Fig. 1F,G), but still remain straight in the size classes examined during this study.

One of the eight juvenile *A. radiata* classified as males (529 g body mass, 7-yr-old) had a normal looking right testis, but showed a small outgrowth of tissue reminiscent of ovarian cortex and stroma tissue protruding from the

		Fei	nales	Males					
Year Hatched	n Mean body n mass (g)		1 SD	1 SD Range (g)		Mean body mass (g)	1 SD	SD Range (g)	
2001*	1	1234	-	-	0	-	-	-	
2002*	6	852	$\pm 220$	608-1252	2	1108	-	1067-1148	
2003*	7	683	$\pm 325$	399-1333	4	681	± 197	503-997	
2004*	1	428	-	-	0	-	-	-	
2005	-	-	-	-	-	-	-	-	
2006	6	292	± 37	223-334	0	-	-	-	
2007	17	203	± 64	126-417	2	165	-	117-212	
2008	12	110	±21	81-146	0	-	-	-	
2009	17	47	±13	21-71	0	-	-	-	

**Table 1.** Year of hatching, sex (n = number), and body mass (SD = standard deviation) of *Astrochelys radiata* sexed by endoscopy at the Behler Chelonian Center, \* = incubated at St. Catherine's Island, Georgia.

left testis (Fig. 1H,I; about 20% of the gonadal volume). Although some blood vessels from the theca testis extended to the surface of this outgrowth, it did not show the network of fine bloodvessels typical for the theca testis. No follicles could be seen on this outgrowth, but their appeared to be a few oocytes and primary follicles in the cortex (Fig. 1H,I) as in ovaries of hatchlings and very small juveniles (Fig 1D,E).

Sex Ratio. — Of the 75 A. radiata, 67 were females (89.3%) and 8 were males (10.7%), giving an overall male to female sex ratio of 1:8.4. Broken down according to the breeding location (Table 1), eggs which hatched prior and up to 2004 (n = 21) on St. Catherine's Island produced 15 females (71.4%) and 6 males (28.6%; m:f ratio = 1:2.5). Broken down according to incubation temperatures at the BCC since 2004, eggs incubated at about 28.9°C (n = 25, hatched 2006–07) produced 23 females (92%) and 2 males (8%; m:f ratio = 1:11.5), and eggs incubated at about 30°C (n = 29, hatched 2008–09) produced 29 females (100%) and no males (0%).

#### DISCUSSION

The good news of this study is that the breeding program produced males as well as females. The sex ratio was strongly female biased, but this is generally favored in turtle conservation programs (Seigel and Dodd 2000). The majority of juvenile A. radiata recovered without problems from the endoscopic procedure and continued to grow normally. Unfortunately, 3 of the 75 (4%) endoscopically sexed A. radiata died a few days following endoscopy. All three were from the 1-yr-age group, which was maintained in a large thermostatically controlled greenhouse and were kept together in one particular group. Two juveniles from a different group that were not endoscopically sexed, also died during this period (March 2010); these two specimens, however, were from a different age cohort (7-8 yrs), maintained in a different building ("nursery"), and were also kept together in one group. The mortality rate following the endoscopy did not differ from the overall background mortality rate of juvenile A. radiata that were not examined by endoscopy at the BCC at that particular time. The cause of death in both groups remains unknown and was an exceptional event; since the inception of the

BCC in 2005 a total of 115 A. radiata have hatched and, except for those five deaths, only one other mortality occured in a 1-2 month-old juvenile. During the time when endoscopic sexing was performed (4 to 12 March 2010) southern California had unusually cold weather and the tortoises remained in the indoor winter quarters for longer than usual. No mortalities were recorded at the BCC during the same time period following endoscopic sexing of 38 juvenile Geochelone platynota (the majority of them in the 1-yr-age group; Kuchling et al. 2011), four juvenile Heosemys depressa, two juvenile Siebenrockiella leytensis, and the four juvenile Chelonoidis nigra. The mortalities in the endoscopically sexed and non-endoscopically examined juvenile tortoises were restricted to A. radiata. Since there have been no health issues or deaths of Radiated Tortoises in the BCC since this episode, it may be concluded that the five deaths in March 2010 were an anomaly, possibly related to the endoscopy, but not related to any systemic problem with the collection or the maintenance of the collection. In the future it would seem prudent to perform endoscopic sexing in captive breeding programs only during times of optimal environmental and husbandry conditions.

Morphology of Gonads and Accessory Ducts. — This study provides descriptions and endoscopic images of testes and ovaries of hatchling and juvenile tortoises (family Testudinidae) and shows the changes of the gonads with the growth of the juveniles. Endoscopy has been successfully used before to sex captive-raised juvenile Desert Tortoises, Gopherus agassizii, with a size range of 28-1250 g body mass (Rostal et al. 1994), but that paper, as well as Kuchling and López (2000) for A. yniphora, did not provide endoscopic images and did not describe the morphology of gonads and accessory ducts with changing age and/or body size. Other tortoise species with similar appearance of testes and ovaries in hatchlings and juveniles include Geochelone platynota (Kuchling et al. 2011) and Aldabra Tortoises (Kuchling and Griffiths 2012). However, the morphology of the testis in hatchling and juvenile Gopherus agassizii is quite different from those species and A. radiata with testes being bright yellow, long, flat bands (Rostal et al. 1994). Thus, there is some variability in the development of gonads in hatchling and juvenile Testudinidae. Epididymis and vas deferens in small juvenile tortoises are thin and translucent and difficult to image during endoscopy.



Figure 2. Freshly hatched *Astrochelys radiata* at the Behler Chelonian Center. Photo G. Kuchling.

So far only a few published papers have provided endoscopic images of juvenile testes and ovaries of species in other turtle families which can be used as guidance to identify gonads and sex (Podocnemididae: Kuchling 2006; Cheloniidae: Wyneken et al. 2007; Trionychidae: Kuchling and Kitimasak 2009). In hatchling and small juvenile turtles of those families and of G. platynota (Kuchling et al. 2011), Aldabra Tortoises (Kuchling and Griffiths 2012) and A. radiata (this paper), gonads and accessory ducts are of tiny size and often of transparent appearance (Fig. 1A,D,E). Testes in particular can be transparent structures, flat or half-roundish in cross section, sometimes smaller than adjacent adrenal glands (Fig. 1A) and, therefore, easily overlooked. The theca testis is always thin and translucent, never contains melanocytes, and tubular structures of different size and color (transparent, white, pinkish, or yellow) and/or a fine net of surface vasculature is visible in testis close up (e.g., Fig. 1C). However, in the Asian box turtle Cuora flavomarginata the juvenile testis shows melanocytes in the theca and can appear pendulous (Hernandez-Divers et al., 2009: p. 802, Fig. 2a). A close up of this structure shows a robust, whitish external membrane with thick blood vessels and spots of melanocytes, with no tubuli structures visible through it (Hernandez-Divers et al. 2009: p. 802, Fig. 2b). Because of this striking differences to juvenile testes images of other turtle groups (see above) it has been suggested that Hernandez-Divers et al. (2009) may have misidentified an unrelated structure as testis (Kuchling 2009), but the identification of this structure as testis was accurate (Divers and Stahl 2009; Innis 2012) and juvenile testes of similar appearance have in the mean time also been found in Cuora trifasciata (Kuchling 2012).

An interesting finding in the present study was the male *A. radiata* that showed a small area of ovarian tissue on only one of the otherwise normally developed testes (Fig. 1H, I). Kuchling and López (2000) classified one out of 60 *A. yniphora* as an intersex, but in that specimen testes and ovaries appeared to develop more or less normally side by side, although the ovaries appeared to be slightly smaller than in normal females of similar body mass. Similar intersex conditions have been found in three specimens of juvenile Aldabra Tortoises (Kuchling and Griffiths 2012). However,

in the case of the male *A. radiata* in this study, the ovarian tissue formed only a small outgrowth on one testis and did not show the appearance of ovaries of females of similar age and size. Since it is possible that this abnormal ovarian tissue will be suppressed with future growth and gonadal development, we did not classify this specimen as an intersex, but as a male (although with a slight abnormality on one testis).

Sex Ratio and Sex Determination. - The female-biased sex ratio of captive-bred A. radiata indicates that the species has temperature-dependent sex determination (TSD). At the BCC, the sex ratios of juveniles from eggs incubated at the lower temperature (hatchlings of 2006 and 2007) and at the higher temperature (hatchlings from 2008 onwards) suggest, at least inside the temperature range tested, a malefemale TSD pattern in which cooler incubation temperatures produce males and warmer incubation temperatures produce females. Important TSD parameters are the transitional range of temperatures (TRT), which is the range of temperatures in which sex ratios shift from 100% male (below the TRT) to 100% female (above the TRT); and within the TRT, the constant incubation temperature that will produce a 1:1 sex ratio, which is referred to as the pivotal temperature (Mrosovsky and Pieau 1991).

Unfortunately, the incubation conditions were not monitored rigorously enough to allow reliable estimates of pivotal temperatures and TRTs. Therefore only crude estimate can be made, since eggs incubated at ca. 28.9°C up to 2007 produced a male to female ratio of 1:11.5, and eggs incubated at ca. 30°C since 2008 produced 100% females, the pivotal temperature of *A. radiata* is most likely below 28.9°C, with the upper limit of the TRT between 28.9–30°C. Interestingly, eggs of the Burmese Star Tortoise, *Geochelone platynota*, incubated at the BCC at the same time, at the same temperatures, and in the same incubators as those of *A. radiata*, produced a male to female ratio of 1:0.08 at ca. 28.9°C and of about 1:1.2 at ca. 30°C (Kuchling et al. 2011), indicating that this species has a higher pivotal temperature than *A. radiata*.

With more varied incubation temperatures and more rigorous incubation temperature control and monitoring, it should be possible in the future to assess more accurately the pivotal temperature and TRT of *A. radiata*. This information is important to enable informed decisions on how to produce desired offspring sex ratios in future breeding operations. In the mean time, in order to produce a better balanced sex ratio of *A. radiata*, the incubation protocols at the BCC have been changed recently to increase the number of male hatchlings by lowering the incubation temperature to ca. 27.8°C and by moving the incubator to a climate-controlled room to avoid day-night fluctuations in temperature.

Acknowledgments. — Funding was provided by the Behler Chelonian Center and Turtle Conservancy through a consultancy provided to the senior author. We thank for technical assistance Guundie Kuchling and Lukasz Pogorzelski. We thank the Karl Storz Company, Germany, for donating endoscopic equipment. The study was approved by the Animal Ethics Committee of the University of Western Australia. We thank Ross Kiester for critically reading an earlier draft of the paper.

#### Résumé

L'évaluation du sex-ratio de la progéniture est importante dans tout programme d'élevage d'espèces menacées à grande échelle lorsque la détermination thermodépendante du sexe (DTS) est une possibilité. Dans le cadre du programme de reproduction en captivité de l'espèce au Behler Chelonian Center (BCC), nous avons évalué le sexe ratio de tortues radiées juvéniles, Astrochelys radiata, par observation directe de leurs gonades à l'aide d'un endoscope. Les gonades des juvéniles de petite taille sont minces, de forme allongée, et fixées à la partie dorsale de la cavité du corps. Les ovaires apparaissent comme des enveloppes transparentes avec quelques ovocytes visibles. Quant aux testicules, ce sont des structures en forme de saucisse qui apparaissent petites, transparentes, minces, avec un réseau de fins vaisseaux sanguins à leur surface. Avec la croissance, les ovaires se développent et des masses de follicules prévitellogènes apparaissent à la surface. Les testicules sont transparents chez les petits juvéniles et, au cours de la croissance, deviennent blanc-rose puis jaunâtres, avec des structures tubulaires visibles à travers une thèque mince et transparente contenant un réseau de fins vaisseaux sanguins, mais pas de mélanocytes. Le programme de procréation en captivité a produit un sexe ratio biaisé en faveur des femelles avec un ratio mâle femelle de 1:8.4 (n = 75), suggérant que A. radiata présente une DTS, avec des basses températures d'incubation produisant des mâles et des températures plus chaudes produisant des femelles. Malheureusement, les conditions d'incubation n'ont pas été suivies assez rigoureusement pour permettre une détermination précise de la température de basculement, mais une estimation préliminaire la situe entre 28.0 et 28.9°C; et la limite supérieure de la rangée de températures transitionnelle (i.e., au-dessus de laquelle seules des femelles seront produites) se situe entre 28.9 et 30.0°C.

## LITERATURE CITED

- DEVAUX, B. 2010. Astrochelys radiata, une "Star" très Menacée. Gonfaron: Chelonii 8, Editions SOPTOM, 158 pp.
- DIVERS, S.J. AND STAHL, S.J. 2009. Letter to the editor: differences among studies on sex identification of hatchling turtles. Journal of the American Veterinary Medical Association 235:932–933.
- EWERT, M.A., ETCHBERGER, C.R., AND NELSON, C.E. 2004. Turtle sex-determining modes and TSD patterns, and some TSD pattern

correlates. In: Valenzuela, N. and Lance, V. (Eds). Temperature-Dependent Sex Determination in Vertebrates. Washington: Smithsonian Books, pp. 21–32.

- HERNANDEZ-DIVERS, S.J., STAHL, S.J., AND FARRELL, R. 2009. An endoscopic method for identifying sex of hatchling Chinese box turtles and comparison of general versus local anesthesia for coelioscopy. Journal of the American Veterinary Medical Association 234:800–804.
- INNIS, C.J. 2012. Commentary. Testes Morphology in *Cuora flavo-marginata*. A response to Kuchling and Griffiths (2012; Chelonian Conservation and Biology 11(1)). Chelonian Conservation and Biology 11:273–274.
- KUCHLING, G. 1999. The Reproductive Biology of the Chelonia. Zoophysiology. Volume 38. Berlin, Heidelberg, New York: Springer, 223 pp.
- KUCHLING, G. 2006. Endoscopic sex determination in juvenile freshwater turtles, *Erymnochelys madagascariensis*: morphology of gonads and accessory ducts. Chelonian Conservation and Biology 5:67–73.
- KUCHLING, G. 2009. Letter to the editor: differences among studies on sex identification of hatchling turtles. Journal of the American Veterinary Medical Association 235:932.
- KUCHLING, G. 2012. Reply to the commentary of Charles J. Innis "Testes Morphology in *Cuora flavomarginata*". Chelonian Conservation and Biology 11:274–275.
- KUCHLING, G. AND GRIFFITHS, O. 2012. Endoscopic imaging of gonads, sex ratios, and occurrence of intersexes in juvenile captive bred Aldabra giant tortoises. Chelonian Conservation and Biology 11:91–96.
- KUCHLING, G. AND KITIMASAK, W. 2009. Endoscopic sexing of juvenile softshell turtles, *Amyda cartilaginea*. The Natural History Journal of Chulalongkorn University 9:91–93.
- KUCHLING, G. AND LÓPEZ, F.J. 2000. Endoscopic sexing of juvenile captive-bred ploughshare tortoises *Geochelone yniphora* at Ampijoroa, Madagascar. Dodo 36:94–95.
- KUCHLING, G., GOODE, E., AND PRASCHAG, P. 2011. Endoscopic imaging of gonads, sex ratio, and temperature dependent sex determination in captive bred juvenile Burmese star tortoises *Geochelone platynota*. Asian Herpetological Research 2:240–244.
- MROSOVSKY, N. AND PIEAU, C. 1991. Transitional range of temperature, pivotal temperature and thermosensitive stages of sex determination in reptiles. Amphibia-Reptilia 12:169–187.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu: Natural History Publications (Borneo), 147 pp.
- ROSTAL, D.C., GRUMBLES, J.S., LANCE, V.A., AND SPOTILA, J.R. 1994. Nonlethal sexing techniques for hatchling and immature desert tortoises (*Gopherus agassizii*). Herpetological Monographs 8:83–87.
- SEIGEL, R.A. AND DODD, C.K., JR. 2000. Manipulation of turtle populations for conservation: halfway technologies or viable options? In: Klemens, M.W. (Ed). Turtle Conservation. Washington, DC: Smithsonian Institution Press, pp. 218–238.
- WIBBELS, T., OWENS, D.W., AND LIMPUS, C.J. 2000. Sexing juvenile sea turtles: is there an accurate and practical method? Chelonian Conservation and Biology 3:756–761.
- WYNEKEN, J., EPPERLY, S.E., CRODER, L.B., VAUGHAN, J., AND ESPER, K.B. 2007. Determining sex in posthatchling loggerhead sea turtles using multiple gonadal and accessory duct characteristics. Herpetologica 63:19–30.

# **Do Bigger Females Produce Bigger Eggs? The Influence of Female Body Mass on Egg Mass in** *Astrochelys radiata*

# JUTTA M. HAMMER<sup>1</sup>

<sup>1</sup>Department of Animal Ecology and Conservation, University of Hamburg, Biozentrum Grindel und Zoologisches Museum, Universität Hamburg, Martin-Luther-King Platz 3, 20146 Hamburg, Germany [jutta.m.hammer@gmail.com]

ABSTRACT. – A possible correlation of egg mass with female body mass was examined in *Astrochelys radiata*, a tortoise species endemic to Madagascar. Data from a wild population were compared with observations from captive individuals. Nesting data and egg mass were related to female body mass. Females from the captive population were significantly larger than those in the wild. They also produced significantly larger eggs with larger mean egg mass. Regular feeding and access to a water supply in captivity may have enabled these females to be highly productive during the breeding season.

KEY WORDS. – Reptilia, Testudines, Testudinidae, captive breeding, Madagascar, Radiated Tortoise, reproductive biology

Through the development of shelled eggs, reptiles became able to live independently from water bodies, about 300 million years ago, and colonize terrestrial habitats (Benton and Donoghue 2007). Over time these animals have developed further adaptations towards terrestrial living conditions. Today, several species occur in dry areas with unpredictable climatic conditions and prolonged dry periods, such as the southwestern part of Madagascar (Gould et al. 1999; Dewar and Richard 2007). One of these species endemic to this subarid region is the Radiated Tortoise, *Astrochelys radiata*.

At present, this species is at high risk of extinction in the wild due to poaching and the illegal pet trade (Nussbaum and Raxworthy 2000; O'Brien et al. 2003; Leuteritz et al. 2005), and may as well be predated from other animals, such as bushpigs. Population densities of *A. radiata* are declining in the wild (Lewis 1995; O'Brien et al. 2003) and at the same time the species population growth is limited by slow reproductive rates, which is similar to other tortoise species (Hailey and Willemsen 2003; Inman et al. 2009).

This underscores the importance to produce hatchlings that are fit enough to survive in the wild to help ensure the species survival. In this context, egg mass might be an important factor to hatchling development. Tortoise eggs incubate for several months enduring the dry season when food availability is limited. Larger eggs contain more fluids providing nutrition for the embryos during the incubation period and therefore impart greater offspring survival (Tucker 2000; Valenzuela 2001). Larger eggs in tortoises are also believed to result in larger hatchlings (Loehr et al. 2004).

This study examined egg mass and nesting frequencies of two tortoise populations that were exposed to different living conditions. Data from a wild population of A. *radiata* was compared to a population held in enclosures

under natural climatic conditions, but which was provided with food and drinking water on a regular basis. More specifically, this study addressed the following questions. Do big females produce bigger clutch sizes and bigger eggs than small females? And what factors determine egg mass?

#### **METHODS**

Two sites in southwestern Madagascar were surveyed for tortoise breeding activity. The sites were chosen for their differences in the living conditions of the tortoises in order to allow a comparison to be made between female *A*. *radiata* held in enclosures and those from the wild.

*Ifaty-Mangily.* — The first study site was the Village des Tortues in Ifaty-Mangily, which maintains tortoises that were confiscated from the illegal trade by authorities. The animals live in enclosures that are built into the natural forest. This forest is located within the original geographic distribution of A. radiata; therefore, these animals remain exposed to their natural climatic conditions. Due to the limited space and availability of food resources in the enclosures, additional food and water is supplied, with food plants every two days and drinking water twice per week. Two enclosures with both male and female A. radiata were surveyed. These individuals arrived as two different groups in January and February 2008. The first group was returned to Madagascar after being confiscated in Mayotte (Razafindrakoto 2008) while the second group was confiscated in the southeast of Madagascar (WWF Toliara, pers. comm.). Each of the two groups was kept in an enclosure as a mixed-sex group, but separated from other tortoises. These groups were formed haphazardly and do not represent natural tortoise populations. Nesting data were recorded from 2008 to 2010. In total, 21 female A. *radiata* were found to be nesting during the study period. These animals from Ifaty-Mangily are referred to as the captive population (CP) throughout the remainder of this document.

*Tsimanampetsotsa.* — The second study site was located in the northwestern part of Tsimanampetsotsa National Park, which is located approximately 100 km south of Ifaty-Mangily. A total of 26 females from a wild population at this site were studied during two consecutive breeding seasons from February to June in 2009 and 2010. The tortoises were equipped with radio transmitters and surveys were conducted daily in order to record breeding activities and locate their nests through direct observation. In the first year, 19 tortoises were surveyed and during the second year 16 females were provided with radio-tags. Nine of these individuals were surveyed during both years. The tortoises from the National Park are referred to as the wild population (WP).

Body mass of *A. radiata* was recorded either with a spring scale (Pesola Macro-line, accuracy 100 g) or a digital scale (MyWeigh Ultraship 55, accuracy 10 g). The number of eggs per clutch was recorded for each nest. Each egg was weighed on a digital scale (MyWeight Pointscale PT-500, accuracy of 0.1 g). Prior to handling, all eggs were marked with a pencil to avoid a change in their orientation during data acquisition. The number of clutches per female was also recorded. Mean egg mass per clutch was determined and used in the data analysis. To avoid bias from highly productive tortoises, those females that laid more than one clutch within the study period were included only once. The mean egg mass was then determined for all their clutches laid within the study period. All mean values are indicated with their standard deviation.

The analysis of tortoise data was carried out using Excel. A linear regression was performed to examine the relationship of female body mass to mean egg mass per clutch. As graphical analyses indicated regular variations, the residuals of both study groups were tested for differences. A Pearson correlation was performed to describe the relation of female body mass and total clutch mass. All statistical testing was performed using SPSS



**Figure 1.** The number of nests per season per female *A. radiata* for the two survey areas: CP (n = 64) is shown in gray bars, WP (n = 10) is displayed as white bars. Numbers above the bars indicate the number of nesting females. WP = wild population in Tsimanampetsotsa National Park, CP = captive population in the Village des Tortues, Ifaty-Mangily.

**Table 1.** The total number of female *A. radiata* observed in this study, the number of breeding females that were observed during egg deposition, as well as the total number of nests and eggs. The data are divided by study site and survey year. WP = wild population in Tsimanampetsotsa National Park, CP = captive population in the Village des Tortues, Ifaty-Mangily.

	Year	Total Females	Breeding Females	No. of Nests	No. of Eggs	
WP	2009	19	6	7	18	
	2010	16	3	3	7	
СР	2008	40	15	40	134	
	2009	40	6	14	45	
	2010	40	7	10	39	

13.0 (Bühl 2006). Only data from female tortoises that were observed during egg deposition were considered for analyses.

### RESULTS

The two surveyed tortoise populations differed greatly in body mass. The CP tortoises were significantly heavier than the WP tortoises (Mann-Whitney-U-Test, z = -2.2, p = 0.03, n = 30). CP tortoises showed a mean body mass of 7.1  $\pm$  2.2 kg (mean  $\pm$  1 S.D.; range = 4.3–12.3 kg), while mean body mass in WP tortoises was  $5.3 \pm 0.7$  kg (range = 3.9–6.3 kg).

In the WP, seven female *A. radiata* were observed laying eggs during the study period (see Table 1) with one female laying two clutches in 2009 and two females were found nesting during both survey years. In the CP most females produced more than one clutch per breeding season (Fig. 1). Nesting activities during consecutive years were observed in several tortoises in the CP: two tortoises were recorded to nest during all three survey years, one



**Figure 2.** Comparison of mean egg masses per clutch in captive (CP) and wild (WP) populations of *A. radiata*. Both populations differed significantly (T-Test: t = -2.95, p = 0.006, n = 30).



**Figure 3.** Distribution of mean egg masses per clutch in *A. radiata* for both study sites: CP (captive population, n = 21) in gray bars, WP (wild population, n = 9) shown in white bars. Numbers on top of the bars indicate the number of clutches. Concerning females that laid several clutches, the mean egg mass was determined for all clutches within the whole study period.

female nested during the first two years of data recording and two females were observed to nest during the first and last survey year. All of these females produced at least three nests within one of the surveyed years.

While in the WP only one female was observed laying eggs twice within the same breeding season, the CP females produced up to five clutches per nesting season (Fig. 1) with 71% of the nesting females laying more than one clutch. The internesting interval ranged from 11 to 148 days (mean =  $51 \pm 25$  days, n = 34).

The CP tortoises laid bigger eggs than the WP females. Mean egg mass in CP females ranged from 28.2 to 47.5 g with a mean of  $36.3 \pm 5.2$  g, while the WP females produced eggs ranging from 26.6 to 37.2 g with a mean of  $30.6 \pm 3.8$  g. The two populations differed significantly in mean egg mass (Fig. 2; T-Test: t = -2.95, p = 0.006, n = 30). In the WP no mean egg mass larger than 40 g was detected, while about 25% of all CP clutches had mean egg masses larger than 40 g (Fig. 3).

There was a significant difference in the relationship of mean egg mass and female body mass between CP and WP. The bigger CP tortoises produced bigger eggs than the smaller females from the WP. The residuals gained from



**Figure 4.** Residuals from the regression between tortoise body mass and mean egg mass per female *A. radiata*. WP = wild population in Tsimanampetsotsa National Park, CP = captive population in Village des Tortues, Ifaty-Mangily.



**Figure 5.** The relation of total clutch mass and tortoise body mass for female *A. radiata*. WP-data (n = 9) are shown as black crosses, CP-data (n = 21) are displayed as gray dots. The equation for total fit line is: y = 14.6 x + 5.03;  $R^2 = 0.39$ .

linear regression tended to have positive values in CP, while in WP the residuals had more negative values (Fig. 4; T-Test: t = -2.1, p = 0.045, N = 30).

Clutch sizes of both populations differed considerably with CP tortoises producing 1 to 7 eggs per clutch (total clutch mass: 36.7 to 221.9 g) and WP clutches contained 2 to 3 eggs (total clutch mass: 53.1 to 111.5 g). Total clutch mass was positively correlated with female body mass (Fig. 5; Pearson: r = 0.63, p < 0.001, n = 30) and mean total clutch mass (CP: 111.4 ± 52.3 g; WP: 76.9 ± 20.2 g) was significantly higher in CP (T-Test: t = -2.6, p = 0.015, n = 30).

#### DISCUSSION

The surveyed tortoise populations of A. radiata differed significantly in body mass and mean egg mass. Captive tortoises were larger and produced heavier eggs as well as larger total clutch masses than animals from the wild population. Positive correlations between female body mass and egg mass are known from other tortoise species (Hailey and Loumbourdis 1988; Averill-Murray and Klug 2000; Loehr et al. 2004; Bertolero et al. 2007) and in freshwater turtles (Congdon and Gibbons 1985). Big females may contain more or bigger eggs than small individuals. Still, captive tortoises were also observed to produce several clutches within the same reproductive season and during consecutive years. O'Brien (2002) reported captive female A. radiata producing 3 clutches per year on average, with two females nesting within ten consecutive years. In the wild population in the present study, nesting activities during consecutive years were observed in two individuals and only one female produced two clutches within the same breeding season. Wild populations of European tortoises are commonly observed nesting multiple times within the same breeding season (Hailey and Loumbourdis 1988), while the North American desert tortoise (Gopherus agassizii) does not appear to produce more than one clutch per year and most individuals skip reproduction for at least one year after nesting (Averill-Murray and Klug 2000). Leuteritz (2002) found individual females A. radiata of a wild population at Cap Sainte Marie to be producing up to three clutches within the same season. Furthermore, mean egg mass recorded by Leuteritz (2002) in the Cap Sainte Marie population (39.0 g; range, 28.0-55.0 g; n = 56) was higher than records from the wild population from Tsimanampetsotsa in the present study. Site differences surely influence living conditions of A. radiata at both sites, with the Reserve Cap Sainte Marie lying further to the south and possibly representing a more productive habitat with less human impact.

Living conditions and food availability play a major role in the ability of animals to breed. Due to their herbivorous diet tortoises can take a long time to accumulate enough energy for laying eggs (Hailey and Loumbourdis 1988). In the wild, *A. radiata* is exposed to harsh living conditions with less than 400 mm of rainfall per year (Pedrono and Smith 2003) resulting in scarce food resources during the dry season. Within this study, wild female *A. radiata* may not have been able to build up enough energy to produce several clutches per year, nor able to produce eggs larger than 40 g as the captive females.

In contrast, the regular feeding and water supply in Ifaty-Mangily allowed the captive tortoises to be highly productive, with over 70% of the breeding females laying more than one clutch within the same season and between consecutive years. The captive population benefited from unlimited food resources, which allowed them to overcome seasonal constraints, resulting in an extended breeding season. In Ifaty-Mangily nesting activities were still recorded in late September, while the females in the wild population appeared to go into estivation by the end of June (pers. obs.).

While populations in captivity that receive food regularly may easily produce bigger animals, the observed differences in the body mass of tortoises between the surveyed populations could not be related to their living conditions. The captive tortoises arrived only shortly before this study was carried out in Ifaty-Mangily, with former living conditions unknown. The largest female detected in the wild during this study had a body mass of 6.3 kg. In contrast, Leuteritz (2002) found an average female body mass of 6.3 kg (range, 4.3-8.4 kg) at Cap Sainte Marie. These numbers are still very low considering that this species can grow up to 13 kg (Pritchard 1979). However, adult females are of major interest to tortoise poachers as they might contain eggs that can be consumed in addition to their meat (Leuteritz et al. 2005). The wild population of A. radiata in Tsimanampetsotsa National Park is clearly influenced by human activities, as large individuals are rare (Goodman et al. 2002; Leuteritz 2002; Hammer and Ramilijaona 2009). Accessibility to this area can easily be achieved and fishing boats from Toliara are known to sail down south for tortoise collections (O'Brien 2002; SuLaMa 2011). Differences in body mass between the two populations of A. radiata in this study are therefore assumed to be related to differences in the age of the tortoises rather than in food availability or living conditions. A continuing depletion of wild populations of A. radiata, with a special demand for big females, will likely result in smaller individuals that produce smaller egg masses. These smaller eggs contain less nutritious egg yolk, which is essential for embryonic development during incubation, and this might ultimately lead to embryonic development failures during incubation, and produce underdeveloped hatchlings. Lower survival rates of hatchlings after emergence would be the expected outcome, especially with prolonged dry periods in a local climate as unpredictable as in Madagascar (Dewar and Richard 2007).

Acknowledgments. - This study was carried out under the Accord de Collaboration between ANGAP (now MNP: Madagascar National Parks), the Département de Biologie Animale, Université d'Antananarivo, and the Department of Biology, Hamburg University. I am grateful to the late Olga Ramilijaona, Daniel Rakotondravony, and Miguel Vences for their help at various stages of the study, and Jocelyn Rakotomalala and Domoina Rakotomalala (both MNP Toliara) and WWF Madagascar for their logistical support in the field. Part of this study was carried out in the Village des Tortues in Ifaty-Mangily where I would like to thank Jean Kala, Daniel Kotonirina Ramampiherika, and Bernard Devaux for their support. In Tsimanampetsotsa I would like to thank M. Edson and the Team Andranovao. The study was financed by grants from the German Academic Exchange Service (DAAD) to Jutta Hammer, DFG/BMZ (Ga 342/15-1), the European Association of Zoos and Aquaria (EAZA), and WWF Germany to Jörg Ganzhorn.

### Résumé

Les tortues n'arrivent à maturité sexuelle qu'après de longues années. De ce fait, les populations sauvages peuvent s'éteindre lorsque les tentatives de reproduction échouent. La survie tout au long de l'incubation pourrait être influencée positivement par un plus grand volume des œufs. Des œufs plus gros constituent une source plus grande de nourriture pendant l'incubation et protège de la sécheresse pendant les périodes sans pluie. Une possible corrélation entre le volume des œufs et la masse de la femelle a été examinée chez Astrochelys radiata, une tortue endémique de Madagascar. Deux populations de tortues soumises à des conditions de vie différentes ont été étudiées. Des données provenant d'une population sauvage ont été comparées aux observations d'individus en captivité. Les données du nid et la taille des œufs ont été reliées à la taille de la femelle. Les femelles provenant de la population en captivité étaient significativement plus grandes que celles sauvages. Elles ont produit également, de façon significative, des œufs plus gros et des couvées plus importantes. Une alimentation régulière et l'accès à de l'eau en captivité peuvent avoir permis à ces femelles d'être hautement productives pendant la période de reproduction.

# LITERATURE CITED

- AVERILL-MURRAY, R.C. AND KLUG, C.M. 2000. Monitoring and ecology of Sonoran desert tortoises in Arizona. Phoenix, AZ: Arizona Game and Fish Department, Nongame and Endangered Wildlife Program, Technical Report 161.
- BENTON, M.J. AND DONOGHUE, P.C.J. 2007. Paleontological evidence to date the tree of life. Molecular Biology and Evolution 24(1):26-53.
- BERTOLERO, A., NOUGARÈDE, J.P., CHEYLAN, M., AND MARÌN, A. 2007. Breeding traits of Hermann's Tortoise *Testudo hermanni hermanni* in two western populations. Amphibia-Reptilia 28:77–85.
- BUHL, A. 2006. SPSS 14 Einführung in die moderne Datenanalyse. München: Addison-Wesley, 862 pp.
- CONGDON, J.D. AND GIBBONS, J.W. 1985. Egg components and reproductive characteristics of turtles: relationships to body size. Herpetologica 41:194–205.
- DEWAR, R.E. AND RICHARD, A.F. 2007. Evolution in the hypervariable environment of Madagascar. Proceeding of the National Academy of Sciences of the USA 104:13723–13727.
- GOODMAN, S.M., RAHERILALAO, M.J., RAKOTOMALALA, D., RAKOTON-DRAVONY, D., RASELIMANANA, A.P., RAZAKARIVONY, H.V., AND SOARIMALALA, V. 2002. Inventaire des Vertébrés du Parc National Tsimanampetsotsa (Toliara). Akon'ny Ala 28:1–36.
- GOULD, L., SUSSMAN, W., AND SAUTJER, M.L. 1999. Natural disasters and primate populations: the effects of a 2-year drought on a naturally occurring population of Ring-Tailed Lemurs (*Lemur catta*) in southwestern Madagascar. International Journal of Primatology 20:69–84.
- HAILEY, A. AND LOUMBOURDIS, N.S. 1988. Egg size and shape, clutch dynamics, and reproductive effort in European tortoises. Canadian Journal of Zoology 66:1527–1536.
- HAILEY, A. AND WILLEMSEN, R.E. 2003. Changes in the status of tortoise populations in Greece 1984-2001. Biodiversity and Conservation 12:991–1011.
- HAMMER, J.M. AND RAMILIJAONA, O. 2009. Population study on

*Astrochelys radiata* (Shaw, 1802) in the Tsimanampetsotsa National Park, southwest Madagascar. Salamandra 45:219–232.

- INMAN, R.D., NUSSEAR, K.E., AND TRACY, C.R. 2009. Detecting trends in desert tortoise population growth: elusive behavior inflates variance in estimates of population density. Endangered Species Research, doi: 10.3354/esr00214.
- LEUTERITZ, T.E.J. 2002. Distribution, status and reproductive biology of the Radiated Tortoise *Geochelone radiata* (Shaw 1802) in southwest Madagascar. Ph.D. Thesis, George Mason University, Fairfax, VA, USA.
- LEUTERITZ, T.E.J., LAMB, T., AND LIMBERAZA, J.C. 2005. Distribution, status, and conservation of radiated tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124:451–461.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). Unpublished Report, WWF, Madagascar.
- LOEHR, V.J.T., HENEN, B.T., AND HOFMEYR, M.D. 2004. Reproduction of the smallest tortoise, the Namaqualand Speckled Padloper, *Homopus signatus signatus*. Herpetologica 60:444–454.
- NUSSBAUM, R.A. AND RAXWORTHY, C.J. 2000. Commentary on conservation of "Sokatra", the radiated tortoise of Madagascar. Amphibian and Reptile Conservation 2:6–14.
- O'BRIEN, S. 2002. Population dynamics and exploitation of the radiated tortoise *Geochelone radiata* in Madagascar. Ph.D. Thesis, Darwin College, University of Cambridge, UK.
- O'BRIEN, S., EMAHALALA, E.R., BEARD, V., RAKOTONDRAINY, R.M., REID, A., RAHARISOA, V., AND COULSON, T. 2003. Decline of the Madagascar radiated tortoise *Geochelone radiata* due to overexploitation. Oryx 37:338–343.
- PEDRONO, M. AND SMITH, L.L. 2003. Testudinae, Land Tortoises. In: Goodman, S.M. and Benstead, J.P. (Eds.). The Natural History of Madagascar. The University of Chicago Press, pp. 951–956.
- PRITCHARD, P.C.H. 1979. Encyclopedia of Turtles. Neptune, New Jersey: TFH Publications, 895 pp.
- RAZAFINDRAKOTO, L. 2008. De Mayotte à Ifaty un repatriement exemplaire. La Tortue 81:36–43.
- SULAMA 2011. Diagnostic participatif de la gestion des resources naturelles sur le plateau Mahafaly. Unpublished report, www. sulama.de, downloaded 24 Feb 2013.
- TUCKER, J.K. 2000. Annual variation in hatchling size in the redeared slider turtle (*Trachemys scripta elegans*). Herpetologica 56:8–13.
- VALENZUELA, N. 2001. Maternal effects on life-history traits in the Amazonian giant river turtle *Podocnemis expansa*. Journal of Herpetology 33:394–408.

# Illegal Poaching of Radiated Tortoises, *Astrochelys radiata*, in Arid Southern Madagascar: Contributing Factors, Conservation Initiatives, Critical Challenges, and Potential Solutions

# TIANA A. RAMAHALEO<sup>1</sup> AND MALIKA VIRAH-SAWMY<sup>1</sup>

<sup>1</sup>World Wildlife Fund Madagascar and Western Indian Ocean Programme Office, B.P. Antananarivo 101, Madagascar [tramahaleo@wwf.mg]

ABSTRACT. – The Radiated Tortoise, *Astrochelys radiata*, is endemic to the spiny forest ecoregion of Madagascar, and is threatened by habitat degradation and harvesting for bushmeat and the international pet trade. The World Wildlife Fund's (WWF) initiative for tortoise conservation began with the establishment of the Ala Maiky ecoregion in 1998. As all enterprises on natural resource conservation and management, WWF considers the involvement of local communities in tortoise conservation, as well as partnerships with all stakeholders (e.g., gendarmes, justice, environmental and regional authorities, park managers), as being keys to its success. An analysis of the strengths, weaknesses, and risks of the past and current experiences with Radiated Tortoise conservation was conducted and recommendations for future comprehensive strategies for endemic terrestrial species are provided.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, *Astrochelys radiata*, bushmeat, endemic tortoises, illegal trade, Radiated Tortoise, spiny forest ecoregion, Madagascar

Madagascar is renowned for its unique and rich biodiversity as illustrated by the fact that it is ranked 3rd in the world in terms of reptile diversity and endemism. Five out of the nine terrestrial and freshwater turtles found on this island are endemic. Two of these, the Radiated Tortoise, *Astrochelys radiata* or sokake, and the Spider Tortoise, *Pyxis arachnoides* or kapila, are only known from the dry and spiny forest of the southern and southwestern parts of Madagascar. Both tortoises are sympatric across most of their ranges and exposed to the same threats: habitat degradation and harvesting for bushmeat and the international pet trade.

World Wildlife Fund's [WWF's] initiatives on tortoise conservation started with the establishment of the Ala Maiky ecoregion in 1998, through awareness campaigns during special events (e.g., Independence Day, religious occasions, etc.), and police checks on roads or marine routes followed by releases of confiscated tortoises into the forest. Controls and seizures at the main international airport in the country (Ivato in Antananarivo) has intensified since 2006; while at the international level, seizures and arrests were recorded from airports in France in 1998 and by Thailand customs officers after 2006. In 2005, a Population and Habitat Viability Assessment (PHVA) was carried out by all stakeholders, which resulted in the development of short and long-term conservation strategies. These efforts led to the global vision for freshwater turtles and tortoises from Madagascar called the "Vision Sokatra Gasy" in 2008 (Mittermeier et al. 2008; reprinted in this volume).

*Distribution.* — The endemic terrestrial tortoises of the southwest live in spiny forests composed mainly of Didieraceae and *Euphorbia* species. They have historically ranged from south of the Mangoky River in the north to near the transitional forest of the Anosyan mountains in the southeast (Fig. 1). Precipitation levels can be as low as 200–400 mm per year in these areas. Even though the ranges of these species overlap with the spiny forest ecoregion, the Spider Tortoise is more confined to the littoral zones that lie mostly within a 20 km wide strip along the coast (Pedrono 2008). Radiated Tortoises can be located as far as 100 km inland (Glaw and Vences 1994; Leuteritz et al. 2005).

Radiated Tortoise Populations. - The Radiated Tortoise has been described historically as abundant across its natural range. Currently, it is mostly visible in very remote areas within its core range or within protected areas. According to O'Brien (2002), Radiated Tortoise populations have experienced a steep decline in their range, which has contracted by 1/5 in the last 25 years. Estimates of tortoise abundance are variable and range from 1.6 to 12 million individuals (Lewis 1995; Leuteritz et al. 2005). An inventory conducted in 2007 in Tsimanampetsotsa National Park produced estimates of tortoise densities that ranged between 65 and 48 individuals/km<sup>2</sup> during the wet and dry seasons, respectively, for the three main vegetation types: 1) dry forest on sandy soils, 2) spiny bush on limestone, and 3) dry forest on red sand. Densities around the park varied from 0 to 500 individuals/km<sup>2</sup> and no correlation with soil, habitat type, or human disturbance of habitat was observed (Rasoma et al. 2010).

A model created during the PHVA meeting in 2005, which was based on various natural history parameters for the Radiated Tortoise (e.g., initial size of the population, age at maturity, longevity, and harvest rates) showed that with the current collecting rate, it would go extinct in the wild within 45 years (Randriamahazo et al. 2007). Preliminary



**Figure 1.** Distribution ranges of terrestrial tortoises in the south and southwest of Madagascar, based on O'Brien (2002) and Walker (2008). Map courtesy of WWF.

results from fieldwork conducted in 2010 between Fiherenana River in the north and Cap Sainte Marie in the south showed that Radiated Tortoise populations are still dense in protected areas, especially at the Special Reserve at Cap Sainte Marie (Walker et al. 2010). The newly established community protected area of Voihindefo reportedly harbors a very good population of Radiated Tortoises, though field studies need to be conducted to confirm this (Flavien Rebara, pers. comm.). Outside of protected areas, tortoise abundance is variable: between the Linta and Menarandra Rivers, densities are low, probably because of intense human pressures, while from the Menarandra River to the vicinity of Cap Sainte Marie Special Reserve, populations are considered to be good.

# Main Challenges with Radiated Tortoise Conservation

Anthropogenic Threats. — Various threats affect the viability of Radiated Tortoise populations, including harvesting for local bushmeat, national and international pet trades, and habitat destruction (Behler 2000). In addition, raising Radiated Tortoises on poultry farms is traditionally done to avert poultry diseases (Durrell et al. 1989; Leuteritz et al. 2005) and many households across Madagascar have at least one Radiated Tortoise in the backyard as a pet.

O'Brien (2002) estimated that more than 45,000 individuals are collected from the wild every year. During the PHVA workshop, participants agreed that this number ranges between 22,000 and 241,000, with a staggering average of about 60,000 per year (Fig. 2). During a public debate on tortoise trafficking organized by WWF and Madagascar National Parks in Toliara in July 2010, participants from the coastal areas of the southwest near Itampolo claimed that no less than 10 zebu carts filled with tortoises go across the Mahafaly Plateau every week. With an average of about 100 tortoises per cart, this leads to an estimate of 48,000 tortoises harvested per year (WWF 2010). The terrestrial and marine circuits of the tortoise trafficking scheme in southern Madagascar are illustrated in Fig. 3. While the terrestrial route is mainly operated by the Antanosy tribes, the marine route is led by the Vezo tribe (Fig. 4).

In January 2010, TRAFFIC conducted an investigation in Thailand of the trade in reptiles from Madagascar; done in collaboration with a local NGO called Madagascar Voakajy



Figure 2. Smoked meat from Radiated Tortoises seized in the Itampolo area. Photo courtesy of WWF.



Figure 3. Tortoise trafficking scheme in southern Madagascar. Map courtesy of WWF.

and with financial support from the Darwin Initiative Project, the study showed that Thailand constitutes a major hub for the reptile trade in Asia (Todd 2010). Chameleons and other reptiles were sold furtively door to door, whereas tortoises were sold in open public markets. Of 140 seized tortoises, 106 were *A. radiata*, 3 *Astrochelys yniphora*, and 31 *P. arachnoides*. Follow-up on the trade for three weeks revealed that 36 *A. radiata*, 3 *A. yniphora*, and 14 *P. arachnoides* were sold during that period (Todd 2010). Moreover, this survey helped to establish that many of the animals that enter Thailand are laundered through fictitious "captive breeding" farms in Kazakhstan or Lebanon, with false CITES documents. The same documents are used to re-export animals to other countries, including Hong Kong and Japan.

Habitat destruction is also considered to be a major threat to endemic terrestrial tortoises in Madagascar. Harper et al. (2007) documented a 1.2% annual loss of the spiny forest between 1970 and 2000, the main habitat for Radiated and Spider Tortoises. During this period, the total surface area of the forest was reduced from 29,782 to 21,322 km<sup>2</sup>, which is a 29% reduction in 30 years. Uncontrolled fires from slash and burn practices and charcoal production are highly devastating for tortoises that do not have the capacity to flee these events.

# Contributing Factors to Radiated Tortoise Poaching

Factors behind tortoise harvesting and poaching include:

• The Antandroy and Mahafaly taboos on Radiated Tortoises are not protective taboos, but instead inspire total indifference towards the animal. This has become negative for tortoises, as communities will do nothing against poaching. In some cases members of the communities will help the traffickers collect tortoises. • Laws on species are not enforced. This is the result of different factors, including corruption, lack of resources to conduct adequate controls, lack of motivation among law enforcers, and new laws that are not yet known. A training workshop on environmental laws and the justice system in collaboration with the National Magistrate College (ENMG) showed that almost all of the stakeholders (i.e., communities, environmental and justice officials, park managers and agents, law officers, etc.) are not aware of the new national law on wildlife trade adopted in 2005 (Law no 2005-018 of 17/10/2005).

• Many control agents, law enforcers, and officials are tortoise consumers and are part of the trafficking ring.



Figure 4. Radiated Tortoises smuggled by sea at Itampolo. Photo courtesy of WWF.

• The range of the Radiated Tortoise is within the area prone to recurrent drought and famine. This animal constitutes an easy source of food or revenue during the lean season (Fig. 5). Populations of Radiated Tortoises in the Amboasary-sud region were decimated following the famine period of the 1990s.

• The political crisis that started in early 2009 has been accompanied by a harsh environmental crisis, epitomized by unprecedented, uncontrolled, and illegal exploitation of natural resources (Global Witness and The Environmental Investigation Agency, 2009). The Radiated Tortoise was not spared from this situation, as open markets for tortoise meat were visible in Beloha. This crisis was also marked by an atmosphere of instability within different governmental departments, with officials being reluctant to make firm decisions. Moreover, the crisis has favored the emergence of armed and dangerous traffickers.

• Actions by the various entities involved in the control and monitoring of tortoises at the local, regional, and national levels are not always known, because communication is lacking between them. Information on seizures and arrests are not centralized and there are no reliable statistics on the trafficking available.

• Decentralized authorities (i.e., "fokontany" and communes) rarely have a clear vision of their role in relation to natural resources management and this fact reinforces the idea of a lack of accountability in addressing those resources.

## Analyses of Past and Present Initiatives on Radiated Tortoise Conservation

Past and Present Initiatives. - Since early 2000, diverse actions and strategies to reduce illegal activities related to Radiated Tortoises in harvesting areas, along transportation routes, and international airports, have been developed and implemented (WWF 2003). Until 2003, sporadic control and seizure activities based on joint actions by WWF, Madagascar National Parks, and the Direction Générale de l'Environnement et des Forêts (DREF) were carried out. In 2003, this responsibility was given to the Joint Brigade, which included representatives from the justice system, communes, and communities (especially the Association Intercommunale pour la Protection du Plateau Mahafaly, or AICPM). It is worth noting that joint actions on the ground were facilitated at a high level (i.e., the Gendarmerie commandment, the Ministry of the Environment, and top regional leaders). A joint communiqué against tortoise harvesting was then published in national newspapers following this collaboration. Regular missions by the Joint Brigade resulted in a significant increase in seized tortoises from 912 in 2003 to 1689 in 2004 (WWF Archives). These initiatives were supported by the hiring of specialized informants who conducted intelligence missions and inquiries in villages. Due to a lack of sustained funding, these actions became sporadic, or continued to function at a very low level until 2008. Seized tortoises were most often released into the forest, until the opening in 2005 of the quarantine and care



Figure 5. Prevalence of food insecurity in southern Madagascar in 2009; dark reddish-brown = 73% of households. Source: FAO.

center at Ifaty, the Village des Tortues. At this time, more than 580 Radiated and 800 Spider tortoises are being held at the center. Reintroductions have not been conducted, despite this being the main mission of this facility.

Mass awareness campaigns using radio broadcasting, articles in newspapers, and theater plays were used in association with the Joint Brigade's actions. A rural radio network that is comprised of 15 radio stations and four theater groups composed of members of local communities were instrumental in bringing the tortoise message across the ecoregion. The groups organized regular tours of their regions, presented thematic plays on environment and regional development, and addressed local needs in local languages. These were the fruit of collaboration between WWF, Andrew Lee's Trust (ALT), and the European Union.

Between 2001 and 2010, more than 8870 live tortoises were seized, along with more than 4.8 tons of meat. These seizures only represent between 1.5 to 2.3% of the estimated 60,000 tortoises collected annually from the ecoregion (Table 1). A recent analysis of court cases on tortoises at the Tribunal of Ampanihy, the main jurisdiction that deals with tortoise issues, showed that during the same period 15 dossiers involving 4640 tortoises were prosecuted. Curiously, no records have been found for the years between 2004 and 2006 and all dossiers from 2001 and 2003 are absent. Jail terms ranging from five to 12 months, along with fines between 0 and 10.8 million Ariary (\$5400 USD), were issued (Table 1). According to a tribunal officer, only 5% of legal

Year	Number of seized tortoises	Tortoise products	Number of legal cases	Number of tortoises seized in the tribunal records	Sentences	Observations
2001	320		1	320		Dossier absent
2002	1323		1	1323		Dossier absent
2003	912	100 kg meat	4	>351		Dossier absent
2004	1689	3250 kg meat, 330 kg liver, 3 liters fat	0			
2005	125		0			
2006			0			
2007	96		1	96	Jail terms: 6 mo Fees: 561,000 Ar	
2008	1035	80 kg smoked meat	5	1116	Jail terms: 5-24 mo Fees: 0-2.4 M Ar	
2009	580	860 kg smoked meat	3	1440	Jail terms: 8-12 mo Fees : 1-10.8 M Ar	
2010	2793	12 bags meat				
Total	8873	4.8 tons meat	15	4646		

Table 1. Number of seized tortoises and tortoise products, with number of resulting legal cases in southern Madagascar 2001–10.

cases on tortoises are treated by the tribunal and until 2010, no fees have ever been collected because of lack of follow up by the plaintiff (i.e., the Ministry of the Environment).

Analysis of Tortoise Conservation Actions and Strategies. — Because of a lack of funding, many activities identified during the PHVA meeting and in the Sokatra Vision have not been implemented, or only partially implemented. We conducted our analysis based on the following strategic axes for which lessons have been drawn: law enforcement, update of the laws, involvement and motivation of local communities, sensitization (public awareness), setting up of national and regional tortoise committees, habitat conservation, promoting farming systems, and research.

Many strengths have been identified in the design and implementation of tortoise conservation actions:

1. Good understanding of the species ecology. Strategies on terrestrial endemic species were based on a good understanding of ecological, phenological, and biological characteristics of the species as the result of research activities targeting them (Glaw and Vences 1994). The setting up of the Village des Tortue in Ifaty was made possible thanks to this knowledge.

2. Model of partnership. Tortoise conservation has always constituted grounds for partnership between NGOs (e.g., WWF, Wildlife Conservation Society, Durrell Wildlife Conservation Trust), Madagascar National Parks, the gendarmes, and environmental authorities, and was made possible thanks to the complementarities of their mandates: NGOs for their technical expertise and financial support, the gendarmes for law enforcement, arrests and prosecutions in justice, and environmental authorities for the coordination, supervision, and facilitation of actions.

3. *Innovative actions*. The fight against the trafficking spurred the launching of innovative public awareness, incentive, and control approaches. Prizes were distributed among environmental and law enforcement agents who helped arrest traffickers. Successes during 2003–04 campaigns were due

in part to these prizes. Roadblocks by the gendarmes at key points of the main roads to Toliara and Antananarivo, and controls in main shipping areas were carried out to stem trafficking at these pivotal hubs. These kinds of moves were only possible because of detailed knowledge of the tortoise trade circuits.

4. Engaged communities. Thanks to the large communication and public awareness campaigns, some villages set up, on their own initiatives, local associations designed to end the trafficking. This was the case with the Tsiombe village association. Almost all poaching cases have been detected thanks to intelligence information coming from members of the community. In fact, most of the time, traffickers ask people in the communities for shelter, drinking water, or guidance in the forest.

5. *Firmness of the administration*. During the seizure of 70 tortoises on their way to Toamasina in December 2003, a judge intervened for the release of the culprit, but fortunately the gendarmes stood their ground and did not bend to the injunction. The prosecution went ahead according to the justice procedure until the condemnation of the traffickers.

6. International support. In 1999, French custom officers recorded 861 seized tortoises at the airports of Orly and Roissy (France). This illustrates the effectiveness of control systems in destination or transit countries, when they are committed to this cause. The confiscation of Radiated and Ploughshare Tortoises in Mayotte in 2008, 2009, and 2010 were the direct result of the involvement of foreign customs.

7. The quarantine center is operational. In 2005, the Village des Tortues was set up to receive all seized tortoises, with the ultimate goal to reintroduce them back to the wild, especially in areas where populations were decimated. This center continues to provide shelter and care for confiscated tortoises, though it receives no subsidy from the government.

8. *Tangible results*. The Sokake campaign conducted by the joint commission in 2003 and 2004 resulted in the confiscation of 2290 live animals and 2700 kg of meat.

9. National platform for tortoises was established. Thanks to the adoption of a common vision on tortoises, a national committee for tortoises was established. Composed of representatives from the environmental ministry, NGOs, and national and international institutions, it had the mission to supervise, coordinate, and provide orientation on all actions for the Radiated Tortoise (Ministerial decision n° 066/2008/MEFT/SG/DGEF/DVRN/SGFF). This platform offered an opportunity to influence policies on the conservation and management of species specifically targeted by trafficking in general. However, the committee has yet to meet.

The weaknesses identified include:

1. Weak communication. Many communities were eager to participate in the fight against trafficking, but later became discouraged because they did not receive any feedback on the results of their specific actions. Moreover, decisions taken by the joint commission were not systematically transmitted to the local communities. This is all the more important as communities play a pivotal role in providing intelligence information about trafficking in their territories. The same communication problem occurs between regional and national entities. Even within the same ecoregion, information on seizures and arrests are most of the time confused. This is illustrated by the absence of any prosecution between 2004 and 2006 while it is known that seizures were made during that period.

2. Lack of trust between stakeholders. Many communities do not trust the Village des Tortues in Ifaty because it is located in the vicinity of Vezo villages that are accused of being regular consumers of tortoises. The justice system is also not considered to be reliable because many judicial cases were either dropped, or the traffickers were given suspended sentences, as a result of "lack of charges". Traffickers often appear afterwards in the villages and threaten the communities, dissuading them from future arrests.

3. Complicity of some members of the joint committee. During the Sokake campaign, it was noticed that information leaks regarding seizure and arrest missions occurred that jeopardized the operations. This means that some members of the committee were accomplices of the traffickers, and proof of the illegal activity was generally removed before the arrival of the committee.

4. *Financial gains*. Some members of the joint committee saw only in its mission an opportunity to earn money (e.g., per diem, lodging, etc.) and shied away from the objectives for which the committee had been created. This calls into question the effectiveness of the committee's actions and also squanders resources.

5. Flexibility of the national committee. The National Steering Committee on tortoises has not been functional since it was set up in 2008 because of a lack of leadership. This situation is compounded by its heavy structure, which hampers its flexibility to face urgent matters.

6. Unsustainable initiatives. Control campaigns conducted between 2003 and 2005 produced promising results. Unfortunately, these initiatives were not sufficient to reverse the trafficking trend, as they were mostly project-based.

7. Lack of synergy at the national level. Actions to stem the trafficking to date remain compartmentalized between initiatives by stakeholders in the field and by those in the capital, especially customs officers at the international airport. Knowing that 90% of the smuggling occurs at the international airport, synergistic actions based on common intervention procedures and effective communication systems at various levels are required.

8. *Reluctance to adapt to face new smuggling strategies*. Following the regular pressure campaigns of 2003–04 traffickers changed their strategies. Instead of transporting live animals, they often opted to kill them and smoke the meat, which was easier to hide and to transport. This means that the strategy to address the trafficking needs to be upgraded to more effectively stem the poaching.

9. Abuses and corruption. The first action made by the joint committee just after it was set up was the seizure of tortoise specimens held by a tourism operator. The latter was forced to pay fictitious and unlawful fees, which were not conforming to the mission of the committee. Clear and transparent procedures should be developed and implemented to avoid future abuses. In addition, the absence of prosecutions in 2004, 2005, and 2006 when 1800 tortoises were seized aroused questions about corruption.

10. Scientific rigor of actions. Thus far, almost all tortoises seized were sent to the Village des Tortues. Although no tortoises have yet been re-introduced from these confiscations, potential problems associated with this approach include: 1) high risk of epizootic diseases following repatriation of specimens with poor health; 2) loss of genetic diversity due to the mixing of individuals from different subpopulations; 3) re-introductions in areas where there are still native remaining populations; and 4) releases potentially in violation of the IUCN guidelines (IUCN, 1998).

*Threat Analysis.* —There are also other factors that are beyond the sphere of influence of the project that either directly, or indirectly, affect the success of tortoise conservation. These include:

1. *Political crisis*. The crisis that started in early 2009 was associated with an increase in trafficking of natural resources in general, and tortoises were no exception, with more than 3300 tortoises seized in 2009 and 2010. These periods are favorable for trafficking and poaching because of the unstable political atmosphere and lack of clear regulatory processes.

2. *Replication of exit points*. Many airports in Madagascar have been upgraded to become international airports (i.e., Toliara, Fort-Dauphin, Toamasina, Nosy-be, and Antsiranana). This will increase the risk of smuggling through these airports. This is all the more crucial as the level of control in these airports is much less rigorous compared to the control at the capitol airport in Antananarivo.

# **Recommendations for Future Conservation Strategies for Tortoises**

Numerous initiatives to stop the harvesting and poaching of tortoises have been implemented so far. These have resulted in tangible outcomes; however, challenges remain to overcome the trafficking. In-depth surveys need to be conducted to grasp the scope and size of the traffic and to understand all the networks involved. This is crucial, as the gendarmes suspect the presence of well-established networks behind the current trafficking scheme. The possibility of the presence of massive exports by sea needs to be investigated. Control systems at the main international airport (Ivato in Antananarivo) need to be overhauled and reinforced, especially for flights leaving for Asian destinations. Recent seizures and arrests in Kuala Lumpur airport will dissuade traffickers from using Malaysian routes in the future. The new law on wildlife trade (no. 2005-018) urgently needs to be distributed and highlighted to all stakeholders. The current structure of the National Steering Committee does not make it effective. A smaller flexible entity with more fluid communication and exchanges will be more relevant to react and make rapid decisions in the face of urgent tortoise issues.

The sizes of seizures in the field and at airports do not automatically reflect the effectiveness of the strategies, but might be the sign of the intensity of the traffic. Successes on stemming tortoise smuggling will depend on coherent and synergistic efforts all along the trade chain from the initial collecting trips, to transport to the international airports, and arrivals at the destination countries. The National Steering Committee will play a crucial role by coordinating and facilitating the circulation of information among all stakeholders. The fast development of new technologies of information in Madagascar in the mobile phone and internet domains is a valuable asset towards the materialization of these efforts.

Local communities living within the distribution of the Radiated Tortoise are highly vulnerable because of lack of economic alternatives, access to markets, and climate uncertainties. Their effective involvement in stopping tortoise trafficking will depend on the incentives they obtain by providing intelligence information on collecting and transportation of tortoises. Tortoise conservation strategies should include means to improve the livelihood of communities that will contribute to their well-being.

The reintroduction of animals should be science-based and follow rigorous and well-established procedures (e.g., IUCN guidelines) to avert the spread of illnesses among wild animals and to avoid the mixing of genetically different subpopulations. Such enterprises should go through a concerted process and be validated by an ad hoc scientific committee appointed by the National Steering Committee.

A linkage between the environment and the justice systems needs to be promoted to dissipate all misunderstanding and mistrust among them. In-depth study on the systemic, procedural, and institutional causes of these prejudices will provide the way to materialize this action. External factors (e.g., political crisis) might influence the tortoise trafficking, however, the commitment of communities to stop the harvesting or the smuggling of tortoises in their territories constitutes an effective way to lessen the impacts of these factors.

The fight against tortoise harvesting needs sustained funding. The establishment of a Tortoise Foundation and the launching of a sponsorship scheme are potential solutions. The development of captive breeding loans is a possibility, although contrary to other species, the legal market (i.e., zoos) for the Radiated Tortoise is already saturated. All these funding schemes should be accompanied by rigorous monitoring, reporting, and verification systems to ensure that they contribute to the conservation of tortoises on the ground.

It is clear that strategies for the conservation of habitats (e.g., landscape conservation, fight against invasive species, etc.) involve many species and ecosystems and should be addressed in wider conservation approaches across the spiny forest ecoregion.

The international scope of tortoise trafficking is wellknown. CITES regulations should be reinforced between Madagascar and destination countries. Specific bilateral collaborations might constitute effective approaches to effectively stop the trafficking between countries. This kind of collaboration can be extended to other species once its effectiveness has been proved.

#### Conclusions

The conservation of the endemic tortoises of southern Madagascar reflects the challenges of conserving flagship species in Madagascar in general. The high dependency of the local economy on natural resources, combined with widespread poverty, especially across the range of these species, require a balanced, integrated approach to conservation and development. In its new 5-year conservation plan, WWF will focus its actions in the spiny forest ecoregion in three priority landscapes: PK32 Ranobe, Mahafaly Plateau, and the Mandrare Valley. The analysis made in this document showed that the Mahafaly Plateau is a major hub for Radiated Tortoise trafficking. We believe that by enhancing partnerships among all stakeholders intervening in this landscape, both in the development and conservation domains, the harvesting and poaching of tortoises can be stemmed. Local communities play a key role in this scheme and sustained economical, social, and cultural solutions need to be rolled-out to enhance their living conditions in order to divert anthropogenic pressures away from natural resources and threatened species.

#### Résumé

Astrochelys radiata et Pyxis arachnoides sont toutes deux endémiques de l'écorégion des forêts épineuses de Madagascar. Les deux espèces sont sympatriques presque tout le long de leurs territoires et sont soumises aux mêmes menaces, à savoir la dégradation de l'habitat, la collecte pour leur viande et pour le commerce international d'animaux de compagnie. L'initiative du Fonds Mondial pour la Nature (WWF) pour la conservation des tortues a débuté avec la création en 1998 de l'écorégion Ala Maiky. Comme pour toute entreprise de gestion et de conservation des ressources naturelles, WWF considère que la réussite repose aussi bien sur l'implication des communautés locales dans la conservation des tortues, que sur la collaboration avec toutes les parties prenantes (gendarmes, justice, autorités environnementales et régionales, directeurs de parcs). Une analyse des faiblesses, des points forts et des risques de toutes les expériences passées et présentes liées à la conservation des tortues radiées a été effectuée. Il en découle des recommandations pour des stratégies complètes pour le futur des espèces terrestres endémiques.

## LITERATURE CITED

- BEHLER, J. 2000. Letter from the IUCN Tortoise and Freshwater Turtle Specialist Group. Turtle and Tortoise Newsletter 1:4–5.
- DURRELL, I., GOOMBRIDGE, B., TONGE, S., AND BLOXAM, Q. 1989. Geochelone radiata. In: Swingland, I.R. and Klemens, M.W. (Eds.). Occasional papers of the IUCN Species Survival Commission 5:96–98.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. First Edition. Cologne: Vences and Glaw Verlag, 496 pp.
- GLOBAL WITNESS AND THE ENVIRONMENTAL INVESTIGATION AGENCY. 2009. Investigation into illegal felling, transport, and export of precious wood in the SAVA Region Madagascar. First Mission report, 40 pp.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D., AND HAWKINS, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34:325–333.
- IUCN. 1998. Guidelines for Re-introductions. Prepared by the IUCN/ SSC Re-introduction Specialist Group. Gland, Switzerland, and

Cambridge: IUCN, 10 pp.

- LEUTERITZ, T.E.J., LAMB, T., AND LIMBERAZA, J.C. 2005. Distribution, status, and conservation of radiated tortoises (*Geochelone radiata*) in Madagascar. Biological Conservation 124:451–461.
- LEWIS, R. 1995. Status of the radiated tortoise (*Geochelone radiata*). Unpublished technical report. Antananarivo: World Wildlife Fund, 33 pp.
- MITTERMEIER, R.A., RHODIN, A.G.J., RANDRIAMAHAZO, H., LEWIS, R.E., VAN DIJK, P.P., HUDSON, R., AND RIOUX PAQUETTE, S. 2008. Vision sokatra gasy—Madagascar turtle vision. Turtle and Tortoise Newsletter 12:7–9.
- O'BRIEN, S. 2002. Population dynamics and exploitation of the radiated tortoise, *Geochelone radiata*, in Madagascar. Ph.D. Thesis, University of Cambridge, UK.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Borneo: Natural History Publications, 147 pp.
- RANDRIAMAHAZO, H., TRAYLOR-HOLZER, K., LEUS, K., AND BYERS, H.O. 2007. Population and habitat viability assessment workshop for endemic tortoise species in Madagascar *Geochelone radiata* (radiated tortoise) and *Pyxis arachnoides* (spider tortoise). Minnesota: IUCN/ SSC Conservation Breeding Specialist Group, 108 pp.
- RASOMA, R.V.J., RANIVOARIVELO, S., MARQUARD, M., RAMILIJAONA, O.R., RAKOTOMALALA, D., RASELIMANANA, A.P., AND GANZHORN, J.U. 2010. Estimation de la densité des populations d'une espèce menacée de tortue terrestre (*Astrochelys radiata*) dans le Parc National Tsimanampetsotsa au Sud de Madagascar. Malagasy Nature 4:33–48.
- TODD, M. 2010. Analyzing the trade in chameleons and other key reptile species in Thailand. Malaysia: TRAFFIC South-East Asia, 45 pp.
- WALKER, R.C.J., RAFELIARISOA, T.H., SMITH, I., AND RAZATIMANATSOA, R. 2010. How range reduction and fragmentation is threatening the long-term survival of the critically endangered Madagascar spider tortoise (*Pyxis arachnoides*). In: Walde, A., Walton, E., and Schaffer, R. (Eds.). Program and Abstracts of the Eighth Annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles. Turtle Survival Alliance, Orlando, FL, pp. 58–59.
- WWF. 2003. Madagascar Dry forest Ecoregion Program: Plan for Biodiversity Conservation in the Spiny Forest Ecoregion. Action Plan for WWF (2003–2006), 43 pp.
- WWF. 2010. Synthèse des informations resueillies sur les tortues (Plateau Mahafaly et PK32 Ranobe). Unpublished internal report.

# **Repatriated Malagasy Tortoises Contribute to their Survival**

LEON A. RAZAFINDRAKOTO<sup>1</sup>

<sup>1</sup>Association Salamandra Nature, 10 Route de Courcival, 72210 Rouperroux-Le-Coquet, France [razaleofr@yahoo.fr]

ABSTRACT.-Illegal traffic of Malagasy tortoises is causing significant population declines. The Brigade Nature of Mayotte confiscated large groups of illegally collected Radiated and Spider Tortoises in Mayotte in 2007 and 2009. The Salamandra Nature Association returned these individuals to the Village des Tortues center (SOS Tortues) in Mangily-Ifaty, near Toliara in southwest Madagascar. In spite of the difficult administrative procedures, the operation was a success due to effective collaboration with other NGOs and the Malagasy and French authorities.

KEY WORDS. – Reptilia, Testudines, Testudinidae, *Astrochelys radiata*, Radiated Tortoise, *Pyxis arachnoides*, Spider Tortoise, illegal trade, confiscation, repatriation, Mayotte, Madagascar

One of the threats placing pressure on the endemic tortoises of Madagascar is the illicit collection of live tortoises for export. In spite of the existence of current laws at national and international levels, traffickers continue to illegally transport these animals by air and sea to international destinations, including Asia (especially Thailand, Hong Kong, and Malaysia) and the Indian Ocean islands, including Reunion and Mayotte.

Mayotte is a French Territory in the Comoros Archipelago, northwest of Madagascar. Between 2008 and 2010, the Salamandra Nature Association, in conjunction with SOPTOM, organized repatriation to Madagascar of Radiated and Spider Tortoises seized in Mayotte by the Brigade Nature de Mayotte and the Office National de la Chasse et de la Faune Sauvage (BNM/ONCFS) (Fig. 1).

Repatriating tortoises is administratively difficult and especially rigorous because the survival of a critically endangered species is at stake. A good example of this was the recent seizure of Ploughshare Tortoises (*Astrochelys yniphora*) in Mayotte and their subsequent repatriation to Madagascar in 2007. The method of transport had to be sufficient to maintain the well-being of the tortoises from Mayotte to the Village des Tortues (Station d'Observation et de Sauvegarde des Tortues – SOS Tortoises) at Mangily-Ifaty, southwest Madagascar near Toliara. The administrative procedures associated with this process lasted about six months and required frequent reporting through e-mail or by telephone.

Unfortunately, when tortoises are collected in nature they are piled up in dugout canoes or cars. It is the same situation when tortoises are put in sealed suitcases without air holes and transported by airplane. To minimize problems during transport, we make boxes with air holes to ensure proper ventilation (Fig. 2). Compartments within the boxes are of suitable dimensions that are proportional to the size of tortoises being transported. Dry herbs are placed in every compartment to prevent the tortoises from coming into direct contact with the wood, and green leaves are provided for food. Air Madagascar is always used for air transport because they provide this service free of charge thanks to our sustainable partnership. In every tortoise repatriation project, the team of Air Madagascar facilitates the return of these animals once all of the administrative paperwork is complete (Fig. 3). When the tortoises arrive at the Village des Tortues, the local team opens the boxes and places the tortoises in basins filled with water containing Betadine, which cleans and also rehydrates them. Then every individual is closely examined and placed in quarantine to avoid passing on diseases to the other tortoises at the center (Fig. 4).

Thanks to the fruitful collaboration with BNM/ON-CFS, the repatriation of 19 Radiated Tortoises (*Astrochelys radiata*) and one Spider Tortoise (*Pyxis arachnoides*) was made in January 2008 (Razafindrakoto 2008). Subsequently, 11 Spider Tortoises were repatriated in February 2010 (Razafindrakoto 2010a). These tortoises will be returned to their natural habitat under care and supervision at a protected area in Tsimanampesotse National Park. In 2010, two students conducted a feasibility study of the release in Tsimanampesotse that was financed by the Turtle Survival Alliance (TSA).

The repatriation is also an initiative to share information and raise public awareness, especially for the Malagasy authorities that need to work together with NGOs to stop the illegal trafficking of tortoises (Fig. 5). Indeed, the authorities should strengthen the means of control at air and sea ports to eradicate or reduce this traffic significantly. In 2010, Salamandra Nature released a 15-minute documentary video to raise awareness about the tortoises and the Village des Tortues at Mangily-Ifaty. This documentary played on Air Madagascar flights during 2010 to celebrate the "International Year of Biodiversity". The magazine Orchid, also produced by Air Madagascar, provided travellers with an article on the



**Figure 1.** The repatriation of the confiscated tortoises was organized by Salamandra Nature, SOPTOM, and the Brigade Nature de Mayotte. Photo by Leon A. Razafindrakoto.

Village des Tortues at Mangily-Ifaty and the repatriation project (Razafindrakoto 2010b).

Thus far, the movie has proven to be the best option for communicating the message; therefore, Salamandra Nature will be seeking financial support to reproduce a version of the movie in dialects of the southwest region of Madagascar. It is recommended to have a seminar on the theme of cooperation among the Mascarene Islands to fight against the illicit export of the biodiversity of Madagascar. The target participants are the forest agents from Madagascar, the Brigade Nature from Mayotte and from Reunion, and the customs officers and gendarmes of the concerned countries. The seminar should be organized by NGOs working with the tortoises in Madagascar and the Ministry of the Environment and Forests.

Repatriation is an action that contributes to the survival of tortoises as long as the responsible authorities



Figure 2. Wooden boxes are used to transport confiscated tortoises. Photo by Leon A. Razafindrakoto.

implement solutions to eradicate illegal trafficking. It is time to act. Associations of local NGOs and communities should be in perfect synergy in the process of the preservation of tortoises. The preservation could become the motivation behind local socioeconomic development by integrating a socio-cultural approach. The purpose would be to give the responsibilities to the people of the valuation and preservation of their natural heritage, including the tortoises, which is the principle of transfer of management (Razafindrakoto 2010a). Finally, all NGOs working on tortoises should form a coalition to have a common strategy, which already exists as "an action plan for conservation". This plan now needs to become a reality in the field.

Acknowledgments. - I send my thanks to the TSA and more particularly, Rick Hudson, President, and his



**Figure 3.** Air Madagascar prepares the paperwork and facilitates the transport of the tortoises once they arrive at the airport. Photo by Leon A. Razafindrakoto.



Figure 4. When the tortoises arrive at the Village des Tortues center, the local team opens the boxes and examines every individual and places them in quarantine to avoid passing on diseases to the other tortoises at the center. Photo by Leon A. Razafindrakoto.



**Figure 5.** The repatriation program provides an opportunity to share information and raise public awareness in local communities. Photo by Leon A. Razafindrakoto.

team, who invited me to participate in their 8th annual symposium in Orlando in August, 2010. In the name of all the team of Salamandra Nature, I am, to all our partners, very grateful, without them these repatriations would not have taken place in time: SOPTOM, ASE, the botanical and zoological Garden of Mulhouse, the Zoo of the Pal, the Bioparc de Doué La Fontaine, the Zoo of Jurques, the Cerza Conservation, the association of Museum SECAS, the Brigitte Bardot Foundation, the Zoo of Champrépus, and the Spaycific' zoo. And I thank very sincerely, the company Air Madagascar that was kind enough to transport, free of charge, the tortoises. Finally, I express all my gratitude to BNM and all the services of the French State between Mayotte and the Ministry of the Environment and Forests Malagasy for their efforts and their efficiencies in the administrative procedure for the repatriation of the tortoises. Thank you to all the team of SOS Tortoises of Mangily-Ifaty for their dedication in the service of the preservation of Malagasy tortoises.

#### Résumé

Le trafic illicite de tortues malgaches conduit au déclin de leurs populations. La Brigade Nature de Mayotte avait confisqué, en 2007 et 2009, de larges groupes de tortues radiées et de tortues araignées collectées illicitement. L'Association Salamandra Nature a rapatrié ces tortues vers le centre SOS Tortues de Mangily-Ifaty à Toliara. Malgré de lourdes procédures administratives, l'opération a été un succès, grâce notamment à la collaboration avec d'autres ONG et les autorités malgaches et françaises.

## LITERATURE CITED

- RAZAFINDRAKOTO, L. 2008. Repatriation of the tortoises Malagasy in Mayotte towards Ifaty. Unpublished report of Mission, February 2008.
- RAZAFINDRAKOTO, L. 2010a. Repatriation of the Spider Tortoises, *Pyxis arachnoides*, Sokapila, from Mayotte to Madagascar. Unpublished report of Mission, July 2010.
- RAZAFINDRAKOTO, L. 2010b. The village SOS Tortoises. Orchid Magazine, Air Madagascar, No. 28, pp. 12–15.

# Conservation of the Madagascar Spider Tortoise (*Pyxis arachnoides*) Amid Changing Land Use Policy: Assessing the Spatial Coincidence of Relict Populations with Protected Areas and Mining Concessions

# RYAN C.J. WALKER<sup>1,2</sup>, CHARLIE J. GARDNER<sup>3,4</sup>, TSILAVO H. RAFELIARISOA<sup>5,6</sup>, INGE SMITH<sup>7</sup>, RICHARD RAZAFIMANATSOA<sup>8</sup>, AND EDWARD E. LOUIS, JR.<sup>6</sup>

<sup>1</sup>Nautilus Ecology, Oak House Pond Lane, Greetham, Rutland, LE15 7NW, United Kingdom [ryan@nautilusecology.org];
<sup>2</sup>Department of Environment, Earth and Ecosystems, The Open University, Milton Keynes, MK7 6AA, United Kingdom;
<sup>3</sup>Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NS, United Kingdom;
<sup>4</sup>WWF Madagascar and Western Indian Programme Office, BP 738, Antananarivo 101, Madagascar [cjamgardner@yahoo.co.uk];
<sup>5</sup>Département de Biologie Animale, Université d'Antananarivo, BP 906, Antananarivo 101, Madagascar;
<sup>6</sup>Madagascar Biodiversity Partnership, Omaha's Henry Doorly Zoo, Grewcock's Center for Conservation and Research, 3701 South 10th Street, Omaha, NE 68107 USA [rafelykely@hotmail.com, genetics@omahazoo.com];
<sup>7</sup>Gardline Marine Sciences Limited, Endeavour House, Admiralty Road, Great Yarmouth, Norfolk, NR30 3NG, United Kingdom [inge\_smith@gardline.co.uk];

<sup>8</sup>Madagascar National Parks, BP 1424-103 Antananarivo, Madagascar

ABSTRACT. – Understanding the spatial distribution of any endangered species threatened by anthropogenic drivers is important if effective management is to be employed. Here we present the results of a comprehensive range survey of the Madagascar Spider Tortoise, Pyxis arachnoides, with resulting species' spatial area of occupancy data applied to a GIS database containing layers detailing: 1) the distribution of current and proposed protected areas within the species range; and 2) sites that have been proposed or are under consideration for commercial mineral extraction activities within the species' area of occupancy in southwest Madagascar. The species is geographically divided into three subspecies, in addition to two newly discovered populations of intergrades. Results show that the species' current area of occupancy is only 29% of the historical suspected extent of occurrence. Of the 2,463 km<sup>2</sup> of remaining area of occupancy, 74% occurs within existing or proposed protected areas (PAs). However, it would be naïve to assume that most of these tortoises will receive complete protection under this management regime from the habitat destruction and poaching that currently threatens the species. Nine of the 12 PAs are classified as IUCN Category III, V, or VI multiple-use PAs that are co-managed by local community associations, and four of these areas are to yet attract promoters for PAs establishments, thus making the threats difficult to manage under this more flexible management structure. We propose that strong mitigation strategies be devised for the 18% of the populations potentially threatened by mineral extraction. Despite this initial bleak outlook for the species, allowing for the fact that most areas that support tortoise populations are now managed, or under tenureship in some way, makes a more coordinated response easier to implement.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, distribution, mineral extraction, protected areas, *Pyxis arachnoides*, area of occupancy, Madagascar

Geographical range size and how it changes through time is one of the fundamental ecological characteristics of a species (Gaston 2003). However, measurement of geographical range is not straightforward (Gaston 1991, 1994, 2003) and from a historical perspective, a multitude of measurements were often used to assess the range of species. From a current conservation perspective, it is now widely regarded that geographical range can be distinguished through two different kinds of measure; 'extent of occurrence', which captures the overall geographic spread of the localities at which a species occurs and 'area of occupancy' which typically is much smaller and is defined by the area of distributions where the species can be actually found, determined from range-wide occurrences (Gaston and Fuller 2009). The range size of narrowly distributed species plays a key role in categorizing species according to their short term likelihood of extinction (Gaston and Fuller 2009). Therefore, in an increasingly human dominated natural environment, the management of such species needs to include not only information on the current spatial distribution of the species in question (Gaston 2003; Gaston and Fuller 2009), but also the potential or actual land use and land tenancy, within this current range, which may have future negative impacts on the species' distribution (Scott et al. 1993). This is particularly evident for non-mobile species with specific habitat requirements. The Madagascar Spider Tortoise (*Pyxis arachnoides*) is one such species, which is thought to have very specific habitat requirements (Walker et al. 2007) and, as a result, is probably sensitive to habitat



Figure 1. Madagascar Spider Tortoise (P. a. arachnoides) from the forests of Tsimanampesotse National Park. Photo by Ryan C.J. Walker.

alteration brought about by land use change (Walker et al. 2012).

The Spider Tortoise (Fig. 1) has historically been one of Madagascar's least studied Critically Endangered chelonians (Pedrono 2008; Walker 2009). It is endemic to a thin strip of coastal dry forest within southwest Madagascar (Bour 1981; Pedrono 2008). The species is currently divided into three genetically and morphologically distinct subspecies (Chiari et al. 2005; Pedrono 2008), with the defining character being a mobile plastral lobe present in the southern form (Pyxis arachnoides oblonga), a semi-mobile lobe present in the nominate subspecies (P. a. arachnoides), and a completely rigid plastral lobe in the northern subspecies (P. a. brygooi) (Fig. 2). To date, the literature can only speculate the exact range of these tortoises (Bour 1981; Durrell et al. 1989; Pedrono 2008). Some authors have suspected a recent decline in numbers and an increase in the fragmentation of populations (Bour 1981; Raxworthy and Nussbaum 2000; Pedrono 2008), as a result of habitat destruction brought about by slash and burn agricultural practices (Seddon et al. 2000), collection to support the exotic pet trade (Walker et al. 2004; Pedrono 2008), and collection as a local food source (Pedrono 2008; Walker 2010).

Two major developments in land use and governance have occurred within the range of the Spider Tortoise over the last decade: the expansion of the protected area system (Système d'Aires Protégées de Madagascar [SAPM]) and the liberalization of the mining sector. As a result of a pledge made at the 5th World Parks Congress in Durban in 2003, Madagascar's government has attempted to increase the country's protected area coverage threefold by 2012 (Rabearivony et al. 2010). A number of new protected areas have been recently established within the spiny forest ecoregion of the southwest, which was previously the least represented ecoregion within the protected area network (Fenn 2003) and also suffers the fastest rates of forest loss in the country (Harper et al. 2007). With the exception of the Mikea Forest National Park and the extension to Tsimanampesotse National Park, all new Protected Areas (PAs) currently in the establishment phase within the region are proposed as IUCN category III, V, and VI multiple-use protected areas, to be co-managed by local community associations (Gardner 2011).

During the late 1990s the government adopted a World Bank-backed Mining Code, with the primary goal of improving the industry's productivity and subsequent economic development (Sarrasin 2006). This Mining Code was instrumental in the development of the 700,000 tons/ yr ilmenite extraction project at Tolagnaro on Madagascar's southeastern coast (Li et al. 2009). Currently a number of mineral extraction projects are in the development stages on the southwest coast, including the proposed exploitation of the Ranobe deposit, which contains an estimated 465 million tons of mineral sands with 6.2% heavy mineral content (Ranjatoelina 2007). Much of the remaining land falling outside of existing and proposed protected areas has been leased to mineral extraction companies, or is in the process of being subjected to Mining Code-backed exploratory mining for mineral sands (Cardiff and Andriamanalina 2007; WWF 2010).



**Figure 2.** Suspected extent of occurrence of the three subspecies of Spider Tortoise; (top to bottom) *P. a. brygooi*, *P. a. arachnoides* and *P. a. oblonga* described by Bour (1981) and Pedrono (2008) with vegetation cover data overlaid and the locations of the 131 presence/absence survey points.

Much of the coastal forests of the southwest, both within proposed protected areas and proposed exploitation zones, have been subjected to little or no baseline biodiversity surveying (Fenn 2003); therefore, little is known about the distribution of remnant populations of Spider Tortoises (Raxworthy and Nussbaum 2000; Pedrono 2008; Walker 2010). As a result of the two conflicting land use policies planned for this region of coastal southwest Madagascar, and the tortoise becoming a focal species for WWF's southern spiny forest ecoregion conservation programme (WWF 2010), we undertook a detailed presence/absence survey across the extent of occurrence of P. arachnoides, described by Bour (1981) and Pedrono (2008). This survey aimed to develop a real time, distribution GIS, detailing current tortoise area of occupancy (Gustafson et al. 2001; Anadón et al. 2006; Gaston and Fuller 2009), historical extent of occurrence (Bour 1981; Pedrono 2008), proposed or existing protected area distribution, and finally, spatial data describing the extent of the land proposed to be subjected to mineral extraction. These results will then assess the potential conservation risk to the species resulting from mineral exploitation.

# METHODS

*Study Area.* — *Pyxis a. brygooi* inhabits the coastal, dry Mikea forest of southwest Madagascar (Durrell et al. 1989; Pedrono 2008; Fig. 2), a habitat which is classified as a subtype of the southern dry spiny forests. These forests are unique to the southwest coast of Madagascar (Fenn 2003). The Mikea forests have historically stretched from north of Toliara to approximately 30 km north of Morombe (Seddon et al. 2000; Fig. 2). Pyxis a. brygooi is thought to support an extent of occurrence within the Mikea forest spanning approximately 102 km of coastline between the Manombo River and the forests north of Morombe (Bour 1981; Pedrono 2008; Fig. 2). Further south, Pyxis a. arachnoides and P. a. oblonga are thought to inhabit approximately 258 km and 195 km of coastline, respectively (Pedrono 2008; Fig. 2), that is classified as southern dry spiny forest (Fenn 2003). These arid coastal forests have long been identified as extremely important for their biodiversity (Domergue 1983; Seddon et al. 2000), in particular for reptiles (Raxworthy and Nussbaum 2000).

*Image Processing.* — Vertebrate biologists have long used knowledge of a species' habitat to predict its presences or absence in an area (Baker 1956; Armstrong 1972) and to date this has been the case with *P. arachnoides* (Bour 1981; Pedrono 2008). However, it is thought that extensive poaching has removed Spider Tortoises from large areas of their natural range, where intact areas of habitat remain (Walker et al. 2007; Pedrono 2008; Walker 2010),

The maps published by Bour (1981) and Pedrono (2008) detailing the extent of occurrence of *P. arachnoides* were scanned from original documents and converted into electronic Joint Photographic Experts Group (JPEG) files. These JPEGs were imported into the GIS software ArcMap (ArcGIS 9.0), georeferenced, and then polygons represent-



Figure 3. Spatial distribution of existing or proposed protected areas under the Madagascar Protected Areas expansion program and sites proposed under the Madagascar Mining Code for mineral extraction within the southwest coastal zone of Madagascar.

Figure 4. Google Earth image of a section of the presence/absence survey area within the in the Manombo River discharge point, southwest coastal Madagascar. The dark line delineates intact habitat to the north of the line that was selected for surveying with degraded land south of the line characterized by parcels of agriculture and livestock corrals. These high resolution images were also used in conjunction with the Landsat imagery to identify the limits of the polygon boundaries for parcels of habitat that support tortoise populations and to identify areas of degraded habitat and, therefore, areas devoid of tortoises.

ing the extent of occurrence of the species were produced using the digitizing function. Using a base map of southern Madagascar these polygons were used as the base layer for our GIS database.

Unlike Astrochelys radiata, a tortoise species sympatric in part of its range with P. arachnoides, Spider Tortoises are seldom found in degraded habitats, such as areas cleared for charcoal production or agriculture (Pedrono 2008; Walker et al. 2102; Fig. 4). Shapefiles derived from high-resolution remotely sensed imagery (IKONOS and QuickBird) from Google Earth<sup>TM</sup> and shapefiles representing southern dry spiny forest classification derived from Landsat Enhanced Thematic Mapper Plus (ETM+), acquired from Conservation International and used in the production of the GIS work reported in Harper et al. (2007) were imported in our GIS. The Landsat shapefiles represented a supervised classification based on a simple set of classes: forest or non-forest using Erdas imagine 8.4. software (Harper et al. 2007).

Using the polygon describing the extent of occurrences (Bour 1981; Pedrono 2008) as a geographical guide, the entirety of the extent of occurrence of P. arachnoides plus some areas of suitable habitat within the periphery of the range were categorized into the following two classes: suitable habitat (intact forest) and non-suitable habitat (degraded forest or areas of cleared habitat). The high degree of resolution of Google Earth<sup>TM</sup> images (4m pixel resolution) allowed for the classification to be undertaken by human eye (Rollinson et al. 1999). This classification revealed 69 suitable survey areas (Figs. 2 and 4). All spatial data were georeferenced and both data and the GIS database were projected to WGS84.

Field Methodology. — Across these 69 survey areas, a total of 131 1-km transects were surveyed (Fig. 2) and concurrent to each transect, a timed search was also undertaken (Walker 2012). Transect and timed search sites were allocated to as many areas as were physically accessible within the wider 69 survey areas, with field work undertaken during the logistically challenging wet season. Field work was undertaken during January and February 2009, 2010, and 2011 during the annual period of heightened tortoise activity (Walker 2012). Surveying was limited to 0630–1030 hrs and 1530-1830 hrs during the cooler parts of the day, when these crepuscular tortoises are most active (Walker 2012). Upon reaching each survey point, two observers traversed each transect, taking an easterly bearing for 1 km using the tracking function on a hand-held GPS to measure distance. The surveyors walked side by side, each carefully searching for tortoises on their respective side of the transect line and directly in front of them. Surveyors moved very slowly, with transects taking on average 77.3 ( $\pm$  40.2) min to traverse, with the time being dependent upon terrain and density of the vegetation. Spider Tortoises do not spend time underground in burrows, unlike some species of desert tortoises such as Gopherus spp. (McCoy et al. 2002), thus ensuring easier detection; however, the species can often be partially buried in the substrate. Because of their small size and cryptic nature (Walker et al. 2007; Walker 2012) tortoises were normally detected only within 3 m of the middle of the transect line. As a result, an additional two surveyors undertook a timed search concurrently to the transect survey. Each timed search lasted the length of the time taken to traverse the transect with surveyors searching at least 10 m from the middle of the transect to eliminate duplicate detection by the two teams. Timed searchers focused their search on the base of low lying vegetation, a microhabitat favored by the species (Walker et al. 2007; Pedrono 2008). Walker (2012) showed that in field trials, adult Spider Tortoises during the summer months support a detection probability of 1.0. Detected tortoises were marked using a small dot of nail polish on the top of the carapace to avoid duplicate counting.

Establishing Tortoise Distribution. — The reliance of Spider Tortoises upon intact habitat (Walker et al. 2012) and their low dispersal rates, which are similar to other arid environment tortoises (Eubanks et al. 2003), suggest that the species will generally not move across large open degraded areas. Waypoints marking the start of each transect/timed search were added to our GIS (Fig. 2) and each waypoint was coded as either having a presence or absence of tortoises recorded within the transect/timed search. By zooming into the GIS and using the classified Google Earth<sup>™</sup> and Landsat ETM+ data (Fig. 4), it was possible to digitize around the perimeter of the areas classified as suitable habitat which supported populations of tortoises, which in turn forms a polygon. It was then possible to interpret areas (polygons) of habitat where tortoises were recorded as present and areas that appeared, from these results, to be devoid of tortoises. These polygons were added as a layer to the GIS and used to represent a reliable estimation of the current area of occupancy of the species. By applying the area calculation function in ArcGIS 9.1 to each polygon occupied by tortoises it was possible to establish the current area of occupancy of P. arachnoides in km<sup>2</sup>.





**Figure 5.** Current spatial area of occupancy (AOO) for the three subspecies and two intergrade populations of Spider Tortoises (populations A-E on main map) displayed in black in relation to the proposed/existing protected areas displayed in cross hatch (green) and areas of proposed mineral extraction displayed in cross hatch (red). The red dots represent small remnant populations missed by the survey, as reported by Scott et al. (2008) north of the *P. a. arachnoides* range (C), and an individual missed by the survey, reported by Rick Hudson (pers. comm.) to the east of the *P. a. arachnoides* range (C).

In addition to our field data, we included the reports of two recent (2008 and 2010) reliable observations of very small remnant populations. These areas were either missed by our survey as a result of the very small size of the population or the record fell significantly outside of the extent of occurrence.

Applying Land Use Classes to Tortoise Distribution. — We added GIS land use data to the GIS database (Fig. 3), acquired from WWF Madagascar (SAPM 2010). Land use was represented as three classes: 1) existing/ proposed protected area; 2) areas of proposed mineral exploitation; and 3) land neither protected, proposed protected, or proposed for exploitation. The data layer representing the current range of the tortoises was then overlaid on the land use data layer, and polygons were created representing three classes of the species' range: la) range within proposed protected areas; 2a) range within proposed exploitation areas; and 3a) range neither

**Table 1.** Current area of occupancy (AOO) of Spider Tortoises, *Pyxis arachnoides*, displayed against the suspected extent of occurrence (EOO) as documented by Bour (1981) and Pedrono (2008), in addition to the extent of AOO for each population of tortoise that fall within existing or proposed protected areas or sites of proposed mineral extraction.

Subspecies	Cur- rent AOO (km <sup>2</sup> )	EOO (km²)	Reduc- tion in EOO to AOO (km <sup>2</sup> )	Percent reduc- tion in EOO to AOO	Current AOO in Protect- ed Areas (km <sup>2</sup> )	Per- cent of current AOO in Pro- tected Areas	Current AOO in proposed extrac- tion areas (km <sup>2</sup> )	Percent current AOO in proposed extrac- tion areas	Protected areas	Proposed resource to be ex- tracted	No. of potential extrac- tion sites
P. a. brygooi (A)	500	2439	1939	80	500	100	0	0	Zone 1 - Mikea Forest Na- tional Park, Mangoky Ihotry Protected Area Complex, Zone 2 - Velondriake Com- munity Managed Protected Area Zone 3 - Mikea Forest Na- tional Park	N/A	0
P. a. brygooi x arachnoi- des intergrade (B)	100	-	-	-	55	55	38	38	PK32-Ranobe Protected Area	Zircon, Ilmenite	2
P. a. arach- noides (C)	1029	3178	2149	68	796	77	205	20	Tsimanampesotse National Park Extension, Tsiman- ampesotse National ParkA, Tsinjoriake Protected Area, SAPM Unnamed/Unpro- moted Protected Area	Calcaire, Ilménite, Monazite, Zircon, Granite	26
P. a. ara- chnoides x oblonga in- tergrade (D)	267	-	-	-	187	70	11	4	Southwestern Coastal Wetlands Protected Area, Mahafaly Plateau South, Unnamed/Unpromoted Pro- tected Area	Ilménite, Granite, Calcaire, Zircon	3
P. a. oblonga (E)	568	2865	2297	80	268	47	197	25	Cap Sainte Marie Special Reserve, SAPM South Un- promoted Protected Area	Ilménite, Zircon	1
Total	2464	8482	6018	71	1805	74	451	18			32

protected nor exploited. The area calculation function was then applied to these three classes. All spatial data were georeferenced and both data and the GIS database were projected to WGS84.

## RESULTS

Tortoise Distribution. - Spider Tortoises are now confined to eight isolated sites across the area of what was thought to be the species' extent of occurrence (Fig. 5). The last remaining populations of P. a. brygooi are confined to the extreme north of the range, within the forests east of the coastal town of Morombe, the extreme south of the range north of the Manombo River, and a small isolated coastal forest within the center of what was considered the historical range. Large expanses of suitable habitat appear to be devoid of tortoises, in particular towards the center of the extent of occurrence (Fig. 5). Tortoise density is highly variable, with a mean encounter rate of 1.7 ( $\pm$  6.2), ranging from 0–46 ( $\pm$ 6.2) tortoises recorded per linear km of transect for the region surveyed north of Toliara. Pyxis a. brygooi now occupies a total area of occupancy of 500 km<sup>2</sup> (Fig. 5), compared to the 2439 km<sup>2</sup> area of suspected extent of occurrence described by Bour (1981) and Pedrono (2008) (Fig. 2). This current area of occupancy represents a reduction of 1939 km<sup>2</sup>(79%) from the suspected area of occurrence stated in the previous studies (Table 1).

We discovered a currently undescribed transitional zone within the coastal zone south of the Manombo River and north of Toliara (Figs. 5, Table 1) where populations of tortoises displayed variable morphology. Individual tortoises in this zone had three distinctly different variations in plastron hinge mobility morphology. There were individuals displaying characteristics consistent with P.a. brygooi, some animals had characteristics consistent with the nominate subspecies (P.a. arachnoides), and there were tortoises displaying morphological traits which display a mixture of the two subspecies. We suggest that this area is a zone of intergradation between P. a. brygooi and P. a. arachnoides. This population of intergrades covers an area of occupancy of 100 km<sup>2</sup> (Fig. 5; Table 1) and falls within the zone which was previously described by Pedrono (2008) and Bour (1981) as part of the suspected extent of occurrence of P. a. arachnoides (Fig. 2).

Spider Tortoises appear to be largely absent within the coastal zone between the Fiherenana and Onilahy Rivers (Fig. 5), probably as a result of poaching and habitat loss on account of the close proximity of the provincial capital Toliara (Walker and Rafeliarisoa 2010). However, a very small isolated population has been recently reported to occur approximately 8 km north of the Onilahy River (Scott et al. 2008) (Fig. 5). An unfragmented zone supporting a large population of *P. a. arachnoides* begins south of the Onilahy River to the west of the Mahafaly Plateau. This population

stretches west of the Plateau along the coastline for approximately 72 km, south to the Ampalaza region (Fig. 5) and up to about 8 km inland. One isolated individual female tortoise was found during a separate study in March 2010, 62 km inland on the main road serving the coastal region south of the Onilahy River (Rick Hudson, pers. comm.) (Fig. 5). On account of the large discrepancy in what is considered to be the species' natural range, and that it was found next to the only route in or out of the region, it is suspected that this tortoise was probably an escapee that had fallen off an ox cart used by a poaching operation. We discovered a further undescribed zone of intergradation between P.a. arachnoides and P.a. oblonga on either side of the Linta River, occupying an area of 267 km<sup>2</sup> (Fig. 5; Table 1), in what was historically considered to be the range of P. a. arachnoides (Bour 1981; Pedrono 2008) (Fig. 2).

Tortoise density for *P.a. arachnoides* and the population of *P. a. arachnoides* x *oblonga* intergrades is less variable than that of *P. a. brygooi* and the northern intergrade population. We recorded a mean encounter rate of 2.3 ( $\pm$  2.2) tortoises, ranging from 0–7 ( $\pm$  2.2) tortoises per linear km of transect. *Pyxis a. arachnoides* now occupies a total area of occupancy of 1029 km<sup>2</sup> (Fig. 5; Table 1), compared to the 3178 km<sup>2</sup> area of suspected extent of occurrence described by Bour (1981) and Pedrono (2008) (Fig. 2; Table 1). This current area of occupancy represents a reduction of 2149 km<sup>2</sup> (68%) of the extent of occurrence described by the previous authors, however, it must be noted that the reclassification of the range of the subspecies to include the two populations of intergrades contributes largely to this decline in range for *P. a. arachnoides*.

The area of occupancy of *P. a. oblonga* equals 568 km<sup>2</sup> of forests around the Cap Sainte Marie region and the dunes stretching east of the Cape (Fig. 5, Table 1). This subspecies has the greatest discrepancy in area of occupancy compared to the historical extent of occurrence. Our data suggests that the species occupies only 19% of the range described by Bour (1981) and Pedrono (2008).

Land Use Analysis. — With the proposed protected area expansion in place, all 500 km<sup>2</sup> of the area of occupancy of *P. a. brygooi* falls within three newly proposed protected areas (Fig. 5; Table 1) and currently no proposed mineral extraction is planned for any of this subspecies' remaining range. The northern reaches of the most northerly population of *P. a. brygooi* fall within the Mangoky/Ihotry Protected Area Complex and the southern portion of this population falls within the Mikea Forest National Park (Zone 1; Fig. 5). The small population in the middle of the historical range is covered by the Velondriake Community Managed Marine and Coastal Protected Area (Zone 2; Fig. 5; Table 1).

The *P. a. brygooi* x *arachnoides* intergrade population south of the Manombo River faces the greatest potential impact from proposed mineral extraction, with a possible 38% of the remaining population under threat. Our results suggest that 55% of this population falls within four protected areas (Fig. 5; Table 1). *Pyxis a.arachnoides* currently has the greatest remaining range of all the subspecies or intergrade populations; it covers a continuous coastal belt of forest measuring 1029 km<sup>2</sup>. Fragments of this population occur within three proposed protected areas and one currently gazetted protected area (Tsimanampesotse National Park), as well as one area which has been prioritized for inclusion in Système d'Aires Protégées de Madagascar (SAPM), but currently is unpromoted as a protected area (Fig. 5, Table 1). However, the population of *P. a. arachnoides* could be potentially impacted by 26 mineral extraction operations (Table 1).

The only protected part of the narrow range of *P. a. oblonga* is within Cap Sainte Marie Special Reserve (Fig. 5); however, some of the range falls within a currently unpromoted proposed protected area. Of the remaining range, only 268 km<sup>2</sup> is currently within this one protected area and one proposed area (Table 1, Fig. 5), and represents the smallest protected population of the three described subspecies.

## DISCUSSION

Pedrono (2008) stated that authors as far back as the late 1970s were reporting suspected declines of *P. arachnoides* populations. Bour (1981) suggested that although the potential range of the Spider Tortoise was relatively large (i.e. extent of occurrence), populations may have been fragmented from one another and contain variable numbers of individuals. Raxworthy and Nussbaum (2000) estimated that there were probably more than 10 populations of *P. arachnoides*, thus recognizing that the population was probably fragmented to some degree and that the suspected area of occurrence was probably not accurate. However, until now, no data have been collected to quantify this fragmentation for any of the three subspecies. The perceived decline of a 70.8% reduction in range when one compares the current area of occupancy compared to the extent of occurrence described by Bour (1981) and Pedrono (2008) appears dramatic. However, the earlier estimates of range were made by ground truthing only 28 sites (Bour 1981) without any GIS analysis. Our work involved far greater ground truthing and spatial analysis effort, and as a result the distribution estimate is spatially better resolved, so that discontinuities and disjunctions are apparent, and more areas are found to be unoccupied (Gaston 1994; Goehring et al. 2007). Despite this, habitat loss and poaching have had, and continue to have, serious impacts on the species' distribution, with range decline often a strong predictor of extinction risk (Gaston and Fuller 2009). For example, Walker et al. (2012) reported projection modelling exercises that showed that a population of Spider Tortoises within the Anakao region is declining by 1.4% per year as a result of habitat loss. Also tortoises have been all but extirpated from most regions where the local population hunts them for food, particularly within the northern part of the range (Walker 2010; Fig. 6). Therefore, despite the true rate of range decline remaining relatively unknown, the current data should now be used as a baseline for future distribution monitoring.

False absences are always considered a risk when undertaking presence/absence surveys using single visits. The



**Figure 6.** The remains of 60–70 adult and juvenile *P. a. brygooi* probably collected and cooked in the forest by nomadic stock herders in the Velondriake Community Managed Protected Area, March 2010. Photo by Ryan C.J. Walker.

precision of these surveys could possibly have been improved through site occupancy modelling (Mackenzie et al. 2002), however, this methodology would have required multiple visits to each survey site, which would have been logistically unfeasible. Site occupancy modelling becomes more relevant for species with a detection probability of <1.

The results of this study show that *P. a. brygooi* is now confined to three isolated areas of forest across its historical suspected extent of occurrence. Habitat destruction and fragmentation has had, and could continue to have, wide-ranging impacts for the conservation of this subspecies. Aponte et al. (2003) have demonstrated that habitat fragmentation amongst forest tortoises (in this case *Chelonoidis carbonaria*) can result in altered age structure and population density.

Pyxis a. arachnoides enjoys a relatively uninterrupted area of occupancy (Fig. 5); however, this region of coastline is relatively heavily populated compared to the Mikea forests further north and is suffering from habitat loss and invasion from non-native floral species such as Opuntia spp. (Walker and Rafeliarisoa 2010). In addition to range reduction as a result of habitat fragmentation, the Spider Tortoise could be currently facing direct exploitation for the pet trade. During the past 20 years, very heavy levels of collection took place prior to the species becoming listed on Appendix I of the Convention on International Trade in Endangered Species (CITES) in 2004 (Walker et al. 2004; Pedrono 2008). This harvesting may still pose a problem for the species. Some authors have also suggested that P. a. brygooi is being impacted as a result of collection by the Mikea tribes as bushmeat (Pedrono 2008; Walker 2010; Fig. 5); however, no data are currently available to quantify that impact.

Of the remaining range of Spider Tortoises, 74% lies within recently gazetted or existing protected areas, including 100% of the existing *P. a. brygooi* population. However, four of these areas across the species' range, while prioritized for protected area creation within SAPM, are yet to attract promoters to catalyse the protected area establishment process. With the exception of the two National Parks (Mikea Forest and Tsimanampesotse) and Cap Sainte Marie Special Reserve, all proposed new protected areas in the region are proposed as IUCN category III, V, or VI multiple-use PAs, which will be co-managed by local community associations (Gardner 2011). These PAs seek to simultaneously conserve biodiversity while promoting the sustainable use of natural resources for poverty alleviation and local development (Gardner et al. 2008), and emphasize the avoidance of negative impacts on local communities due to resource use restrictions. As a result, these PAs will be zoned so as to permit continued forest resource use through much of their area, and are likely to suffer continuing habitat degradation (Gardner 2009) with potential negative implications for tortoise populations. Further, surveillance and control within these PAs will largely be undertaken by local communities themselves, with the result being that local consumption of tortoises and overexploitation of the habitat can be expected to continue unless local agreements can be reached to cease the practice (see discussion of dina below). Such agreements may be difficult to reach, however, given the poverty and food insecurity (Gardner 2011) of these communities. It is therefore simplistic to assume that protected area creation alone will be sufficient to ensure the viability of Spider Tortoise populations within such sites.

Outside such protected areas, a significant proportion of the remaining global population of Spider Tortoises could potentially face threats from future mineral extraction under the proposed mining schemes for the southwest. Currently, 18% (451 km<sup>2</sup>) (Table 1) of the range of the species falls within proposed mineral extraction sites. As a result of ca. 40% of the range of the northern intergrade population (Fig. 5; Table 1) currently occurring within sites proposed for mineral extraction, there is a need for some sort of adaptive conservation management or mitigation to be adopted by the mineral extraction companies in collaboration with, or under the guidance of, local conservation practitioners or NGOs.

Spider Tortoises are protected under Malagasy law (Pedrono 2008); however, there is no set policy or guidelines in place to mitigate potential or actual impact as a result of operations undertaken under the Mining Code, to either endangered species such as these tortoises or habitats (Tiana Ramahaleo, pers. comm.). Mining operations, particularly in developing counties where environmental impact assessment is sometimes poorly enforced, have often contributed to a negative perception by the general public and conservation community of mining companies and the way that they operate (Labonne 1999; Veiga and Hinton 2002). As a result, the government of Madagascar, the international mining companies engaged in these proposed mineral extraction projects, and conservation NGOs need to work in partnership during the planning stage of these proposed operations in order to plan and implement effective environmental mitigation strategies for this and other threatened species occurring within the region.

Two main mitigation strategies are available and have been used in similar situations; the first being a thorough and well-coordinated tortoise translocation program, whereby
animals are collected from sites where populations face threats from mineral extraction impacts and are then moved to protected areas within the taxon's natural range (Burke 1991; Soorae and Baker 2002; Field et al. 2007). Translocation has been accomplished reasonably effectively in North America for some of the *Gopherus* species of tortoises (Berry 1986; Field et al. 2007). However, mortality can be high in certain circumstances, due to stress or spread of disease between different populations (Berry 1986). The preservation of genetic diversity is important when managing the conservation of endemic species with restricted ranges (Booy et al. 2000). Translocation projects can run the risk of causing unwanted genetic mixing (Dodd and Seigel 1991), which could be problematic in the case of the Spider Tortoise on account of the now fragmented populations and the need to preserve the genetic and morphological characteristics of the zones of intergradation and the three subspecies. An example of a successful translocation project involving lemurs (Eulemur collaris) was supported by QIT Madagascar Minerals (QMM) prior to the development of the mineral sands project which is currently operational within the forests around Tolagnaro on the southeast coast (Donati et al. 2007). In the case of the Spider Tortoise, however, the success of such a program would depend on the existence of translocation areas in which the threats (i.e., collection, local consumption, and habitat destruction; Fig. 6) that have led to local extinctions through much of their range could be successfully reduced to ensure the persistence of translocated populations.

The second potential form of mitigation strategy could be for mining companies, in consultation with the conservation sector, to identify some proposed extraction sites which support areas with good populations of tortoises and good habitat to gazette as protected areas, managed by the mining companies with technical support from conservation NGOs. The Venetia Limpopo Nature Reserve in South Africa, initially established by the De Beers mining company, then later incorporated into the Vhembe Dongola National Park, provides an example of such partnerships (Yakovleva 2005). This strategy has often been seen as an easy way of generating positive publicity for companies operating within a sector with an actual or perceived poor environmental record (Yakovleva 2005). On account of southwestern Madagascar's unique biological diversity (Domergue 1983; Seddon et al. 2000) and its attention and focus from the international conservation community, it is important that any mineral extraction be undertaken with a full and rigorous environmental mitigation strategy. Currently the lack of infrastructure and political instability are the limiting factor restricting mineral exploitation within this region in the imminent future (Sarrasin 2006), thus allowing time for full mitigation and impact strategies to be established.

If managed correctly, this proposed mineral extraction could bring much needed economic development to the impoverished southwest coastal region of Madagascar. At present the forest loss within the range of the Spider Tortoises is estimated at 1.2% per year (Harper et al., 2007), which is mostly attributable to uncontrolled subsistence agricultural practices and charcoal production (Seddon et al. 2000). It is inevitable that forest resource use and subsequent habitat degradation will continue within most of the region, on account of the multiple-use nature of most of the new protected areas, and the proposed mineral extraction will also have some degree of environmental impact. However, with careful planning, management and dialogue between the mineral extraction companies, local communities, government, and conservation practitioners, this impact can be mitigated and controlled to some extent.

Almost all of the Spider Tortoise's current range will come under some form of tenureship by mineral extraction companies, Madagascar National Parks, or the communities who will soon manage the new multiple use protected areas. This new regional protected area structure could facilitate the implementation of large-scale community sensitization programs, such as the environmental education, community outreach work, and tortoise poaching enforcement work currently being undertaken on a smaller scale by WWF (WWF 2010). Communities can also be encouraged to address tortoise hunting for bushmeat in the Mikea region through the introduction of local bylaws (dinas) banning the harvest of tortoises, although the success of this approach is dependent on community buy-in and the perceived legitimacy of such rules (Rabesahala Horning 2003; Andriamalala and Gardner 2010).

It is suspected that most of the poaching of tortoises for the pet trade is undertaken by people from outside of the region and will therefore be more difficult to address (WWF 2010); however, WWF has had a limited amount of success in intercepting poachers and poached tortoises in the region (WWF 2010). The conservation issues facing these last remaining populations of Spider Tortoises are wide ranging and complex, and protected area creation alone will not be sufficient to guarantee their viability. However, the fact that most areas that support tortoises are now managed in some way will make a more coordinated response to their conservation easier to implement.

Acknowledgments. - This three-year project was financially supported by conservation grants from the Turtle Conservation Fund and EAZA/Shellshock Campaign, Turtle Survival Alliance, Mohamed bin Zyed Species Conservation Fund, Royal Geographical Society of London, British Chelonia Group, Leicester Tortoise Society, and Chelonian Research Foundation. Logistical support and help with field work was provided by Madagascar National Parks, Solonombana Vitantsoa, Alice Ramsay, Julean Bruchard, Harrison Randrianasolo, Hery Rasolohery, Jean Claude Rakotoniaina, Athanase Maminrina, Gervais Sylvestre Rakotoarivelo, Al Harris, and project partners Blue Ventures Conservation, Madagascar Institut pour la Conservations des Ecosystèmes Tropicaux, Ministere de l'Environnement et de Forets, and the University of Antananarivo. GIS forest cover and land use cover data was generously supplied by Conservation International Madagascar and WWF Madagascar respectively. Unpublished information on isolated tortoise sightings was provided by Rick Hudson. Advice on survey design was provided by Mike Gillman and Justin Gerlach. Review comments from Richard Young and Jonathan Silvertown much improved this paper. Thank you to the coastal forest communities of southwest Madagascar for granting access to community land.

#### Résumé

La gestion efficace de toute espèce menacée par des facteurs anthropogéniques requiert la connaissance de sa distribution spatiale. Nous présentons ici les résultats d'une étude complète de l'aire de distribution de la tortue araignée de Madagascar, Pyxis arachnoides, dont les données sur la distribution spatiale ont été soumises à une analyse des écarts pour une seule espèce. La distribution actuelle de la tortue a été ajoutée à une base de données SIG contenant des strates détaillant: 1) la répartition des aires protégées existantes ou proposées à l'intérieur de l'aire de distribution de l'espèce, et 2) les sites proposés ou en cours de discussion pour des activités commerciales d'extraction minière au sein de l'aire de distribution de l'espèce dans le sud-ouest de Madagascar. L'espèce est géographiquement divisée en trois sous-espèces. En outre, deux populations intermédiaires ont été récemment découvertes. Les résultats montrent que l'aire de distribution actuelle de l'espèce ne représente que 29% de la zone d'occurrence historique suspectée. Sur les 2463 km<sup>2</sup> de territoire restants, 74% sont compris dans des aires protégées (AP) actuelles ou proposées. Il serait toutefois naïf de croire que les tortues bénéficieront en majorité de ces zones protégées et qu'elles ne subiront plus ni destruction de l'habitat ni braconnage. Neuf des 12 AP sont classés par l'UICN en AP à usage multiple de Catégorie III, V, ou VI, co-gérées avec les associations communautaires locales. Quatre de ces zones intéressent malgré tout les promoteurs immobiliers, rendant les menaces plus difficiles à cerner sous cette manière flexible de gestion. Nous recommandons que soient élaborées des stratégies rigoureuses d'atténuation des impacts de l'extraction minière sur les 18% de populations à risque. Même si cette perspective ne présage rien de bon pour les tortues, le fait de savoir que la majorité des zones où se trouvent les tortues sont soit gérées, soit sous un régime foncier particulier, permet de réagir en conséquence plus facilement.

#### LITERATURE CITED

- ANADÓN, J.D., GIMÉNEZ, A., MARTÍNEZ, M., MARTÍNEZ, J., PÉREZ, I. AND ESTEVE, M.A. 2006. Factors determining the distribution of the spur-thighed tortoise *Testudo graeca* in south-east spain: a hierarchical approach. Ecography 29:339–346.
- ANDRIAMALALA, G., AND GARDNER, C. J. 2010. L'utilisation du dina comme outil de gouvernance des ressources naturelles: leçons tirés de Velondriake, sud-ouest de Madagascar. Tropical Conservation Science 3: 447–472.
- APONTE, C., BARRETO, G.R., AND TERBORGH, J. 2003. Consequences of habitat fragmentation on age structure and life history in a tortoise population. Biotropica 35:550–555.

- ARMSTRONG, D.G. 1972. Distribution of mammals in Colorado. University of Kansas Publication of Natural History Monographs 3:415.
- BAKER, R.H. 1956. Mammals of Coahuila, Mexico. University of Kansas Publication of Natural History Survey of North American Fauna 55:416.
- BERRY, K.H. 1986. Desert Tortoise (*Gopherus agassizii*) relocation: Implications of social behavior and movements. Herpetologica 42:113–125.
- BOOY, G., HENDRIKS, R.J.J. SMULDERS, M.J.M. VAN GROENENDAEL, J.M., AND VOSMAN, B. 2000. Genetic diversity and the survival of populations. Plant Biology 2:379–395.
- BOUR, R. 1981. Etude systématique du genre endémique Malagache Pyxis Bell, 1827 (Reptilia, Chelonii). Bulletin Mensuel de la Société Linnéenne de Lyon 50:154–176.
- BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., AND LAAKE, J.L. 2001. Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, London, UK.
- BURKE, R.L. 1991. Relocations, repatriations, and translocations of amphibians and reptiles: Taking a broader view. Herpetologica 47:350–357.
- CHIARI, Y., THOMAS, M., PEDRONO, M., AND VEITES, D.R. 2005. Preliminary data on genetic differentiation within the Madagascar spider tortoise, *Pyxis arachnoides* (Bell, 1827). Salamandra 41:35–43.
- DODD, C.K., JR. AND SEIGEL, R.A. 1991. Relocation, repatriation and translocation of amphibians and reptiles: Are they conservation strategies that work? Herpetologica 47:336–350.
- DOMERGUE, C. A. 1983. Note préliminaire en vue de la mise en réserve de la forêt du P.K. 32 au nord de Tuléar Madagascar. Bulletin de l'Académie Malgache 61:105–114.
- DONATI, G., RAMANAMANJATO, J.B., RAVOAHANGY A.M., AND VIN-CELETTE, M. 2007. Translocation as a conservation measure for an endangered species in the littoral forest of southeastern Madagascar. The Case of *Eulemur collaris*. In: Ganzhorn, J.U., Goodman, S.M and Vincelette, M. (Eds.). Biodiversity, Ecology and Conservation of Littoral Ecosystems in Southeastern Madagascar, Tolagnaro (Fort Dauphin). Series editor Alfonso Alonso. SI/MAB Series #11. Smithsonian Institution, Washington DC, pp. 237–246.
- DURRELL, L., GROOMBRIDGE, B.S., TONGE, S., AND BLOXAM, Q.D. 1989. Pyxis arachnoides, Madagascar Spider Tortoise: Tsakafy; Kapila. In: Swingland I.R. and Klemens, M.W. (Eds.). Occasional Papers of the IUCN Species Survival Commission. The Conservation Biology of Tortoises. No. 5, Gland, Switzerland, pp. 103–104.
- EUBANKS, J.O., MICHENER, W.K., AND GUYER. C. 2003. Patterns of movement and burrow use in a population of gopher tortoises (*Gopherus polyphemus*). Herpetologica 59:311–321.
- FENN, M. 2003. The spiny forest ecoregion. In: Goodman, S.M. and Benstead, J.P. (Eds.). The Natural History of Madagascar. University of Chicago Press, Chicago, Illinois, pp. 1525–1530.
- FIELD, K.J., TRACYA, C.R., MEDICAB, P.A., MARLOWA, R.W., AND CORN, P.S. 2007. Return to the wild: translocation as a tool in conservation of the Desert Tortoise (*Gopherus agassizii*). Biological Conservation 136:232–245.
- GARDNER, C.J., FERGUSON, B., REBARA, F., AND RATSIFANDRIHAMA-NANA, A.N. 2008. Integrating traditional values and management regimes into Madagascar's expanded protected area system: the case of Ankodida. In: Mallarach, J.M. (Ed.). Protected Landscapes and Cultural and Spiritual Values. IUCN, GTZ and Obra Social de Caixa Catalunya. Kasparek Verlag, Heidelberg, pp. 92–103.
- GARDNER, C.J. 2009. A review of the impacts of anthropogenic habitat change on terrestrial biodiversity in Madagascar: implications for the design and management of new protected areas. Malagasy Nature 2:2–29.
- GARDNER, C.J. 2011. IUCN management categories fail to represent new, multiple use protected areas in Madagascar. Oryx

44:336-346.

- GASTON, K.J. 1991. How large is a species' geographic range? Oikos 61:434-438.
- GASTON, K.J. 1994. Measuring geographic range sizes. Ecography 17:198–205.
- GASTON, K.J. 2003. The Structure and Dynamics of Geographic Ranges. Oxford University Press, UK.
- GASTON, K.J AND FULLER, R.A. 2009. The size of species geographic ranges. Journal of Applied Ecology 46:1–9.
- GOEHRING, D.M., DAILY, G.C., DASGUPTA, S., AND EHRLICH, P.R. 2007. Range occupancy and endangerment: a test with a butterfly community. The American Midland Naturalist 157:106–120.
- GUSTAFSON, E.J., MURPHY, N.L., AND CROW, T.R. 2001. Using a GIS model to assess terrestrial salamander response to alternative forest management plans. Journal of Environmental Management 63:281–292.
- HARPER, G., STEININGER, M., TUCKER, C., JUHN, D., AND HAWKINS, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34:325–333.
- JESU, R. AND SCHIMMENTI, G. 1995. A preliminary study on the status of a population of Malagasy Spider tortoise, *Pyxis arachnoides* Bell (1827) from SW Madagascar. In: Devaux, B. (Ed.). International Congress of Chelonian Conservation. Gonfaron, France, pp. 144–147.
- LABONNE, B. 1999. The mining industry and the community: Joining forces for sustainable social development. Natural Resources Forum 23:315–322.
- LI, K., DENG, X-C., AND YE, Z-P. 2009. Development and utilization of shore sand minerals in Madagascar. Resources and Industries 2009-05.
- MacKenzie, D.I., NICHOLS, J.D., LACHMAN, G.B., DROEGE, S., ROYLE, J.A., AND LANGTIMM, C.A. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* 83:2248–2255.
- McCoy, E.D., STYS, B., AND MUSHINSKY, H.R. 2002. A comparison of GIS and survey estimates of Gopher Tortoise habitat and numbers of individuals in Florida. Chelonian Conservation and Biology 4:472–478.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications (Borneo), Kota Kinabalu, Malaysia.
- RABEARIVONY, J., THORSTROM, R., RENE DE ROLAND, L.A., RAKOTON-DRATSIMA, M., ANDRIAMALALA, T.R.A., SAM, T.S., RAZAFIMANJATO, G., RAKOTONDRAVONY, D., RASELIMANANA, A.P., AND RAKOTOSON, M. 2010. Protected area surface extension in Madagascar: do endemism and threatened species remain useful criteria for site selection? Madagascar Conservation and Development 5:35–47.
- RABESAHALA HORNING, N. 2003. How rules affect conservation outcomes. In: Goodman, S.M. and Benstead, J.P. (Eds.). The Natural History of Madagascar. University of Chicago Press, Chicago, pp. 146–153.
- RAFELIARISOA, T.H., SHORE, G.D., MCGUIRE, S.M., AND LOUIS, E.E., JR. 2010. Innovative solutions to conservation challenges for the radiated tortoise (*Astrochelys radiata*) project at Lavavolo Classified Forest, Madagascar. Turtle Survival Magazine 2010:64–66.
- RANJATOELINA, W. 2007. International mining and oil companies exploration and development activity. Mining Journal 2007:8.
- RAXWORTHY, C. AND NUSSBAUM, R. 2000. Extinction and extinction vulnerability of amphibians and reptiles in Madagascar. Amphibian and Reptile Conservation 2:15–23.
- RowLINSON, L.C., SUMMERTON, M., AND AHMED, F. 1999. Comparison of remote sensing data sources and techniques for identifying and classifying alien invasive vegetation in riparian zones. Water SA 25:497–500.
- SAPM. 2010. Protected areas of Madagascar digital GIS shape-

files. Système d'Aires Protégées de Madagascar, Antananarivo, Madagascar.

- SARRASIN, B. 2006. The mining industry and the regulatory framework in Madagascar: some developmental and environmental issues. Journal of Cleaner Production 14:388–396.
- SCOTT, J.M., CSUTI, B., JACOBI, J.D., AND ESTES, J.E. 1987. Species richness: A geographical approach to protecting biodiversity. BioScience 37:782–788.
- SCOTT, J.M., DAVIS, F.W., CSUTI, B., NOSS, R., BUTTERFIELD, B., GROVES, C., ANDERSON, H., CAICCO, S., DERCHIA, F., EDWARDS, T.C., ULLIMAN, J., AND WRIGHT, R.G. 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildlife Monographs 123:1–41.
- SCOTT, D., ANDRIAMBOLANORO, O.A., MBOHOAHY, T., RAHARI-NIRINA, N.C., SMITH, M., TANTELINIAINA, S., THOMPSON, S., AND TSAGNANGARA, C. 2008. University of Brighton Spiny Forest Research Expedition 2007/08: Final Report. Unpublished Report. University of Brighton, United Kingdom.
- SEDDON, N., TOBIAS, J., YOUNT, J.W., RAMANAMPAMONJY, J.R., BUTCH-ART, S., AND RANDRIANIZAHANA, H. 2000. Conservation issues and priorities in the Mikea Forest of south-west Madagascar. Oryx 34:287–304.
- SOORAE, P.S. AND BAKER, A. 2002. Guidelines for Nonhuman Primate Re-introductions. IUCN/SSC Re-introduction Specialist Group.
- STUART, B.L., RHODIN, A.G.J., GRISMER, L.L., AND HANSEL, T. 2006. Scientific description can imperil species. Science 312:1137.
- TOWNSEND, A. AND KLUZA, D.A. 2003. New distributional modeling approaches for gap analysis. Animal Conservation 6:47–54.
- VEIGA, M.M. AND HINTON, J.J. 2002. Abandoned artisanal gold mines in the Brazilian Amazon: a legacy of mercury pollution. Natural Resources Forum 26:15–26.
- WALKER, R.C.J. 2009. The spider tortoise (*Pyxis arachnoides*): Madagascar's forgotten species? Testudo 7:77–84.
- WALKER, R.C.J. 2010. The decline of the northern Madagascar spider tortoise (*Pyxis arachnoides brygooi*). Herpetologica 6:411-417.
- WALKER, R.C.J. 2012. A critical evaluation of field survey methods for establishing the range of a small, cryptic tortoise (*Pyxis* arachnoides). Herpetological Journal 22:7–12.
- WALKER, R.C.J. AND RAFELIARISOA, T.H. 2010. Distribution of the Madagascar spider tortoise, *Pyxis arachnoides*. Turtle Survival Magazine 2010:61–63.
- WALKER, R.C.J., RIX, C.E., AND WOODS-BALLARD, A.J. 2004. The export of the endangered Madagascar spider tortoise, *Pyxis arachnoides*, to support the exotic pet trade. Herpetological Bulletin 90:2–9.
- WALKER, R.C.J., WOODS-BALLARD, A.J., AND RIX, C.E. 2007. Population density and seasonal activity of the threatened Madagascar spider tortoise, *Pyxis arachnoides arachnoides* of the southern dry forests, South West Madagascar. African Journal of Ecology 46:67–73.
- WALKER, R.C.J., LUISELLI, L., WOODS-BALLARD, A.J., AND RIX, C.E. 2012. Microhabitat use by the Critically Endangered Madagascar endemic tortoise, *Pyxis arachnoides*. Herpetological Journal 22:63–66.
- WALKER, R.C.J., WHITMORE, N., RAFELIARISOA, T.H., AND HAMYLTON, S.2012. The effect of habitat degradation on the long term survival of the Critically Endangered Madagascar spider tortoise (*Pyxis* arachnoides). Biological Conservation 152:152–158.
- WWF.2010. Programme d'actions de WWF sur les tortues terrestres endémiques du sud-ouest de Madagascar: *Astrochelys radiata* et *Pyxis arachnoides* 2010-2015. WWF Madagascar, 61 pp.
- YAKOVLEVA, N. 2005. Corporate Social Responsibility in the Mining Industries. Ashgate Publishing Company: Aldershot, Hampshire, England.

## Ecological Husbandry and Reproduction of Madagascar Spider (*Pyxis arachnoides*) and Flat-tailed (*Pyxis planicauda*) Tortoises

## **DANIEL W. PEARSON<sup>1</sup>**

<sup>1</sup>Florida Department of Environmental Protection, 4801 Camp Ranch Road, Gainesville, Florida 32641 USA [Pyxis99@gmail.com]

ABSTRACT. - Tortoises of the genus Pyxis have limited ranges along the southwestern coast of the island of Madagascar. The genus includes P. planicauda and P. arachnoides. Both species are listed on CITES Appendix I and have been assessed as Critically Endangered for the IUCN Red Data List in 2008. Previously, large numbers of both species were exported from Madagascar during 2000 and 2001. A naturally low reproductive rate and an increased rate of habitat loss have generated concern over the status of these species in the wild and in captive collections. Both species are native to tropical dry forests with pronounced wet and dry seasons. An understanding of the climatic and environmental conditions experienced by these species in the wild is important in the establishment of a successful captive breeding program. Replicating the seasonal cycles and maintenance of a dry season aestivation period for adults appears important for successful reproduction in captivity. Pyxis eggs typically undergo an extended embryonic diapause that likely corresponds to the lengthy dry season in their native range. High hatching rates have been achieved in several captive colonies by exposing fertile eggs to cooler and drier conditions. A shift back to warmer and more humid conditions appears to trigger, or reinitiate embryonic development. An embryonic diapause controlled by environmental cues may serve to synchronize and delay hatching until the following wet season. Soil temperature data collected at three sites in Madagascar provide guidance for incubation protocols in captive collections. Current conservation measures include AZA studbooks and Species Survival Plans. Long-term success of existing assurance colonies will require continued cooperation between zoological institutions and private breeders.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, climate, captive breeding, egg, embryonic diapause, incubation, *Pyxis arachnoides*; Spider Tortoise, *Pyxis planicauda*, Flat-tailed Tortoise, Madagascar

The genus Pyxis includes two species of tortoise, Pyxis planicauda (Kapidolo, or Flat-tailed Tortoise) and Pyxis arachnoides (Kapila, or Spider Tortoise), that are endemic to the southwestern coast of Madagascar. Pyxis arachnoides includes three subspecies, P. a. arachnoides, P. a. brygooi, and P. a. oblonga. The northern species, P. planicauda, is restricted to the few remaining remnants of dry deciduous forest in the western portion of the island near Morondava, whereas P. arachnoides is confined to the coastal spiny forest of the southwest (Pedrono 2008). All taxa within this genus have been assessed as Critically Endangered under the International Union for Conservation of Nature (IUCN) Red Data List and are listed on the Convention on International Trade in Endangered Species of Flora and Fauna (CITES) Appendix I. A naturally low reproductive rate and increased rates of habitat loss and harvesting have heightened concerns over the status of these species in the wild and in captive collections. An understanding of the climatic and environmental conditions in the native habitat is important for the creation of successful ex-situ breeding programs. Duplication of seasonal patterns appears critical for successful reproduction in captivity (Loehr 2001; Gibson and Buley 2004; Pearson 2006; Mislin and Eberling 2009).

Loss of habitat has caused a dramatic reduction in the historical range of P.a. arachnoides and P.a. brygooi (Walker 2010; Walker and Rafeliarisoa 2010). It is likely that P. a. oblonga will also show evidence of a reduction in range when surveys are completed (Walker et al., this volume). Pyxis planicauda is under similar habitat pressures, but has always had a much more limited range (Pedrono 2008). Both Pyxis species are also under pressure from collection for the international pet trade, as well as for local consumption (Behler 2002; Pedrono 2008). CITES quotas issued by the government of Madagascar in 2000 and 2001 resulted in the export of thousands of P. arachnoides and P. planicauda, which significantly exceeded the quotas (CITES 2000; Walker et al. 2004; Pedrono 2008). As many as 4000 P. planicauda may have been exported during this time (Leuteritz et al. 2008). As a result of these exports, captive groups of Spider and Flat-tailed Tortoises have been established in many zoological institutions and private collections outside of Madagascar.

Captive reproduction of *Pyxis* has often proved problematic, with either adults failing to reproduce, or the occurrence of high juvenile mortality rates (Razandrimamilafiniarivo et al. 2000; Loehr 2001; Gibson and Buley 2004). An important component of a conservation strategy for *Pyxis* species is the establishment of viable *ex-situ* assurance colonies using founder stock exported from Madagascar during 2000 and 2001. Successful reproduction in *ex-situ* colonies depends upon the understanding of the native environment and natural history of these enigmatic tortoises.

By comparing the climatic patterns of *ex-situ* colony sites with those of the native habitats, it is possible to match temperature and rainfall patterns using a combination of outdoor and indoor facilities. Climate variables play an important role in the annual cycle of *Pyxis* species in the wild. Establishing a similar annual cycle in captivity is a significant factor in successfully reproducing these species. Incubation of eggs must also take into consideration the climate variables in the native environments due to the embryonic diapause that delays the hatching of Pyxis eggs. Diapause is a period of natural delay in egg development that occurs in response to regularly recurring periods of adverse environmental conditions, usually seasonal cold periods; diapause is subsequently broken when warm seasonal periods recur and egg development resumes and continues (see Ewert and Wilson 1996). Soil temperature data from the native environment have provided important guidance in determining proper incubation temperatures and temperature cycles. Incubation temperatures are critical not only for successful hatching, but also for sex determination, since it is likely that Pyxis species have some form of temperature-dependent sex determination.

#### **METHODS**

*Climate Matching*. — Flat-tailed Tortoises are restricted to the few remaining patches of tropical dry deciduous forest on the western coast of Madagascar north of Morondava (Young et al. 2008). This forest type has a closed canopy during the wet season with lush vegetative growth, which is in stark contrast to an open canopy during the harsh dry season. A deep leaf litter layer provides shelter for the tortoises during the prolonged dry season and associated drought. Most

**Figure 1.** Comparison of monthly average daily maximum and minimum air temperatures for Morondava and Tulear, Madagascar, and Gainesville, Florida, USA. Horizontal axis represents month for Gainesville (northern hemisphere) data only. Morondava and Tulear (southern hemisphere) data have been shifted by six months to align data by season instead of calendar month.

activities take place during the relatively short wet season, while the dry season is spent in some form of aestivation under the leaf litter. The wet season extends from roughly October to May and the dry season spans the remainder of the year (Pedrono 2008).

The three subspecies of Spider Tortoise occur along the southwestern coastline in more open habitats characterized by tropical spiny forest and other scrubby coastal areas dominated by plants in the Didieraceae and Euphorbiacae families. Spider Tortoises occur in generally drier habitats than Flat-tailed Tortoises, but they also experience pronounced wet and dry seasons and aestivate during the dry season buried in leaf litter or sandy soil (Pedrono 2008).

When establishing a breeding colony of any species, it is important to understand the ecological constraints and influences on a species in its native range. Species adapted to certain distinct climatic cycles, for instance, may have difficulty adjusting to, or reproducing successfully, in captive situations that are dramatically different. In 2002, I acquired a group of P. planicauda and P. arachnoides and housed them near Gainesville, Florida, USA. At that time very little had been published on the ecology of these species in the wild, or on their husbandry in captivity. Valuable information was available in the annual reports of the European Studbook for P. arachnoides (Loehr 2001). Anecdotal information suggested that the captive husbandry of P. planicauda was not significantly different from that used for P. arachnoides that was being bred in Europe. The European breeders had documented the aestivation behavior of P. arachnoides, and had applied seasonal temperature and humidity changes to stimulate the adults to breed and successfully incubate eggs (Loehr 2001).

To establish the proper captive environment that would reflect the seasonal variation of the native range, I acquired climate data averages for two locations within the range of *Pyxis* to compare with the climate averages for Gainesville, Florida. Climate data were acquired from weather stations located at the airports at Morondava (Weather Underground, 2010a) and Tulear (Weather Underground, 2010b) in Mada-





gascar, and Gainesville (Southeast Regional Climate Center, 2010) in the USA. Morondava is within the range of *P. planicauda* and Tulear is within the upper third of the range of *P. arachnoides*. Gainesville is located in the northern hemisphere, while the native range of *Pyxis* is located in the southern hemisphere. Consequently, there is a six month shift in the wet and dry seasons between Madagascar and Florida. To compensate for this, the data from Morondava and Tulear were shifted by six months to allow direct comparison of the wet and dry seasons rather than by calendar months (Figs. 1, 2).

Temperatures in the summer, or wet season, are very similar between all three locations. The mean maximum and minimum temperatures for the months of May through September in Gainesville are similar to the temperatures for the months of November through March in Morondava and Tulear. However, the winter season temperatures in Gainesville are lower than the corresponding dry season temperatures in the native range for both species.

Likewise, rainfall amounts are very similar during the summer wet season, particularly during June through August (December – February in the southern hemisphere) with Tulear having the lowest levels of precipitation. During the winter dry season, precipitation in Gainesville declines, but is much higher than either site in Madagascar. Both Morondava and Tulear receive minimal amounts of rainfall during the dry season and experience warm and very dry winters with hot and wet summers. Gainesville has much cooler and wetter winters, but also has hot and wet summers. Both regions of the world have summer weather patterns that are frequently dominated by tropical cyclones or tropical waves causing widespread and intense rainfall events. Duplication of the Madagascar wet season is particularly easy in Florida, especially in years with significant tropical cyclone activity.

Based on the climate comparisons, the *Pyxis* group was set up in Gainesville in outdoor enclosures from May to November to take advantage of the warm summer temperatures, rainfall, and sunlight. From November to May, the tortoises were housed indoors in a climate controlled environment with low humidity and fluctuating daily temperatures. Daytime high and nighttime low temperatures were kept within the range of their native environment.

Annual Cycle. — As part of their adaptation to survival in an extreme environment, both *P. arachnoides* and *P. planicauda* undergo a period of dormancy or aestivation as environmental temperatures decrease and rainfall ceases (Kuchling and Bloxam 1988; Walker et al. 2010). This behavior is even seen in captive born juvenile tortoises. In captivity, tortoises burrow into the substrate and can remain in the same location for weeks at a time. This behavior has also been observed in European collections (Loehr 2001).

Rainfall, or wetting of the enclosures, stimulates tortoise activity on both a seasonal and daily basis. Aestivation gradually ends with an increase in rainfall, or misting of enclosures. Mating begins early in the wet season and tapers off in late summer. In captivity, the egg-laying period for *P*. *arachnoides* and *P. planicauda* typically begins in July with a peak in mid-September. Egg-laying may even extend into the dry season and fertile eggs have been produced as late as February.

The eggs of tropical tortoise species from less seasonal environments, such as *Chelonoidis carbonaria*, require about 120-130 days of incubation at moderate temperatures (29°C) before hatching. Pyxis eggs in contrast can take over 300 days to hatch, depending on the incubation protocol (Razandrimamilafiniarivo et al. 2000). The eggs of P. planicauda and P. arachnoides both undergo a diapause during development that corresponds to the dry season in their native environment. The diapause occurs at an early stage of embryogenesis, before the embryo can be seen by candling the egg. If Pyxis eggs in the wild hatched without this delay in development, the hatchlings would emerge during the height of the dry season in a very harsh environment. By delaying development through diapause, Pyxis eggs hatch during the following wet season, when there is abundant food and moisture (Gibson and Buley 2004). Understanding this complex embryonic development process is critical to the successful hatching of *Pyxis* eggs in captivity.

*Egg Incubation.* — Incubation of *Pyxis* eggs has always been deemed a difficult and tricky process. Initial successes with *P. planicauda* eggs at the Chelonian Captive Breeding Centre in Ampijoroa, Madagascar, depended upon allowing eggs to incubate in ground nests (Razandrimamilafiniarivo et al. 2000). This allowed the seasonal climate effects to influence the development of the eggs. At the Jersey Zoo, the Durrell Wildlife Conservation Trust (DWCT) successfully hatched *P. planicauda* eggs by allowing the eggs to remain in the same conditions as the adults, which were subjected to an artificially replicated version of their natural environment that was complete with wet and dry seasons (Gibson and Buley 2004).

Some of the early successes in Europe with hatching *P. arachnoides* were based on cooling the eggs at some point during the incubation process (Loehr 2001). Zovickian (2003) was able to successfully hatch both species of *Pyxis* in the United States by adapting a protocol that had been successful in hatching the eggs of *Astrochelys radiata*, which involved cooling eggs that appeared to have entered diapause. *Astrochelys radiata* is sympatric with *P. arachnoides*; therefore, it may not be coincidental that *A. radiata* eggs may also undergo diapause. Adams and Zovickian (unpubl. data) have noted that there may be a seasonal effect on whether or not *A. radiata* eggs enter a diapause phase during artificial incubation.

To try and replicate the seasonal and diurnal temperature cycles that *Pyxis* eggs encounter in nature, I set up an incubator using a foam ice chest heated with a section of Flexwatt heating tape (Flexwatt Industrial Sales, Maryville, TN, USA) coupled with a thermostat capable of two temperature set points. Initial temperature settings were based on information from the Knoxville Zoo (M. Ogle, pers. comm.), W. Zovickian (pers. comm.), and Loehr (2001). Daytime temperatures were initially set to approximately 31°C (88°F) with the temperature set to drop overnight to 26°C (78°F). Eggs from both species of *Pyxis* were incubated under the same conditions. Eggs were placed in trays filled with vermiculite dampened with water at a 1:1 ratio by weight. The trays were placed inside ventilated plastic shoeboxes and then placed into the incubator, and kept at these warm temperatures for eight to 12 weeks.

While I assumed that cooler temperatures followed by warmer temperatures serves to break the embryonic diapause in Pyxis (as opposed to cooler temperatures causing diapause), the role of low soil moisture followed by higher soil moisture may also play a role in this process. To simulate the cooler temperatures of the dry season, the incubation media was allowed to slowly dry out and the eggs were subjected to a cooler period of temperatures after the period of warm conditions. To achieve this, the incubating eggs were removed from the incubator (after 8–12 weeks) and allowed to remain at room temperature that fluctuated between 20-24°C (68-75°F) for approximately six to eight weeks. After this period of cooler temperatures and drier substrate, the eggs were misted and returned to the warm incubator using the same initial temperatures. The eggs and incubation media were subsequently misted on an approximately weekly basis.

#### **RESULTS and DISCUSSION**

With very few exceptions, all fertile eggs hatched successfully using this or similar protocols. The protocol was modified after some years to lower the maximum daily temperature to approximately 30.5°C (86.9°F), reduce the drop in temperature at night to approximately 26.5°C (80°F), and shorten the length of the initial phase of incubation to four to seven weeks. Although other breeders have reported needing to cool and re-warm eggs a second time to break the diapause, it was rarely necessary in this collection.

Using this technique, 26 *P. arachnoides* (52%) hatched from 50 eggs. The majority (71%) of the 24 eggs that did not hatch failed during the first warm phase or cooling phase of incubation due to infertility. Infertile eggs are usually readily apparent within the first six weeks of incubation when eggs are candled. Infertile eggs display discolorations and



Figure 3. Monthly average daily maximum, mean, and minimum soil temperatures at Kirindy Forest, Madagascar. Monthly average daily maximum and minimum air temperatures recorded at the airport in Morondava, Madagascar.

opaque layers within the fluid, unlike fertile eggs that remain relatively clear prior to the cessation of diapause. Of the 10 *P. planicauda* eggs produced between 2002 and 2009, all were fertile and all hatched successfully.

Eggs were candled frequently during incubation to track their development. The end of diapause was determined by the sudden appearance of the embryo or the characteristic ring of blood vessels that surrounds the embryo. In *P. arachnoides*, diapause ended after an average of 25 days (n = 23; range = 13–57 days) after the eggs were returned to warmer and moister conditions. Diapause in *P. planicauda* eggs ended after an average of 14 days (n = 10; range = 0–32 days). Once embryonic development resumed, *P. arachnoides* eggs hatched in an average of 92 days (n = 23; range = 82–126 days), while *P. planicauda* eggs hatched in an average of 86 days (n = 10; range = 73–97 days).

Total incubation times ranged from 192 to 303 days (mean = 247) for *P. arachnoides* and 213 to 275 days (mean = 240) for *P. planicauda*. The lengthy total incubation periods observed in *Pyxis* are due to the extended diapause, with the actual development phase being approximately the same length as for other tortoise species. Other collections have had success hatching both *P. arachnoides* (Ogle 2006) and *P. planicauda* (Gibson and Buley 2004; Mislin and Eberling 2009) with similar warm-cool-warm cycles during incubation.

Sex ratios among the hatchlings produced here appeared to be skewed along taxonomic lines and a high proportion of the hatchlings had split or extra scutes on the carapace. Nearly all of the *P*. *a. brygooi* and *P*. *a. arachnoides* appeared to be males based on the development of secondary sexual characteristics, primarily the lengthening of the tail. However, the *P. planicauda* hatchlings appeared to be female based on tail length and about half had extra or split carapace scutes. Assuming that *Pyxis* have temperature-dependent sex determination, and that shell abnormalities may be related to high incubation temperatures, it is likely that the incubation temperatures initially used were too high. The most recent eggs have been incubated at slightly lower maximum temperatures resulting in normal carapacial scutes in the hatchlings recently produced.

Soil Temperature Data. — Given the complexity of artificial incubation in *Pyxis*, there is a need for more accurate information on incubation conditions in the wild. Fortunately there are now field data available from Madagascar that provide information on the daily and seasonal variation in soil temperatures. Temperature data were collected with HOBO<sup>®</sup> data loggers (Onset Computer Corporation, Bourne, MA, USA) at three locations: 1) Kirindy Forest, Menabe, within the native range of *P. planicauda*; 2) Village des Tortues, Ifaty, within the range of *P. a. brygooi*; and 3) Chelonian Captive Breeding Centre, Ampijoroa, outside the native range of *Pyxis*, but where *P. planicauda* eggs have been successfully incubated in ground nests.

Figure 3 displays the monthly averages of the daily maximum, minimum, and mean soil temperatures that were collected 3 cm below ground within the Kirindy Forest. The

placement of the data logger by DWCT personnel reflected a potential P. planicauda nesting site. For comparison, monthly averages of the daily maximum and minimum air temperatures recorded at the Morondava airport (40 km away) are also included. The data show that soil and air temperatures have a much greater daily range in the dry season than the wet season. Nighttime low air temperatures in the dry season are much lower than daytime highs, which are reflected in the soil temperatures; although the soils do buffer the temperature changes to some extent. If egg deposition patterns are similar between the wild and captivity, then eggs would be laid from the middle of the wet season into the early dry season. The lowering of temperatures in the first half of the dry season and the rising of temperatures in the second half of the dry season appear to be the environmental cues that break diapause in Pyxis.

The data from Kirindy provide valuable information to guide incubation protocols for *P. planicauda* in captivity. Temperatures during the cooling phase of incubation should range from about 17°C (63°F) to 25°C (76°F) on a daily basis to mimic the dry season temperatures that appear to be required to break diapause. Monthly average soil temperatures during the late dry season, when the embryos resume developing, range from daytime highs near 30°C (86°F) to overnight lows near 21°C (70°F) rising to 24°C (75°F)later in the dry season. This would suggest a maximum incubation temperature of 30°C (86°F) with an overnight drop in temperature of 5–10°C (10–15°F) after diapause is broken.

The data from Village des Tortues in Ifaty (Fig. 4) were collected by the Turtle Survival Alliance (TSA) within the *P. a. brygooi* enclosure. This location shows a similar dry season cooling phase that presumably provides the environmental cue to break diapause in *P. arachnoides*. The wet season temperatures at this site are much higher than those in the Kirindy Forest, which may be related to the effect of solar radiation on the soil temperatures. During the wet season, the tropical dry forest would have a denser canopy that would block direct solar radiation, while the spiny forest in the range of *P. arachnoides* typically has more open soil and less leaf litter. Bailey (*pers. comm.*) measured surface soil temperatures at Ifaty as

high as 57°C (135°F) in direct sunlight in January 2009. It is likely that nesting females would choose nesting sites that would provide a proper microclimate for incubation that would prevent eggs from overheating during the wet season temperature peaks.

Based upon the data from Ifaty, the cooling phase of incubation should range from about 20°C (67°F) to 23°C (73°F) on a daily basis. As the dry season progresses, soil temperatures increase gradually. When the rains begin in November, soil temperatures range from average highs near 32°C (90°F) to overnight lows near 27°C (81°F). In captivity, it is likely that *P. arachnoides* is more tolerant of higher incubation temperatures than *P. planicauda*. *Pyxis planicauda* does appear to be more prone to extra carapacial scutes than *P. arachnoides* when incubated at temperatures approaching 32°C (90°F).

At Ampijoroa (Fig. 5) the data logger was buried by the TSA within the *P. planicauda* enclosure where active nests were located, and where successful hatching had occurred. These data are very similar to the seasonal pattern and daily temperatures recorded at Kirindy. At Ampijoroa, however, the nighttime low temperatures in the dry season are not as low as in the Kirindy Forest. Overnight lows averaged only about 21°C (71°F), but daytime highs still reached 25°C (76°F). It appears that the temperatures were still low enough to break diapause in *P. planicauda*, as evidenced by the many successful nests at the Chelonian Captive Breeding Centre (Razandrimamilafiniarivo et al. 2000).

Of the 19 successful hatchings of *P. planicauda* at the Chelonian Captive Breeding Centre between 1995 and 1999, 18 of the eggs hatched between 10 November and 26 December (Razandrimamilafiniarivo et al. 2000). By counting backwards from the hatching dates at Ampijoroa, it can be estimated that embryonic development there resumed in late August and September. Figure 5 shows a marked increase in soil temperatures during that time period, lending support to the theory that cool temperatures followed by rising temperatures cause *Pyxis* eggs to break diapause and resume development. It is also interesting to note that at the point in the dry season when temperatures are rising, there is very little precipitation; therefore, an increase in soil moisture may not play a role in ending



Figure 4. Monthly average daily maximum, mean, and minimum soil temperatures at the Village des Tortues in Ifaty, Madagascar.



Figure 5. Monthly average daily maximum, mean, and minimum soil temperatures at the Chelonian Captive Breeding Centre in Ampijoroa, Madagascar.

diapause in *P. planicauda* eggs. In my breeding colony, the eggs of *P. planicauda* required about 86 days to develop once diapause was broken and embryonic development resumed, with eventual successful hatching (Fig. 6).

*Ex-situ Population Management.* — The Association of Zoos and Aquariums (AZA) maintains the North American Regional Studbooks for *P. planicauda* and *P. arachnoides* (Castellano and Behler 2003, 2004; Ogle 2009a, b) as an *ex-situ* conservation action for these critically endangered tortoises. The studbooks track the captive population and maintain birth and death records. Breeding recommendations for the captive population are included in the Species Survival Plans (SSP) and are based on genetic and demographic analyses (Ogle and Sullivan 2013a, b). Relatively few private collections are included in the studbooks and the SSPs, which is unfortunate, since the majority of *Pyxis* in the U.S. are in private collections.

In order for *ex-situ* assurance colonies to succeed in the long term, a base of genetic diversity must be preserved by producing offspring from the wild caught animals exported from Madagascar in 2000 and 2001. Mortality of the wild caught animals over time will continue to reduce the number of potential genetic founders. Juvenile *Pyxis* are rarely seen in the commercial trade. Considering the large numbers of *P. planicauda* and *P. arachnoides* that have been imported into the U.S., captive born offspring should be commonly available in the commercial trade if private collections were successfully breeding *Pyxis*. It is likely that many collections simply are not able to produce fertile eggs, or cannot hatch fertile eggs due to the complex incubation requirements.

Private collections must be encouraged to participate in the AZA studbook program to increase the number of potential founders in the managed population. Whenever possible, information on breeding techniques and incubation strategies must be shared among institutions and private collections in order to increase reproduction of these species in captivity. Acknowledgments. — I would like to thank the Durrell Wildlife Conservation Trust and the Turtle Survival Alliance for the use of their soil temperature data. I also thank John Bailey for burying data loggers at Ifaty and Ampijoroa, and for graciously providing his field notes for my use. Rick Hudson and Richard Lewis retrieved data loggers and Michael Ogle was kind enough to allow me to analyze the data for him. Michael Ogle, Kevin Wright, and Rick Owen provided insightful comments on this paper. Richard D. Bartlett provided me with the chance to work with these odd tortoises. And lastly, I would like to thank the TSA for the opportunity to participate in the Madagascar Freshwater Turtle and Tortoise Conservation Symposium.

#### Résumé

Les tortues du genre *Pyxis* ont des territoires restreints le long de la côte sud-ouest de l'île de Madagascar. Le genre comprend Pyxis planicauda et Pyxis arachnoides. Les deux espèces sont toutes classées en Annexe I du CITES et ont été évaluées En Danger Critique d'Extinction pour la Liste Rouge de l'UICN en 2008. Un grand nombre d'individus des deux espèces ont été exportés de Madagascar en 2000 et 2001. Un taux de reproduction naturellement bas et un accroissement de la vitesse de la perte d'habitat ont attiré l'attention sur le statut de ces espèces à l'état sauvage et dans les groupes en captivité. Les deux espèces sont natives des forêts sèches tropicales avec une saison humide et une saison sèche prononcées. La compréhension des conditions climatiques et environnementales rencontrées par les deux espèces dans la nature est essentielle à l'établissement d'un programme de reproduction en captivité efficace. Reproduire les cycles saisonniers et maintenir la période d'estivation durant la saison sèche apparaissent importants pour une reproduction réussie en captivité. Les œufs de Pyxis passent typiquement par une diapause embryonnaire prolongée qui semble correspondre à la longue saison sèche de leur lieu d'origine. Des taux d'éclosion élevés ont été obtenus dans



Figure 6. Captive-born hatchling Spider Tortoise, *Pyxis arachnoides brygooi* (left) and Flat-tailed Tortoise, *Pyxis planicauda* (right). Photos by Daniel Pearson.

de nombreuses colonies en captivité par l'exposition d'œufs fertiles à des conditions plus fraîches et plus sèches. Le retour à des conditions plus chaudes et plus humides semble alors déclencher voire réinitialiser le développement de l'embryon. Une diapause embryonnaire contrôlée par des indicateurs environnementaux peut aider à synchroniser ou retarder l'éclosion jusqu'à la prochaine saison humide. Des données sur la température du sol recueillies dans trois sites à Madagascar sont utilisées pour établir les protocoles d'incubation dans les groupes en captivité. Les mesures de conservation actuelles comprennent le stud-book de AZA et les Plans de Survie d'Espèces. Le succès à long terme des colonies souches nécessitera la coopération continue entre les institutions zoologiques et les éleveurs privés.

#### LITERATURE CITED

- BEHLER, J. 2002. Madagascar tortoise crisis: letter to CITES Animal Committee and concerned parties, 9 January 2002. Turtle and Tortoise Newsletter 5:18–19.
- CASTELLANO, C.M. AND BEHLER, J. 2003. Madagascar Flat-tailed (*Pyxis planicauda*) and Spider Tortoise (*Pyxis arachnoides*) North American Regional Studbook, 1st Edition. New York: Wildlife Conservation Society, 67 pp.
- CASTELLANO, C.M. AND BEHLER, J. 2004. Madagascar Flat-tailed (*Pyxis planicauda*) and Spider Tortoise (*Pyxis arachnoides*) North American Regional Studbook, 2nd Edition. New York: Wildlife Conservation Society, 36 pp.
- CITES. 2000. Revised CITES export quotas for chelonians 2000: CITES Secretariat notification to the parties No. 2000/053, 31 Aug. 2000. Turtle and Tortoise Newsletter 3:24–25.
- EWERT, M.A. AND WILSON, D.S. 1996. Seasonal variation of embryonic diapause in the striped mud turtle (*Kinosternon baurii*) and general considerations for conservation planning. Chelonian Conservation and Biology 2(1):43–54.
- GIBSON, R.C. AND BULEY, K.R. 2004. Biology, captive husbandry, and conservation of the Malagasy flat-tailed tortoise, *Pyxis planicauda* Grandidier, 1867. Herpetological Review 35:111–116.
- KUCHLING, G. AND BLOXAM, Q.M.C. 1988. Field-data on the Madagascan flat-tailed tortoise *Pyxis (Acinixys) planicauda*. Amphibia-Reptilia 9:175–180.
- LEUTERITZ, T., RANDRIAMAHAZO, H., AND LEWIS, R. 2008. *Pyxis planicauda*. In: IUCN. IUCN Red List of Threatened Species. Version 2010.4. www.iucnredlist.org. Downloaded on 15 January 2011.
- LOEHR, V. 2001. Studbook Breeding Programme *Pyxis arachnoides*: Annual Report 2001. European Studbook Foundation, 24 pp.
- MISLIN, V. AND EBERLING, G. 2009. Breeding research project EHAP: exchanging experiences on keeping and breeding the Madagascar flat-tailed tortoise (*Pyxis planicauda*). Turtle Survival Alliance 2009:30–33.
- OGLE, M. 2006. Successful egg incubation and rearing of the common spider tortoise (*Pyxis a. arachnoides*). In: Ogle, M. (Ed.). Madagascar Flat-tailed (*Pyxis planicauda*) and Spider Tortoise (*Pyxis arachnoides*) North American Regional Studbook, Third Edition. Tennessee: Knoxville Zoological Gardens, pp. 10–12.
- OGLE, M. 2009a. Madagascar Flat-tailed Tortoise (*Pyxis planicauda*) North American Regional Studbook, 4th Edition. Tennessee:

Knoxville Zoological Gardens, 57 pp.

- OGLE, M. 2009b. Madagascar Spider Tortoise (*Pyxis a. arachnoides*, brygooi, and oblonga) North American Regional Studbook, 4th Edition. Tennessee: Knoxville Zoological Gardens, 105 pp.
- OGLE, M. AND SULLIVAN, S. 2013a. Population Analysis and Breeding and Transfer Plan. Madagascar Flat-tailed Tortoise (*Pyxis planicauda*). AZA Species Survival Plan Yellow Program. Chicago: Population Management Center, 29 pp.
- OGLE, M. AND SULLIVAN, S. 2013b. Population Analysis and Breeding and Transfer Plan. Madagascar Spider Tortoises (*Pyxis* arachnoides arachnoides, *P. arachnoides brygooi*). AZASpecies Survival Plan Yellow Program. Chicago: Population Management Center, 52 pp.
- PEARSON, D.W. 2006. Egg incubation and neonatal care of flat-tailed tortoises (*Pyxis planicauda*). In: Ogle, M. (Ed.). Madagascar Flattailed (*Pyxis planicauda*) and Spider Tortoise (*Pyxis arachnoides*) North American Regional Studbook, Third Edition. Tennessee: Knoxville Zoological Gardens, pp. 13–16.
- PEDRONO, M. 2008. The Turtles and Tortoises of Madagascar. Borneo: Natural History Publications, 147 pp.
- RAZANDRIMAMILAFINIARIVO, O.C., REID, D., AND BEKARANY, E. 2000. Captive management and reproduction of the Madagascar flattailed tortoise *Pyxis planicauda* at the Chelonian Captive Breeding Centre, Ampijoroa, Madagascar. Dodo 36:75–81.
- SOUTHEAST REGIONAL CLIMATE CENTER. 2010. Period of Record Monthly Climate Summary 5/1/1960 to 7/31/2010, Gainesville Muni Airport, Florida (083326). http://www.sercc.com/cgi-bin/ sercc/cliMAIN.pl?fl3326.
- WALKER, R.C.J. 2010. The decline of the critically endangered northern Madagascar spider tortoise (*Pyxis arachnoides brygooi*). Herpetologica 66:411–417.
- WALKER, R.C.J. AND RAFELIARISOA, T.H. 2010. Distribution of the Madagascar spider tortoise, *Pyxis arachnoides*. Turtle Survival Alliance 2010:61–63.
- WALKER, R.C.J., RIX, C.E., AND WOODS-BALLARD, A.J. 2004. The export of the endangered Madagascar spider tortoise (*Pyxis arachnoides*) to support the exotic pet trade. Herpetological Bulletin 90:2–9.
- WALKER, R.C.J., RAFELIARISOA, T.H., SMITH, I., AND RAZATIMANATSOA, R. 2010. How range reduction and fragmentation is threatening the long-term survival of the critically endangered Madagascar spider tortoise (*Pyxis arachnoides*). In: Walde, A., Walton, E., and Schaffer, R. (Eds.). Program and Abstracts of the Eighth Annual Symposium on the Conservation and Biology of Tortoises and Freshwater Turtles. Turtle Survival Alliance, Orlando, FL. pp. 58–59.
- WEATHER UNDERGROUND. 2010a. Seasonal weather averages, Morondava, Madagascar. www.wunderground.com/NORMS/ DisplayIntlNORMS.asp?CityCode=67117&Units=english.
- WEATHER UNDERGROUND. 2010b. Seasonal weather averages, Tulear, Madagascar. http://www.wunderground.com/NORMS/Display-IntlNORMS.asp?CityCode=67161&Units=english.
- YOUNG, R.P., VOLAHY, A.T., BOUROU, R., LEWIS, R., DURBIN, J., AND FA, J.E. 2008. Estimating the population of the endangered flat-tailed tortoise *Pyxis planicauda* in the deciduous, dry forest of western Madagascar: a monitoring baseline. Oryx 42:252–258.
- ZOVICKIAN, W. 2003. Incubation strategies for *Pyxis* eggs. In: Castellano, C.M. and Behler, J. (Eds.). Madagascar Flat-tailed (*Pyxis planicauda*) and Spider Tortoise (*Pyxis arachnoides*) North American Regional Studbook, 1st edition. New York: Wildlife Conservation Society, pp. 17–19.

## Proposed Action Plan for the Conservation of the Madagascar Spider Tortoise, *Pyxis arachnoides*

# Ryan C.J. Walker<sup>1,2</sup>, Christina M. Castellano<sup>3</sup>, Michael Ogle<sup>4</sup>, Tsilavo H. Rafeliarisoa<sup>5</sup>, Riana Rakotondrainy<sup>6</sup>, Tiana A. Ramahaleo<sup>7</sup>, Herilala Randriamahazo<sup>8</sup>, and Charlie J. Gardner<sup>7,9</sup>

<sup>1</sup>Nautilus Ecology, Oak House, Pond Lane, Greetham, Rutland, LE15 7NW, United Kingdom [ryan@nautilusecology.org];
 <sup>2</sup>Department for Earth, Environment and Ecosystems, The Open University, Milton Keynes, MK7 6AA, United Kingdom;
 <sup>3</sup>Utah's Hogle Zoo, 2600 Sunnyside Ave, Salt Lake City, Utah 84108 USA [ccastellano@hoglezoo.org];
 <sup>4</sup>Knoxville Zoological Gardens, 3500 Knoxville Zoo Drive, Knoxville, Tennessee 37914 USA [mogle@knoxville-zoo.org];

<sup>5</sup>Madagascar Biodiversity and Biogeography Project, Henry Doorly Zoo, Grewcock's Center for Conservation and Research,

3701 South 10th Street, Omaha, Nebraska 68107 USA [rafelykely@hotmail.com];

<sup>6</sup>University of Antananarivo, University of Antananarivo, P.O Box 906, Antananarivo 101, Madagascar [riana.mia@gmail.com];

<sup>7</sup>WWF Madagascar and Western Indian Programme Office, BP 738, Antananarivo 101, Madagascar [tramahaleo@wwf.mg];

<sup>8</sup>Turtle Survival Alliance, Antananarivo 101, Madagascar [herilala@turtlesurvival.org];

<sup>9</sup>Durrell Institute of Conservation and Ecology, University of Kent,

Canterbury, Kent CT2 7NR, United Kingdom [cjamgardner@yahoo.co.uk]

ABSTRACT. – We recommend that the following priority actions be included in a Proposed Action Plan for the Spider Tortoise (*Pyxis arachnoides*). 1) Eliminate the illegal harvest and commerce of Spider Tortoises by increasing the awareness, motivation, and capacity of local authorities and law enforcement agencies, lobbying the government, and monitoring international trade. 2) Promote the repatriation and reintroduction of confiscated Spider Tortoises by identifying populations of confiscated tortoises and developing a repatriation framework and reintroduction protocol. 3) Develop rigorous mitigation strategies for Spider Tortoises within sites of mineral extraction through dialogue with mining companies and through the establishment of private protected areas within low value areas of mining concessions, and by developing a translocation protocol for these areas. 4) Develop communications and awareness-raising programs to educate relevant stakeholders on the importance of the Spider Tortoise and the threats it faces, and promote greater respect for traditional Mahafaly and Tandroy customs that protect tortoises. 5) Support existing initiatives to reduce habitat loss through the promotion of improved agricultural techniques and alternative livelihoods. 6) Strengthen research capacity within Madagascar by providing materials and training to Malagasy scientists, and conduct research required to inform management of the species.

# KEY WORDS. – Reptilia, Testudines, Testudinidae, *Pyxis arachnoides*, Spider Tortoise, conservation, action plan, illegal trade, protected areas, captive breeding, mining, Madagascar

The Madagascar Spider Tortoise (*Pyxis arachnoides*) is one of the world's smallest species of tortoise (Fig. 1). It is endemic to the dry, spiny coastal forest of southwest Madagascar. Three subspecies are recognized: the Northern Spider Tortoise, *P. a. brygooi*; the Common Spider Tortoise, *P. a. arachnoides*; and the Southern Spider Tortoise, *P. a. oblonga* (Bour 1979; Chiari et al. 2005). The Spider Tortoise is the only tortoise species with a hinged plastron. This unique character makes it coveted by collectors and as a result it is illegally traded within the international pet market.

The Spider Tortoise once inhabited a stretch of about 550 km of coastline; however, recent studies have shown that it now occupies only a number of fragmented locations across its range with large, once occupied areas now devoid of tortoises (Walker 2010; Walker et al. 2013, this volume). It has been suggested that this is likely the result of a combination of poaching and habitat destruction (Walker 2010). Moreover, future mineral extraction policies for

the coastal southwest region of Madagascar could further compound the effects of habitat loss on this species (Walker et al. 2013, this volume).

Habitat management for the spider tortoise may become increasingly difficult. More than 80% of the remaining tortoise habitat lies within existing or newly gazetted Madagascar National Parks and community-managed protected areas (PA). These PAs are largely proposed as IUCN category III, V, or VI, which are classifications that serve to protect the natural integrity of the landscape while allowing some level of exploitation to meet the needs of local communities. These protected areas will be managed by several different community associations; thus, the threats to the spider tortoise may be difficult to address under this more flexible management system (Walker et al. 2013, this volume). These new and proposed land use policies within the range of the Spider Tortoise highlight the urgent need for a conservation action plan for this species.



Figure 1. Madagascar Spider Tortoise, Pyxis arachnoides. Photo by Ryan Walker.



**Figure 2.** The current known range of *Pyxis arachnoides* (solid black; Walker 2010, Walker et al. 2013, this volume) overlaid against the suspected historical range of *P. arachnoides* (cross-hatched; Bour 1981, Pedrono 2008). Zone A = range of *P. a. brygooi*; Zone B = range of *P. a. brygooi* x *arachnoides* intergrade population; Zone C = range of *P. a. arachnoides*; Zone D = range of *P. a. arachnoides* x *oblonga* intergrade population; Zone E = range of *P. a. oblonga*. The current range of *P. a. oblonga* east of Cap Sainte Marie consists of a very narrow distribution along the coastal dunes of no more than a few 100 m from the coastline, thus difficult to depict on the map.

*Biology.* — Despite inhabiting a highly seasonal environment, the Spider Tortoise exhibits little variation in habitat use throughout the year. However, the amount of vegetation cover preferred by tortoises can vary somewhat between the wet and dry seasons (Walker et al. 2007). These authors showed that tortoises occupied sites with significantly greater vegetation cover during periods of increased temperature and precipitation. The species is thought to be more dependent on canopy cover than the Radiated Tortoise (*Astrochelys radiata*), a considerably larger species that is sympatric with the Spider Tortoise throughout much of its range (Pedrono 2008). The dependence on vegetation cover exhibited by the Spider Tortoise at different times of the year may make this species particularly susceptible to habitat loss and degradation.

The Spider Tortoise is most active during the wet season between November and April (Walker et. al. 2007); significantly more individuals were observed during surveys conducted during the wet season than in the dry. During the latter, this species tends to aestivate partially or completely buried underground for extended periods (Durrell et al. 1989; Walker et al. 2007). Dormant individuals do not appear to feed, although little is known of the foraging habits and diet of this species (Walker et al. 2007). Glaw and Vences (1994) reported that its diet included young leaves and cow dung containing insect larvae. Tortoises exhibit heightened activity in the morning (0700-0900 hrs) followed by a period of reduced movement around midday when temperatures exceed 30°C. They become active again between late afternoon and sunset (Jesu and Schimmenti 1995). In captivity females are significantly more active during the morning hours and feed at higher temperatures than males (Moroni et



Figure 3. (a, left) Suspected routes of tortoise poachers in southwest coastal Madagascar represented by arrows showing routes used. (b, right) A visual representation of the number of poached *A. radiata* carcasses encountered within each area, with larger dots representing more carcasses encountered per km of transect (Walker 2010).

al. 2006). These authors suggested that female behavior might be correlated with high-energy needs associated with egg production. Female tortoises lay a single large egg per clutch during the wet season, although the number of clutches deposited each year remains unknown (Durrell et al. 1989). Hatchling tortoises have been recorded most frequently during February and March, which suggests that emergence from the nest occurs around this time (Walker et al. 2007). It has been suggested that this species reaches sexual maturity between 8 and 12 yrs of age (Walker et al. 2004; Pedrono 2008),

Habitat and Distribution. — The Spider Tortoise inhabits a band of dry, spiny forest that extends approximately 10 km inland and along 550 km of coastline in southwest Madagascar (Pedrono 2008). Within this habitat, this species is divided into at least seven different fragmented populations (Walker 2010). The northern limit of its range is approximately 15 km north of the coastal town of Morombe and the eastern limit extends to ca. 70 km east of the Manambovo River (Walker et al. 2013, this volume).

The Northern Spider Tortoise, *P. a. brygooi*, is divided into three distinct populations within the Mikea forest (Walker 2010). Large expanses of suitable habitat appear to be devoid of tortoises, especially near the center of the historical range (Fig. 2). Tortoise density is highly variable, with a mean encounter rate of  $1.7 \pm 6.2$  (mean  $\pm 1$  SD; range = 0–46) tortoises recorded per linear km of transect for the region surveyed north of Toliara (Walker et al. 2013, this volume). *Pyxis a. brygooi* now occupies a total area of 500 km<sup>2</sup> (Fig. 2), representing an 80% reduction in area from its historical range (Pedrono 2008; Walker 2010; Walker et al. 2013, this volume).

A zone of intergradation between P. a. brygooi and P. a. arachnoides occurs within the coastal zone south of the Manombo River and north of Toliara, covering an area of 100 km<sup>2</sup> (Fig. 2) (Walker et al. 2013, this volume). Spider Tortoises now appear to be largely absent within the coastal zone between the Fiherenana and Onilahy Rivers that straddle Toliara (Fig. 2); this is likely the result of poaching and habitat loss due to the close proximity of the provincial capital (Walker and Rafeliarisoa 2010). A small isolated population has been recently reported to occur approximately 8 km north of the Onilahy River (Scott et al. 2008). An unfragmented zone supporting P. a. arachnoides extends south of the Onilahy River and along the coastline through the Mahafaly Plateau region for approximately 72 km to the area of Ampalaza (Fig. 2). One female Spider Tortoise was located about 62 km inland on the main road that serves the coastal region; but it was suspected to have fallen off an oxcart used by poachers to transport tortoises (Rick Hudson, pers. comm.). A further zone of intergradation of approximately 267 km<sup>2</sup>, between P. a. arachnoides and P. a. oblonga, occurs on both sides of the Linta River in the area that has been traditionally known as the range of P. a. arachnoides (Bour 1981; Pedrono 2008). Pyxis a. oblonga is relatively abundant within the region of Cap Sainte Marie Special Reserve, the only protected part of its narrow range (Walker et al. 2013, this volume).

#### Conservation

*Historical Review.* — This species does not appear to have been as heavily exploited as *A. radiata* in the past. Historically, sailors were said to have occasionally received

them as gifts before departure (Bour 1981). Currently, the greatest threats imposed upon this species are collection for local consumption, the national and international pet trades, and probably most significantly, habitat loss (Walker et al. 2004; SSN 2004; Nijman and Shepard 2007). Local people generally only consume *P. arachnoides* where *A. radiata* is no longer available. This appears to be a significant problem in the area between Morombe and Manombo Atsimo (Pedrono 2008; Walker 2010). Behler (2000a) reported that this species has also been collected to provide tortoise liver for Asian food markets.

The pet trade has had a great impact on this species, with approximately 3000 individuals recorded by CITES entering the trade between 2000 and 2001. This figure significantly exceeded Madagascar's CITES export quota for the pet trade in Japan, Europe, South Africa, and the United States (Reeve 2002; Walker et al. 2004). In addition, the undocumented export of this species around the same time was considerable due to the circulation of falsified export permits and Madagascar's poor record of upholding CITES regulations during that time (Reeve 2002; Walker et al. 2004). Although CITES placed a ban on the international trade in this species in 2005, illegal collection and exportation continued to supply the pet trade (Walker et al. 2004). Specimens are currently being sold for as much as 2900 Euro in Japan (Walker, unpubl. data). Since early 2009, Madagascar has been going through a period of political unrest that has resulted in an increase in wildlife smuggling (Russell Mittermeier, pers. comm.). It is suspected within the Malagasy conservation community that many more illegally collected Spider Tortoises are entering the international black market.

The Spider Tortoise is also suffering from collection for food (Walker and Rafeliarisoa 2010). In many localities, populations have nearly disappeared and remaining healthy populations now occur only in remote locations far from human habitation (Pedrono 2008). Protecting wild populations is a challenge faced by conservation agencies within Madagascar. Behler (2000b) stated that within the previous 10 years collectors had decimated once dense populations of Spider Tortoises. Collectors have been known to harvest this species within protected areas such as the Tsimanampetsotsa National Park (Behler 2002).

The Spider Tortoise is suffering from severe levels of habitat destruction and fragmentation. It has been estimated that 1.2% of the spiny forest is lost per annum, which is the highest rate of loss for any forest type in the country (Harper et al. 2007). Invasive plant species (e.g., *Opuntia* spp. and *Agave* spp.) have also been identified as a significant threat to habitat suitability for this species (IUCN Conservation Breeding Specialist Group 2002).

*Conservation Status.* — The Spider Tortoise is nationally protected under Malagasy law (Decree 60-126; October 1960) that prohibits its consumption. The *fady*, or taboo, that prevents the local Mahafaly and Tandroy tribes from eating tortoise meat has, however, become less powerful in recent times. Moreover, the *fady* does not protect the tortoises from the neighboring Tanosy tribe that does not respect it (Behler

2002; Pedrono 2008). In 1975, the Spider Tortoise was listed on Appendix II of CITES to limit its illegal exportation. Despite this listing, harvesting continued (Walker et al. 2004) and it was later transferred from Appendix II to Appendix I in 2005. This current designation prohibits international trade in this species except for non-commercial purposes, and only when import and export permits are granted. The conservation status of the Spider Tortoise was lifted from Indeterminate to Vulnerable on the IUCN Red List of Threatened Species in 1996, and was later elevated from Vulnerable to Critically Endangered in 2008 on the basis of criteria A4cd + E (Leuteritz and Walker 2008). These criteria correspond to a projected population size reduction of > 80% over a period of three generations, of which the causes of this reduction have not ceased and are based on a decline in the extent of occurrence and quality of habitat and actual and potential levels of exploitation.

In 2005, Madagascar's Ministère des Eaux et Forêts (Ministry of Water and Forests) invited the IUCN Species Survival Commission's Captive Breeding Specialist Group to the village of Ifaty to work with community leaders, law enforcement officials, conservation biologists, and wildlife managers to develop a Population and Habitat Viability Assessment (PHVA) for P. arachnoides (Randriamahazo et al.,2007). The results of the PHVA suggested that an 85% reduction in the harvest of tortoises, both for human consumption and the illegal pet trade, was needed to prevent further declines. The group recommended that a *dina* (i.e., a local pact or convention) be developed which would create a strategy to protect tortoises from over-harvesting, repatriate confiscated individuals, promote awareness of Malagasy culture that shows respect for tortoises, update and enforce wildlife protection laws, and raise awareness through education (Randriamahazo et al. 2007).

Captive Breeding. - Colonies of Spider Tortoises have been maintained internationally in zoological institutions and private collections since 1975 (Ogle 2009). A studbook program for this species was first initiated in 2000 to document the demography of the captive population and to record the location of individuals registered in European collections. The majority of the nearly 100 individuals included in this studbook are housed at locations in the Netherlands, but also in Belgium and Germany (Van Loon 2004, 2007). A similar program was later developed in 2001, which included tortoises held at locations within North America (Castellano and Behler 2002, 2003). Today, the Knoxville Zoological Garden maintains this studbook with five editions having been published to date (Castellano and Behler 2002, 2003; Ogle 2006, 2009, 2012). The North American captive population currently includes approximately 315 individuals located at more than 30 public and private facilities (Ogle 2009). The majority of tortoises in the European and North American studbooks are captive bred individuals. Moreover, these populations are composed mainly of P. a. arachnoides, and contain much fewer representatives of the other subspecies. The North American studbook program is one component of the Association of Zoos and Aquaria Species Survival Plan

(SSP) for this species. The SSP aims to maintain a healthy and viable assurance colony in case the spider tortoise becomes extinct in the wild, and/or to provide individuals for re-introduction programs if required.

Captive breeding efforts for the Spider Tortoise were not very productive until relatively recently. A lack of information on the reproductive biology of this species in nature imposed significant challenges to breeders; however, a successful egg incubation protocol was developed and published in 2003 (Zovickian 2003) and since then more than 150 hatchlings have been produced using this technique (Ogle 2009). Incubation length can range from 80 to more than 200 days (Zovickian 2003; Zwartepoorte 2003). This species lays a single egg and, although oviposition dates have been recorded throughout the year, the majority of eggs in captivity have been deposited from June to September and less frequently through to January (Zwartepoorte 2003; Ogle 2006). Mating behavior including copulation has been observed from April to October in collections in the northern hemisphere. Males trail females before mounting and make soft vocalizations during copulation (Zwartepoorte 2003; Ogle 2006). Nesting females dig an egg chamber approximately 5 cm deep (Zwartepoorte 2003) and may lay multiple clutches per year (Ogle 2006). The average period between egg deposition is 37 days, but is highly variable and can range from 6-176 days (Ogle 2006).

Wild-caught specimens are initially difficult to maintain in captivity due primarily to high parasite loads, and often exhibit various illnesses, including respiratory infections. These individuals may take up to two years to overcome the stress of transport and adjust fully to their new surroundings (Ogle, pers. obs.). Veterinary care is often required, as heavy parasite loads could exacerbate stress-related issues. Moreover, there appears to be an adjustment period associated with the seasonal differences experienced in the northern and southern hemispheres (Ogle, pers. obs.). Spider Tortoises are often maintained in simple indoor and outdoor enclosures that contain a sandy substrate, heat lamps, and an assortment of shelters. They are usually fed a mainly vegetarian diet. Attempts are often made to mimic the environmental conditions that this species experiences in the wild, especially with regards to photoperiod, temperature, and humidity (Ogle 2009).

Ongoing Research. — The Spider Tortoise is one of the least studied of Madagascar's endemic tortoise species. One project aims to gain information on the population status of *P. arachnoides* across its range in order to implement effective *in situ* management strategies (Walker 2009a; Walker 2010). A genetic study is also being conducted to investigate the significance of the suspected intergrade populations on the boundary zone of *P. a. brygooi* and *P. a. arachnoides* (Ogle and Hudson 2008; Walker 2010) and *P. a. arachnoides* and *P. a. oblonga* (Walker, unpubl. data). This study is using genetic data from individuals across the whole of the species' remaining range.

There is a long-term research project on Spider and Radiated Tortoise populations at the Cap Sainte Marie Special Reserve, one of the last remaining strongholds for these species. This research is focused on habitat selection and patterns of movement, and demographic changes over time. This information will inform reserve management, the selection of new protected areas for these species, reintroduction strategies, and captive management and breeding in assurance colonies. There are three Spider Tortoise monitoring sites in Anakao, the Ranobe area, and the island of Lamboara and surrounding mainland, that are the subjects of population monitoring.

Community Conservation Actions. — A collaborative effort by Nautilus Ecology and Blue Ventures Conservation (BV) to safeguard one of the last remaining populations is underway in the Lamboara region within the range of *P. a. brygooi*. The project is implementing a community-based tortoise monitoring project with BV biologists training community members to be paid tortoise monitors within the region.

In southwest Madagascar between the Manombo and Fiherenana rivers, in the zone of intergradation between *P*. *a. brygooi* and *P. a. arachnoides*, WWF is promoting the new community-co-managed category V protected area of PK32-Ranobe. This PA includes areas of spiny thicket on red sand, east of the villages of Ifaty and Mangily, that still maintain significant tortoise populations (Walker 2009b). The Spider Tortoise has been prioritized as a conservation target for the management of this PA. In order to contribute to its conservation, WWF is implementing a number of strategies designed to stabilize habitat loss and degradation

Table 1. Strengths of the current Spider Tortoise conservation programme and management recommendations for the near future.

Program Strengths	Recommendations
Concentrated and well-coordinated community-based monitoring and conservation efforts.	These projects are restricted to small regions within the species' wider range. These projects need to cover a wider distribution across the species' remaining range.
A good knowledge of the spatial distribution of the species across nearly 100% of its current range.	Maintain this work to include resurveying portions of the spe- cies' range to document potential further change.
International support: NGOs and donors are willing to participate in the conservation of this species.	Develop more conservation proposals that are feasible and cost-effective, and strengthen collaborations.
Effective GIS support in mapping the distribution of the species in real time, in relation to protected areas and areas of alternative land use threats (i.e. ca. 13% of the known population is thought to be threatened by mining).	Develop sound mitigation strategies to reduce the impact of destructive land use practices on existing population (i.e. translocation programmes).

 Table 2: Current threats to the Spider Tortoise and recommendations for action.

Program Weaknesses	Recommendations
Lack of engagement and international lobbying of National Government.	Improve communication of tortoise issues in government; Improve communication with other management authorities.
Government turnover of personnel.	Permanent investment in training new recruits; Regular evaluations to ensure that required standards are main- tained.
Poverty in southwestern Madagascar.	Increase conservation benefits to local communities; Encourage development initiatives in the region.
Ineffective enforcement of legislation.	Identify weak points in laws; Identify weak points in applica- tion of laws, with recommendations to government; Strengthen capacity and motivation of law enforcement agencies to enforce the law.
Tortoise not well known by administration and government; Sci- entific information is unreadable to most (regionally very high levels of illiteracy).	Improve communication; Ensure information is in appropriate form for target audiences.
Lack of procedures for confiscated specimens both inside and outside Madagascar.	Develop clear procedures for confiscates, based on IUCN rec- ommendations.
Ongoing poaching, increasingly with threats of violence by poachers to local communities;	Work closely with police and gendarmes; Raise awareness of the situation locally, nationally, and inter- nationally.
Accessibility of habitat by sea from Toliara makes it difficult to control smuggling by sea.	Improve transport (boat) and communications (radio and tel- ephone).
Focal group of poachers and smugglers untouchable.	Raise awareness of the situation locally, nationally, and inter- nationally.
MNP lack of capacity; not enough personnel; lack means of en- forcement and arrest.	Investment of resources, training and working methods; Improve integration of law enforcers with PA managers
Probable lack of effective habitat management and poaching en- forcement within the newly proposed IUCN Category III, V or VI multiple-use protected areas within the species' range.	Improve capacity and motivation of communities within these protected areas, through the provision of alternative livelihood strategies to reduce the probable risk of poaching and habitat destruction.
No government-backed mitigation strategy in place to reduce the impact on the populations of tortoises that could be potentially impacted by the proposed mineral extraction within the species' remaining range.	Develop strong mitigation strategies in consultation with the mineral extraction companies for the potentially impacted popula- tions, such as well coordinated translocation programs or mining company owned protected areas
No re-introduction strategy in place for confiscated animals cur- rently within captivity in Madagascar (Ifaty tortoise village) and overseas.	Identify possible reintroduction sites, engage in community sensitization programs and training of local tortoise monitors or guardians; Support repatriation programs for confiscated animals currently held overseas

and improve community capacity and motivation for management, including the establishment of natural resource management transfers and associated *dina*, capacity building within community-based associations, and the promotion of modern agro-ecology practices to improve revenues and reduce the practice of slash and burn cultivation (WWF 2011).

The Madagascar Biodiversity Partnership is currently engaged in poverty alleviation work with the communities in the Lavovolo region. The project focuses on the production of fuel efficient stoves, which use mashed invasive cactus (*Opuntia* spp.), to draw communities away from the dependence on the destructive production of charcoal.

*Current Situation.* — No up-to-date data are currently available on the levels of poaching and its effect on *P. arachnoides*. However, the threats faced by poaching are thought to be currently less of a risk to the species' survival than the poaching pressures faced by the Radiated Tortoise, *A. radiata*, a species sympatric in much of its range with *P. arachnoides*. Nevertheless, consignments of *P. arachnoides* are turning up with reasonable regularity in the port town of Toliara and the capital, Antananarivo, with Spider Tortoises able to be acquired within the country on the black market with reasonable ease. The recently opened direct flight between Antananarivo and Bangkok has only increased the ease with which smugglers can move Madagascar's rare tortoises into the food and pet markets of Southeast Asia, where market surveys have recorded reasonable numbers of *P. arachnoides* for sale in the recent past (Nijman and Sheppard 2007). The smuggling problem is believed to have been compounded within recent years as a result of the political unrest in Madagascar.

Food security issues resulting from the recent droughts in southwest Madagascar are thought to have placed additional pressure on the Spider Tortoise, whereby animals are collected for bushmeat by local communities. This is particularly evident in regions of its range where the larger *A. radiata* has been hunted to extirpation. Evidence of the hunting of Spider Tortoises for food has been recorded within two of the three remaining populations of *P. a. brygooi* (Walker 2010; Walker, pers. obs.).

Habitat loss is currently estimated at 1.2% per year (Harper et al. 2007) and is mostly as a result of subsistence stock grazing, land clearance for subsistence agriculture,

Table 3. Indicative list of proposed high priority actions for conservation of *Pyxis arachnoides* and projected costs for each action.

	Projected
Action	budget (US \$)
Raise the awareness of local authorities and law	\$5,000
regarding enforcement of existing laws.	
Strengthen capacity of law enforcement	\$10,000
agencies and existing Mixed Squads	
(Commission Mixte) that include the National	
Gendarmerie, MEF, and informers that can	
enforce existing laws against tortoise	
Improve communication and transportation	\$55,000 +
equipment (i.e. motorcycles, two-way radios)	\$5.000/vr
for law enforcement agencies.	. , ,
Develop a protocol, and hold training sessions	\$5,000
on its use, for villagers to report offences.	<b>†2</b> 00
Create and distribute map of tortoise	\$200
distribution and known trafficking routes to	
Create a Tortoise Foundation to ensure the	Unknown
funding of law enforcement agencies.	C mino ( m
Lobby the government to eliminate the	Unknown
provisioning of export permits.	
Send letters of support to governments that	\$100
uphold wildlife protection laws and send copies of letters to Madagascar government	
Monitor trade on the internet identify	\$5,000
translators to monitor foreign websites, and	ψ5,000
establish partnerships with similar groups (e.g.,	
TRAFFIC China).	
Promote cooperation among CITES signatories	Unknown
to enforce importation restrictions, and to	
confiscate and repatriate illegally imported	
Provide the Madagascar government with a	Unknown
country-by-country account of confiscated	
tortoises that have not been repatriated.	
Develop a framework for the repatriation of	\$5,000
confiscated tortoises.	¢5.000
and confiscated tortoises	\$3,000
Build a database on the origin and ultimate	Unknown
location of tortoises seized by authorities.	C mino ( m
Identify potential reintroduction sites within the	\$5,000
range of each subspecies and intergrade	
population.	I.I
genetic testing of confiscated animals to inform	UIIKIIOWII
reintroduction strategies	
Develop a research plan to monitor the	\$10,000
effectiveness of reintroduction efforts.	
Create "tortoise villages" to house confiscated	\$20,000
tortoises in the Androy and Mahafaly regions	
and attract tourists	
Develop a funding strategy to support	\$1,000
repatriation activities.	. ,
Work with mining companies to identify	\$25,000
locations within mining concessions that	
support tortoise populations but have low value for mining, and encourage the actablishment of	
private protected areas.	
Develop protocols for the translocation of	\$10,000
tortoises from mining locations when protection	
is not feasible.	
Train teachers at primary schools, high schools,	\$35,000
and universities, and village elders to share	
for teachers to share information in a positive	
manner (e.g., reading material and games).	

	Deve de et e d
Action	Projected
Increase the understanding of the uniqueness of	\$25,000
native tortoises and their ecological importance,	
the responsibility of all for their conservation,	
potential financial gains through tourism	
associated with tortoises, and the power to eliminate illegal collection that can be achieved	
through stakeholder collaboration using	
appropriate education materials and workshops.	
Use visual images (e.g., posters) to increase the	\$10,000
awareness of illiterate people.	
Raise awareness with t-shirts with relevant	\$10,000
messaging, caps with logos, mobile theaters,	
Create associations or clubs that are focused on	\$5,000
the protection of tortoises in their area (e.g.,	<i>40,000</i>
youth, artists, etc.).	
Conduct workshops and hold carnivals within	\$3,500
local communities, and those outside of the	
tortoise's range, to eliminate the collection by	
crisis and to promote respect for the Tandrov	
and Mahafaly cultures.	
Engage traditional leaders and influential	\$5,000
village elders in raising public awareness for	
tortoise conservation and local traditions and	
customs.	<b>\$5.000</b>
In conjunction with local communities, develop	\$5,000
tortoise collection, and ensure <i>dina</i> are ratified	
in court.	
Promote widespread awareness of new dina that	\$5,000
prohibit the collection of tortoises through the	
dissemination of materials, carnivals, and	
meetings with local mayors, fokontany leaders,	
Provide resources (i.e., funds, equipment, and	\$50,000
technical training) to allow for the	\$50,000
implementation of sustainable and	
environmentally friendly farming practices.	
Develop linkages between community	\$20,000
development and tortoise conservation, e.g.,	
using management transfers.	Unknown
program to restore degraded tortoise habitat.	UIIKIIOWII
Create alternative sources of income (e.g.,	\$75,000
ecotourism) to alleviate poverty and promote	. ,
tortoise conservation.	
Build a laboratory to support research in this	\$75,000
area.	\$50,000
conduct research projects to establish	\$30,000
habitat loss predation invasive species etc.	
Conduct research projects to evaluate the	\$50,000
effectiveness of management and conservation	. ,
actions.	
Provide tools for data collection, analysis, and	\$50,000
management to Malagasy researchers (e.g.,	
Train Malagasy biologists to design and	\$45,000
implement research projects from proposal	$\psi + J, 000$
development to report writing.	
Develop long-term monitoring programs for	\$125,000
this species at multiple sites.	
Conduct research into reproduction and nesting	\$25,000
ecology of this species to inform captive	
breeding programs.	

and charcoal production (Seddon et al. 2000). The new land use policies proposed for coastal southwest Madagascar, which include gazetting much of the southwest region as protected areas, while most of the remaining land has the potential to be used for commercial mineral sand extraction, mean that all 500 km<sup>2</sup> of the existing range of *P*. *a*. brygooi falls within three newly proposed protected areas (Walker 2010; Walker et al. 2013, this volume). The P. a. brygooi x arachnoides intergrade population south of the Manombo River faces the greatest potential impact from proposed mineral extraction, with a possible 38% of the remaining population under threat. However, 55% of this population falls within protected areas. Pyxis a. arachnoides currently has the greatest remaining range of all the subspecies or intergrade populations, covering a continuous coastal belt of forest measuring 1029 km<sup>2</sup>. Fragments of this population occur within three proposed protected areas, including the region's only currently gazetted protected area (Tsimanampesotse National Park), as well as one area which is prioritized for inclusion in SAPM but currently is unpromoted as a protected area. However, the population of P. a. arachnoides could be potentially impacted by 26 mineral extraction operations. Of the P. a. arachnoides x oblonga intergrade population, 70% falls within protected areas, while 4% is potentially threatened by mineral extraction projects (Walker et al. 2013, this volume). The only protected part of the narrow range of P. a. oblonga is within Cap Sainte Marie Special Reserve; however, some of its range falls within a currently unpromoted proposed protected area. Of the remaining range only 268 km<sup>2</sup> is currently within this one protected area and one proposed area, and represents the smallest protected population of the three described subspecies.

Conservation Efforts and Priority Actions. – Strengths of current conservation efforts for the Spider Tortoise and their associated activities are included in Table 1. Barriers to conservation efforts are identified in Table 2. The aim of this Proposed Action Plan is to identify the threatening processes affecting the Spider Tortoise and recommend conservation actions for mitigation. The information provided below combines the threats and recommended actions identified in the PHVA conducted for this species (Randriamahazo et al. 2007) and the most current information available. Table 3 provides an indicative list of priority actions, including proposed implementing organizations and estimated costs. Note that Table 3 represents a proposed indicative plan only, and has not been formally validated by all institutions and partner organizations involved in the conservation of Pyxis arachnoides. The scope of this plan is July 2011 to July 2016.

#### Résumé

Ci-dessous le résumé des actions prioritaires contenues dans le Plan d'Action Proposé pour la tortue araignée (*Pyxis arachnoides*): 1) Enrayer les collectes et le commerce illicites de tortues araignées en accentuant la sensibilisation, la motivation, la capacité des autorités locales et des responsables pour l'application des lois, amener le gouvernement à sévir et enfin, surveiller le commerce international. 2) Promouvoir le rapatriement et la réintroduction de tortues araignées confisquées en identifiant dans un premier temps les populations de tortues confisquées, et en développant par la suite une structure de rapatriement et un protocole de réintroduction. 3) Développer des stratégies rigoureuses d'atténuation des impacts de l'extraction minière sur les tortues araignées, à travers le dialogue avec les compagnies minières et par l'établissement d'aires protégées privées au sein de zones de faible valeur minière. Le développement d'un protocole de translocation est également à prendre en compte pour ces localités.4) Développer des communications et des campagnes de sensibilisation pour éduquer toutes les parties prenantes sur l'importance de la tortue araignée et les menaces auxquelles elle fait face, et pour promouvoir un plus grand respect des coutumes traditionnelles Mahafaly et Tandroy qui protègent les tortues. 5) Appuyer les initiatives courantes de réduction de la perte d'habitat en promouvant de meilleures techniques agriculturales et en proposant de moyens de subsistance alternatifs. 6) Améliorer la recherche à Madagascar en fournissant le matériel et en formant des scientifiques malgaches. Effectuer ensuite des recherches pour bien connaître la gestion de l'espèce.

#### LITERATURE CITED

- BEHLER, J. 2000a. Letter from the IUCN Tortoise and Freshwater Turtle Specialist Group, Turtle and Tortoise Newsletter 1:4–5.
- BEHLER, J. 2000b. Letter from the IUCN Tortoise and Freshwater Turtle Specialist Group to the CITES Secretariat.
- BEHLER, J. 2002. Madagascar Tortoise Crisis: Report of a visit to southern Madagascar, November/December 2001. Submitted to the CITES Animals Committee and Concerned Parties.
- BOUR, R. 1979. Les tortues actuelles de Madagascar (Republique malagache): liste systematique et description de deux sous-especes nouvelles (Reptilia-Testudines). Bull. Soc. Et. Sci. Anjou, N.S., 10:141–154.
- BOUR, R. 1981. Etude systematique du genre endemique Malagache Pyxis Bell, 1827 (Reptilia, Chelonii). Bull. Mens. Soc. Linn. Lyon 50:154–174.
- CASTELLANO, C.M. AND BEHLER, J. 2002. Madagascar flat-tailed (*Pyxis planicauda*) and spider tortoise (*Pyxis arachnoides*) North American regional studbook, 1st Edition. Wildlife Conservation Society, New York.
- CASTELLANO, C.M. AND BEHLER, J. 2003. Madagascar flat-tailed (*Pyxis planicauda*) and spider tortoise (*Pyxis arachnoides*) North American regional studbook, 2nd Edition. Wildlife Conservation Society, New York.
- CHIARI, Y., THOMAS, M., PEDRONO, M., AND VEITES, D.R. 2005. Preliminary data on genetic differentiation within the Madagascar spider tortoise, *Pyxis arachnoides* (Bell, 1827). Salamandra 41:35–43.
- DURRELL, L., GROOMBRIDGE, B., TONGE, S., AND BLOXAM, Q. 1989. *Pyxis arachnoides* Madagascar spidertortoise; Tsakafy; Kapila. In: Swingland, I.R. and Klemens, M.W. (Eds.). Conservation Biology of Tortoises. Gland, Switzerland: IUCN, pp. 103–104.
- GLAW, F. AND VENCES, M. 1994. A Field Guide to the Amphibians and Reptiles of Madagascar. Köln: Moos Druck, Leverkusen and FARBO.
- HARPER, G.J., STEININGER, M.K., TUCKER, C.J., JUHN, D., AND HAWKINS, F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34:325–333.
- IUCN CONSERVATION BREEDING SPECIALIST GROUP. 2002. Evaluation

et plans de gestion pour la conservation (CAMP) de la faune de Madagascar: lemuriens, autres mammifères, reptiles et amphibiens, poissons d'eau douce; 20-25 May 2001, Mantasoa, Madagascar.

- JESU, R. AND SCHIMMENTI, G. 1995. A preliminary study on the status of a population of Malagasy spider tortoise (*Pyxis arachnoides* Bell, 1827) from SW Madagascar. In: Devaux, B. (Ed.). International Congress of Chelonian Conservation. Gonfaron. France, 6-10 July 1995.
- LEUTERITZ, T. AND WALKER, R. 2008. *Pyxis arachnoides*. In: IUCN. IUCN Red List of Threatened Species. Version 2009.1. www. iucnredlist.org. Downloaded on 22 June 2009.
- MORONI, S., MATTIOLI, F., JESU, R., AND ARILLO, A. 2006. Thermal behaviour of the Malagasy spider tortoise *Pyxis arachnoides arachnoides* (Bell, 1827). In: Vences, M., Kohler, J., Ziegler, T., and Bohme, W. (Eds.). Herpetologgia Bonnensis II. Proceedings of the 13th Congress of the Societas Europaea Herpetologica, pp. 95–97.
- NIJMAN, V. AND SHEPHERD, C.R. 2007. Trade in non-native, CITESlisted, wildlife in Asia, as exemplified by the trade in freshwater turtles and tortoises (Chelonidae). Thailand Contributions to Zoology 76:207–212.
- OGLE, M. 2006. Madagascar Spider Tortoise (*Pyxis arachnoides*) North American regional studbook, 3rd Edition. Knoxville, TN: Knoxville Zoological Gardens.
- OGLE, M. 2009. Madagascar Spider Tortoise (*Pyxis arachnoides*) North American regional studbook, 4th Edition. Knoxville, TN: Knoxville Zoological Gardens.
- OGLE, M. 2012. Madagascar Spider Tortoise (*Pyxis arachnoides*) North American regional Studbook, 5th Edition. Knoxville, TN: Knoxville Zoological Gardens.
- OGLE, M. AND HUDSON, R. 2008. Madagascar quest: 12 days to find four Pyxis. Turtle Survival Alliance 2008:40–42.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Natural History Publications, Borneo.
- RANDRIAMAHAZO, H.K., TRAYLOR-HOLZER, K., LEUS, K., AND BYERS, H.O. 2007. Population and Habitat Viability Assessment Workshop for Endemic Tortoise Species in Madagascar Geochelone radiata (Madagascar radiated tortoise) Pyxis arachnoides (spider tortoise). Apple Valley, MN: IUCN/SSC Conservation Breeding Specialist Group.
- REEVE, R. 2002. The reptile trade in Kenya. A report prepared for the International Fund for Animal Welfare (IFAW).
- SCOTT, D., ANDRIAMBOLANORO, O.A., MBOHOAHY, T., RAHARINIRINA, N.L., SMITH, M., TANTELINIAINA, S., THOMPSON, S., AND TSAG-NANGARA, C. 2008. University of Brighton (UOB) spiny forest research expedition 2007/2008: Final report. Unpublished expedition report.

- SEDDON, N., TOBIAS, J., YOUNT, J.W., RAMANAMPAMONJY, J.R., BUTCHART, S., AND RANDRIANIZAHANA, H. 2000. Conservation issues and priorities in the Mikea Forest of south-west Madagascar. Oryx 34:287–304.
- SSN. 2004. Madagascar Reptiles. Species Survival Network, Fact Sheet No. 5, 3 pp.
- Van Loon, F.2004. Studbook breeding programme *Pyxis arachnoides*. Annual report for 2003. Germany.
- Van Loon, F.2007. Studbook breeding programme *Pyxis arachnoides*. Annual report for 2006. Germany.
- WALKER, R.C.J. 2009a. Comprehensive survey of spider tortoise distribution in Madagascar gets underway in the north. Turtle Survival Alliance 2009:8–9.
- WALKER, R.C.J. 2009b. Preliminary results of a population range and density survey for *Pyxis arachnoides brygooi* in Madagascar. TurtleLog No.2, doi:10.3854/tln.002.2009, http://www.iucntftsg.org/ turtlelog\_online\_newsletter/tln002/. Downloaded 22 June 2009.
- WALKER, R.C.J. AND RAFELIARISOA, T.H. 2010. Distribution of the Madagascar spider tortoise, *Pyxis arachnoides*. Turtle Survival Alliance 2010:61–63.
- WALKER, R.C. J., RIX, C., AND WOODS-BALLARD, A.J. 2004. The export of the endangered Madagascar spider tortoise (*Pyxis arachnoides*) to support the exotic pet trade. Herpetological Bulletin 90:2–9.
- WALKER R.C.J., WOODS-BALLARD, A.J., AND RIX, C.E. 2007. Population density and seasonal activity of the threatened Madagascar spider tortoise (*Pyxis arachnoides arachnoides*) of the southern dry forests; South West Madagascar. African Journal of Ecology 46:67–73.
- WALKER, R.C.J., GARDNER, C.J., RAFELIARISOA, T.H., SMITH, I., AND RAZAFIMANATSOA, R. 2013. Conservation of the Madagascar spider tortoise (*Pyxis arachnoides*) amid changing land use policy: assessing the spatial coincidence of relict populations with protected areas and mining concessions. Chelonian Research Monographs 6:135–145.
- WWF. 2011. Plan d'Aménagement et de Gestion de la Nouvelle Aire Protégée PK32-Ranobe. WWF, Antananarivo.
- ZOVICKIAN, W. 2003. Incubation strategy for *Pyxis* eggs. In: Castellano, C. and Behler, J. (Eds.). Madagascar flat-tailed (*Pyxis planicauda*) and spider tortoise (*Pyxis arachnoides*) North American regional studbook, 2nd Edition. New York: Wildlife Conservation Society, pp. 17–18.
- ZWARTEPOORTE, H. 2003. Breeding the Madagascar spider tortoise Pyxis arachnoides, Bell, 1827. In: Castellano, C. and Behler, J. (Eds.). Madagascar flat-tailed (*Pyxis planicauda*) and spider tortoise (*Pyxis arachnoides*) North American regional studbook, 2nd Edition. New York: Wildlife Conservation Society, pp. 19–27.

## Conservation of the Angonoka (Ploughshare Tortoise), Astrochelys yniphora

## A. Ross Kiester<sup>1</sup>, Angelo R. Mandimbihasina<sup>2</sup>, Richard E. Lewis<sup>2</sup>, Eric V. Goode<sup>1</sup>, James O. Juvik<sup>1</sup>, Richard Young<sup>3</sup>, and Torsten Blanck<sup>4</sup>

<sup>1</sup>Turtle Conservancy, 49 Bleecker St., Suite 601, New York, New York 10012 USA [ross@turtleconservancy.org, eric@turtleconservancy.org, jim@turtleconservancy.org]; <sup>2</sup>Durrell Wildlife Conservation Trust, BP 8511, Antananarivo, Madagascar [angelo.ramy@durrell.org, richard.lewis@durrell.org];

<sup>3</sup>Durrell Wildlife Conservation Trust, c/o Dept. of Biology and Biochemistry, University of Bath,

Bath, BA2 7AY, Great Britain [richard.young@durrell.org];

<sup>4</sup>Turtle Survival Alliance Europe, Forstgartenstrasse 44, Deutchlandsberg, 8530 Styria, Austria [cuora\_yunnanensis@yahoo.com]

ABSTRACT. – We describe the conservation history of the Angonoka, or Ploughshare Tortoise (*Astrochelys yniphora*), that has led to its current status as the world's rarest tortoise. Because of the scale of poaching that threatens this tortoise and the fact that individuals are illegally sold around the world, conservation of this species is a truly global problem. The 2011–2013 wild population size is estimated to be 600 individuals (carapace length > 200 mm) down 33% from the 2006–2008 estimate of 900. We conclude that at least a similar number are being held illegally. We believe that significantly marking all animals by engraving will help to reduce this international trade. We review our current anti-poaching efforts and new *ex-situ* colonies composed of animals already confiscated from the illegal trade. This species requires extraordinary measures and a coherent global strategy to prevent its further decline.

KEY WORDS. – Reptilia, Testudines, Testudinidae, *Astrochelys yniphora*, Ploughshare Tortoise, Plowshare Tortoise, Madagascar, illegal wildlife trade, captive breeding, reintroduction

The Angonoka, or Ploughshare Tortoise (*Astrochelys yniphora*), is arguably the most difficult problem in tortoise conservation and one of the most difficult problems in all of conservation. It occupies one of the smallest natural ranges of any extant tortoise species, being endemic to a tiny area around Baly Bay in northwestern Madagascar and it is one of the world's rarest tortoises, with perhaps 400–600 adults remaining in the wild. Although this species was exported for food in large numbers in the 19th Century and has long-been threatened by bush fires in its native habitat, it is illegal collection for the international animal trade, due to its extraordinary value, that has caused it to become ranked as Critically Endangered under IUCN Red List criteria and listed in Appendix I of CITES (Leuteritz and Pedrono 2008).

It is quite possible that the majority of individuals now occur in illegal captive collections outside of the natural range and habitat of this species. Because of this and the fact that the remaining wild population of Ploughshares is so depleted, conservation of the species has become a truly global problem. Conservation planning must consider how to best utilize all extant individuals. Further, we know from the experience of the Asian Turtle Crisis that we must use all possible tools for the conservation of this species. We must adopt an ecumenical approach in which the effective use of one particular conservation tool must not prevent the effective use of any other tool. In this paper we will review the conservation status and possible actions that can be taken to save this species from extinction.

History and Background. - Pedrono (2008) gives a comprehensive review of the biology and conservation of this species and a complete bibliography. Here we give a brief review of the history of the Angonoka. It begins in the late 19th Century when a resident of Anjouan in the Comoros Islands in the Mozambique Channel between Madagascar and East Africa received a strange tortoise from Arab sailors who made vague reference to the animal's origin from small islands to the north near Aldabra. Forwarded to the Paris Museum, the herpetologist Leon Vaillant described the specimen as a new species, Testudo yniphora, in 1885. Fifteen years later the true natural range of the tortoise was discovered by the German biologist Alfred Voeltzkow, who secured a few specimens from the wild at Cape Sada (Baly Bay) on the coast of northwestern Madagascar. Over the next half-century fewer than a half dozen Angonoka specimens found their way into international museum collections, although it is apparent that many were collected for food by sailors from the Comoros Islands. The French zoologist Raymond Decary (1950) described the species as possibly on the verge of extinction.

Encouraged by southern California tortoise aficionado Ronald Beltz in the 1960s, James Juvik teamed up with French Zoologist Charles Blanc in April 1971 to visit the Baly Bay area to resolve the status of this elusive species (Juvik and Blanc 1974; Juvik et al. 1981). They encountered a few Angonoka at Cape Sada on Baly Bay. However, cattle grazing, dry season burning, and probable predation by the introduced African bush pig were seen as severe threats to the small remaining population. These observations led to the development of a draft species Recovery Plan for the IUCN Tortoise and Freshwater Turtle Specialist Group (Juvik et al. 1982). Major recommendations were to establish a protected area on Cape Sada, begin an education program to halt the incidental collection of wild animals, and establish a captive breeding program.

Soon thereafter the Jersey Wildlife Preservation Trust (now renamed the Durrell Wildlife Conservation Trust [DWCT]) began to implement many elements of the Recovery Plan. In 1986 they initiated a captive breeding and headstart program at Ampijoroa in Ankarafantsika National Park. This represented collaboration between Durrell and the then Malagasy Department of Water and Forests (since 2009, called the Direction des Forêts). Breeding occurred from year one of the project (Reid 1996). In 1996, the project was compromised by the theft of 73 juveniles and two adult females from Ampijoroa. Only half of these animals have ever been found and they are now in the hands of a private individual in Madagascar. This breeding program was, until 2011, the only legal breeding program anywhere in the world. The captive breeding program at Ampijoroa led to a trial release of five animals in Baly Baly in 1998 (Pedrono and Sarovy 2000) and further releases of 40 juveniles in 2005-07.

The human population living around the natural range of the tortoise is extremely poor, with many of the communities subsisting on less than \$2/person/day. In the mid-1990s DWCT began working with these local communities to increase public awareness and initiate conservation actions that supported both the local people and the Angonoka, including education and local development initiatives (Durbin et al. 1996). By raising the awareness of local communities, the area and the tortoise gained a new importance for them and they proposed that its habitat become protected. In 1997 the area became Baly Bay National Park (BBNP) and since 2001 has been managed by Madagascar National Parks (MNP).

A continuing threat to the animal's habitat comes from bush fires that are still being set within the boundaries of BBNP to promote grazing for zebu cattle. In collaboration with the Direction des Forêts, the DWCT community-based program has led, in part, to the establishment of a complete set of firebreaks around the Park and, as a result, there has been a year-to-year decrease in fires impacting the Park's boundaries. Unfortunately, fires within the Park have not been fully curtailed with the existing firebreak network, which is only on the perimeter.

Currently, the greatest threat to the Park's tortoises is from poaching for the international pet trade. We know that hundreds of animals exist illegally in private collections around the world (see below). This population may even be approaching the size of the remaining wild population. Individual adult Ploughshares on the international market can change hands for \$5,000-\$50,000 and more and can effectively be stolen on order from BBNP. The Park lies on the coast, so access from the sea is easy and the coastal waters need to be patrolled. The lack of capacity of the local authorities, the difficulties of patrolling the habitat, and the socio-economic situation for most of the local population create ideal conditions for exploitation by poachers and traffickers. Once animals are smuggled out of Madagascar, they appear all over the world. This means that the conservation of this species is a global issue requiring the collaboration and support of non-governmental, inter-governmental, and state organizations to apprehend smugglers and bring illegal animals out into registered collections or back to Madagascar.

2008 Meeting and Action Plan. — In January 2008, a workshop for the conservation of Malagasy chelonians "Turtles on the Brink" was convened in Antananarivo by the IUCN Tortoise and Freshwater Turtle Specialist Group in order to develop specific conservation actions for implementation. This was held, in part, due to a growing realization between the government of Madagascar, IUCN, and the conservation community, that the Ploughshare Tortoise was facing a crisis situation. The workshop resulted in a draft Action Plan (Lewis et al. 2009) that set out the conservation priorities for the species, and it has formed the basis for our review. The main objectives of the Action Plan are to stop poaching and illegal traffic and to reinforce in-country captive breeding and re-introductions. The establishment of further legal ex-situ captive assurance populations was also discussed at the workshop.

Unfortunately, in 2009, just as the Action Plan was being completed, the existing government of Madagascar was ousted, and the new regime has struggled to be internationally recognized and to govern effectively. It has not yet been able to achieve political consensus on the Action Plan and has had trouble preventing the illegal exploitation of the country's natural resources. This lack of effectiveness has put the Ploughshare Tortoise in a more precarious position than ever before, and reinforces the necessity of a global approach to its conservation.

#### A Global Strategy: in-situ, ex-situ, and non-situ

Figure 1 diagrams how the different possible places an individual tortoise can exist are connected, and how different conservation actions can impede or enhance flow between these places. We believe the standard classification of *in-situ* and *ex-situ* is too simplistic and we therefore introduce the term "non-situ" for those animals that are in captivity, but not part of a long-term program to maintain the evolutionary potential of the species. We restrict the use of the term "ex-situ" to captive animals that are included in such programs. In this view, a global conservation strategy will seek to prevent the movement of animals from in-situ to non-situ, while facilitating movement of animals from nonsitu to ex-situ and eventually back to in-situ. Reintroduction of animals maintained or born ex-situ to the native range then closes the loop of this global strategy. A theoretical possibility is that currently clandestine private breeders may eventually produce enough animals to almost qualify the



**Figure 1.** Global pattern of flow of individual Ploughshare Tortoises and the conservation strategies used to manage that flow.

species as domesticated. This has partially happened with other tortoises (e.g., *Centrochelys sulcata*), but certainly not with the Angonoka.

#### In-Situ

Astrochelys yniphora typically inhabits bamboo scrub forest, though it is not confined to this habitat, and can at times be found in more open habitat (Juvik et al. 1997). The current range of the species is believed to be entirely within the limits of the BBNP, created specifically to conserve A. yniphora. In 2000, the total area of suitable habitat was estimated at approximately 7975 ha, of which 6670 ha contained tortoises (Andrianandrasana 2000). Recent estimates by DWCT personnel using satellite images, estimate that as much as 16,000 ha of potentially suitable habitat may exist, although this work has yet to be fully validated through ground surveys. It is important to note that suitable habitat does not necessarily mean the presence of tortoises. Most of this range is close to the coast and its altitudinal range is only 0–90 m above sea level (Andrianandrasana 2000).

*Populations.* — *Astrochelys yniphora* habitats are fragmented and isolated. There are six known populations of *A. yniphora*, with Baly Bay dividing them into eastern and western subpopulations (Mandimbihasina 2004). The eastern populations at Cape Sada, Maroaboaly, and Beheta are all smaller than the western populations of Ambatomainty-Andrafiafaly, Betainalika, and Beaboaly (Mandimbihasina 2004). Figure 2 gives the distribution of these populations and the outline of Baly Bay National Park. Five of the six habitats, covering a total area of 14,528 ha, support original wild populations. The sixth habitat, Beaboaly in the west, previously supported *A. yniphora*, but the area was destroyed by fire in the late 1960s, and it now contains a reintroduced population.

An intensive program of line transect sampling (Burnham et al. 1980) was undertaken by DWCT from 2006 to 2009 (Mandimbihasina and Young, in prep.). Preliminary results suggested a population estimate of 900 individuals > 200 mm in carapace length, with a 95% confidence interval of 560 to 1400 animals. A resurvey during 2001–2013 estimated only 600 animals, a decline of 33%. There is uncertainty associated with this estimate, but it is clear that the species is declining precipitously.



Figure 2. Map of Baly Bay, Madagascar, showing the boundaries of Baly Bay National Park and the six habitat fragments historically occupied by Ploughshare Tortoises.

Habitat Management. — The bamboo scrub forest that forms the habitat of the Angonoka is a relatively tolerant and fast-growing ecosystem that is an advantage in managing this species. Nonetheless, we need to develop long-term strategies to protect tortoise habitat. Funding development programs that use monetary incentives to encourage local villages to avoid burning and grazing key areas and to actively create and maintain firebreaks is one option. African bush pigs are a threat to both eggs and younger tortoises and generally an annoyance to the local villagers, so a program to curtail their populations also may be worth pursuing.

Marking and Branding. — All captive tortoises in Madagascar have been marked by notching their shells, as have those tortoises in the wild encountered through surveys by researchers. These traditional marks are useful for research and management, but it is now apparent that a redundant system of marking should be undertaken using notching, PIT tags, and photographs. This redundancy is necessary because poached animals must be identified in a way that will stand up in courts around the world if poachers and smugglers are to be prosecuted.

A newer approach is to significantly deface animals by engraving the shells with a Dremel® tool. This method was originally used by John Behler in 1999 (Love 2000; Smith 2011) and provoked controversy at the time. The idea now is to undertake similar branding to reduce or eliminate the value of the tortoises for the pet market. Trials with animals at Ampijoroa have demonstrated that it is easy to do and does not appear to have any long-term ill effects on the animals (Fig. 3). Anecdotal information from interviews with smugglers indicated that few pet fanciers would pay for such animals, and that dealers and smugglers would be reluctant to handle them. Marking of wild animal began in January 2012 and appears not to bother the animals, as their scutes are much thicker than those of other tortoise species. We believe that this strategy will provide some real protection for this species.

Anti-Poaching Program at Baly Bay. — Although MNP manages Baly Bay National Park, it does not have



**Figure 3.** Adult Ploughshare Tortoise engraved to prevent sale on the illegal market. Ampijoroa, Madagascar. Photo by A.R. Mandimbihasina.

enforcement rights to stop and search or to arrest poachers. These rights remain the responsibility of the Direction des Forêts, gendarmes, and police. There are eight Park Rangers operating in the field. This separation of detection and enforcement, coupled with the small number of Park Rangers, means that poachers can often find a way to poach inside the Park and avoid arrest. As a consequence, DWCT and the Turtle Conservancy (TC) recently teamed up to strengthen the anti-poaching program in Baly Bay. Given the large surface area (57,142 ha) of BBNP, the existing ranger staff is not enough to protect the remaining wild Angonoka. The four permanent (on site) employees of DWCT are also insufficient to cover the Park. More feet are needed on the ground. But there must also be a way of directly engaging the local communities in the goals of the Park and further legitimizing the existence of the Park.

The reality is that Park Rangers cannot live at all times in the park. They go home on weekends, take holidays, and are called on for other Park duties. Only the local communities are based permanently around the Park. They are logically the first line of protection for the park. DWCT has worked for many years with these communities and most of the time they are sympathetic to the needs of the Park and the plight of the tortoise. They take pride in the fact that the tortoise belongs to them and that the animal exists nowhere else in the wild. Although they do not use the tortoise, they do use other resources in the park on a regular basis, such as raphia, fuel wood, and wood for house building. They also graze zebu cattle there, although this is now not legal. The Park managers do recognize their logistic limitations as well as the need to bring all stakeholders together. So the Park Manager and DWCT agreed to work together, and the principle of creation of "Para-Rangers", using local villagers to systematically patrol Angonoka habitat, was born. Park personnel and DWCT then worked with the village elders to create a system of selecting patrol members and villages to participate, and developed the infrastructure and protocols that the Para-Rangers use.

Because some local villagers have been involved in poaching tortoises, choosing the villages and Para-Rangers was complex. Among the 15 groups of villages originally proposed for conservation patrols, four villages were not involved at this stage due to lack of habitat or known involvement in smuggling. To prevent the employment of people who participate in trafficking of this species, meetings were held with the whole community, the "Fokonolona",

 
 Table 1. Criteria for choosing Para-Rangers to protect Ploughshare Tortoises.

Criterion	Score
Physical condition Literate Knowing how to use a mobile phone Has already worked for either the village and/or State Able to work with partners; ability to understand ideas Knowledge of the area Rumored to be involved in smuggling	+3 +2 +2 +5 +3 +10 -10
Confirmed to be involved in smuggling	-20

from each village. They would offer us four representatives from their village, and MNP and DWCT then chose among those people, using a set of criteria with positive and negative scores to select those who were both trustworthy and capable of doing the work; these criteria are summarized in Table 1.

The persons thus selected then attended a meeting and training workshop on conservation of biodiversity, and how the patrols would act in the field. The workshop emphasized the importance of calling for backup, rather than trying to capture poachers who might well be armed, and of not getting caught in moving fires. Clearly the safety of the patrol members was the most important consideration. These patrols are based permanently at five field sites where huts and sheds have been constructed and equipped. A regular routine for patrolling each area is maintained. Patrols began in June 2010 and these efforts have had some positive results:

• Fast action against fires in Beheta in August 2010.

• Arrest of two poachers in November 2010 in Ambatomainty (Fig. 4).

• Obtaining reports on the observation of footprints of people in many sites (Sada, Ambatomainty, Andranolava, and Beheta).

It has become clear that this anti-poaching effort is complex and difficult. However, at this time we feel that it shows the following strengths:

• Good cooperation and assumption of responsibility by all partners.

• Much greater presence on the ground near and in Angonoka habitats.

•A better understanding of the patterns of human activity in tortoise habitat, both legal and illegal.

• During their patrols, the Para-Rangers record animals they see and their data can be useful to assess relative abundance of these species.

• The cost is less than hiring police or regular park guards.

Despite these strengths, we also recognized some shortcomings of the program:

• Insufficient follow-up for various reasons: time constraints, fuel not available, delayed arrival of salaries, overland routes impassable during the rainy season.

• Some reports are inconsistent or difficult to read as Para-Rangers are often illiterate.

• A few of the guards are suspected of poaching, but together with the Fokonolona and authorities, they are being watched closely.

• The large block to the west of Baly Bay is divided into two sites, but we do not yet have enough personnel to patrol both areas at once. When the guards go to one site, the traffickers who are watching may enter the other site. Thus we need to create at least one additional guard station and patrol team.

The anti-poaching program is too new to evaluate its overall success. However, there are three ways in which we plan to build on the Para-Ranger patrol efforts. First, we must develop a system of incentives for the Para-Rangers and their communities, so that doing a measurably good job of protecting the Angonoka will result in tangible benefits. Developing a measure of success is not easy. One idea is to radiotrack as many animals as possible so that the population can be censused periodically by finding known animals. Rewards would then be based on animals remaining within the Park.



Figure 4. Arrest of two poachers in Baly Bay National Park in November, 2010. Photo by A.R. Mandimbihasina.

Second, we propose to further legitimize the community role by developing a regional Dina, the Malagasy traditional law. Local authorities can accept and legalize these traditional laws as long as they do not conflict with the constitution and other existing codified laws. The different communities around the park have already proposed that a regional Dina could be established to protect the park against arson and animal theft. If a Dina were established, this would allow the communities to directly fine people rather than having the guilty parties punished by the State.

Dina is a Malagasy concept; Rakotoson and Tanner (2006) described the Dina and its use in natural resources management as follows:

"On account of the "legal transplant" of French civil law into traditional customary law in Madagascar, the traditional social code generally known as "Dina" has coexisted with the modern law since the pre-colonial era and has conditioned the implementation of such law. The concept and use of Dina has been influenced by that process. This paper illustrates the role of Dina as a mechanism for reconciling modern decentralized and traditional governance of marine resources and the coastal zones in Madagascar. Democratic participation is important for enforcing the regulations governing marine resources and coastal zones. As law should be the will of people themselves, it is therefore necessary to develop legislation in community forums such as through Dina. It is especially critical that regulations be imbued with community aspiration and culture so that the population can respect laws freely."

We will work with the local communities to establish a Dina for the Ploughshare Tortoise. The lessons from Rakotoson and Tanner (2006) and Andriamalala and Gardner (2010) are important to our effort. A crucial aspect of the Dina must be that the local people see some tangible benefit from the Dina. The income provided to the Para-Rangers is of benefit to the community and is a start.

Third, we must undertake more lobbying and advocacy. During 2010 there were successful identifications of poachers by the Para-Rangers both in the field and in the nearby town of Soalala. We have seen that people are willing and

Table 2. Non-situPloughshare Tortoise confiscations from2008–11.

Country	Entity	Confiscated	Died or Disappeared
Madagascar	DWCT Antananarivo	44	0
-	Olaf Pronk Antananarivo	18	12
	Croc Farm	8	0
	Direction de Forêts	4	0
Taiwan	Taipei Zoo	2	2
	Ping Tung Rescue Center	2	0
Thailand	Government	20	18
Hong Kong	Kadoorie Farm	30	1
China	Kunming	3	3
Malaysia	Government	2	2
Singapore	Singapore Zoo	3	1
United States	Fish & Wildlife Service	1	0
Germany	Frankfurt Zoo	4	0

are capable of supporting confiscations. However, our results have been hindered by the fact that several clear cases of smuggling (poachers caught in the act) were dismissed when brought to court. We have not been able to track down why cases have been dismissed, as typically the courts do not encourage visits by the general public and typically trial dates and court decisions are not published. Since the beginning of the political crisis in 2009, two environmental advocacy groups have sprung up to defend the public's interest in the face of the apparent inability of the State to control smuggling of natural resources such as rosewood and tortoises. At the national level, Alliance Voahary Gasy (www.alliancevoaharygasy.mg) is working to publicize acts of smuggling, and at the regional level, Komanga is lobbying for "environmental justice". Both are Associations made up of members from civil society. DWCT is a member of Komanga and an associate of Alliance Voahary Gasy. We propose to support Komanga by undertaking four activities:

1. Follow the smuggling cases that are brought to the courts in Mahajanga.

2. Lobby the police and the courts to enforce the laws protecting wildlife.

3. Maximize publicity of all arrests and court decisions.

4. Undertake a public awareness campaign for school children and their parents in Mahajanga to raise the plight of the tortoise and to raise the local pride in their unique wildlife.

#### Ex-Situ

Ampijoroa Captive Breeding Facility. — As mentioned above, DWCT's captive breeding program at Ampijoroa has been very successful. It has now recovered from the thefts of 1996 and has a population of 225 offspring. At this time planning is underway to both expand the facility at Ampijoroa and to look to creating a second breeding center within Madagascar, possibly at Soalala on Baly Bay, next to the native range and BBNP.

*Reintroduction Program at Baly Bay.* — Reintroduction of Ploughshare Tortoises into BBNP currently takes place in Beaboaly, an area once inhabited by tortoises where it is thought that they no longer exist naturally. Many of the tortoises previously released initially carried radio transmitters. By and large this program has been success-

**Table 3.** Non-situ
 Ploughshare Tortoises illegally held or offered for sale from 2008–11.

Country	Number	Source
Singapore	10	private communication
Thailand	80	Nantarika Chansue,
		internet and market surveys
China	112	internet and market surveys
Indonesia	6	internet and market surveys
Philippines	6	internet and market surveys
Italy	2	private communication
Germany	2	private communication

Figure 5. Illegally held Ploughshare Tortoises in Thailand. Photo courtesy of the Turtle Conservancy.

ful, although the released tortoises have some years to go before they reach reproductive age. Unfortunately, four of the released tortoises appear to have been poached from this site. Future releases of tortoises are planned and are currently awaiting evaluation of the success of the antipoaching program.

*TC/Behler Chelonian Center (BCC) Program.* — In 2010 the TC/BCC program received a U.S. CITES import permit for 10 Ploughshare Tortoises to be obtained from confiscated animals in Asia. In October 2010, a juvenile and a nearly adult female were sent to the BCC from the Pingtung Rescue Center in Taiwan. In June 2011, seven juveniles and one adult female were sent from Hong Kong by Kadoorie Farm and Botanic Garden. In October 2011, the Center received an adult male owned by the San Antonio Zoo and kept for nearly 40 years by William Zovickian. Together, these three adults will become the first legal breeding colony outside of Madagascar, but as of February 2012 there has not yet been any successful breeding.

#### Non-Situ

Although it is extremely difficult to determine non-situ numbers with any precision because the trade is illegal, we do have data on many animals. We know from studies of other global illegal markets that only a small fraction (ca. 10% or so) is caught by enforcement and interdiction. Even if these numbers are off by an order of magnitude, they are operational in the sense that they guide activities. They show that a significant percentage of the total number of the species is non-situ. We can divide non-situ animals into those that government authorities have confiscated and those that are estimated to be illegally held. Table 2 gives the numbers of confiscated tortoises held around the world. We estimate a total of 141 animals have been confiscated in recent years, of which 39 have died or disappeared. Table 3 shows our estimates of the number of animals held illegally. Many animals were counted because they were offered for sale on the Internet. These numbers add up to 218 individuals. Figure 5 shows animals illegally held in Thailand and Fig. 6 is an Internet advertisement for Ploughshare Tortoises in the Philippines. Most, but by no means all, of the animals held illegally are juveniles, as shown in these figures.



Figure 6. Internet advertisement from 2011 for Ploughshare Tortoises. Photo courtesy of the Turtle Conservancy.

Not recorded in Table 2 are 54 animals confiscated in Bangkok in March 2013, of which only 28 were still held by the government in June 2013, and two animals known to have been confiscated in Japan in 2004 and 2005 (TRAFFIC Data, K. Foley, pers. comm.). Because a large number of A. radiata have been confiscated in Japan in recent years, we suspect that A. yniphora are also being smuggled into Japan. In September 2011, we found Angonoka openly for sale in Mahajanga, Madagascar, and were able to clandestinely purchase two specimens for \$200 USD each. We turned these animals over to the Malagasy Government and they are now in the care of DWCT. The smugglers who offered these animals for sale also informed us that they could easily move animals to Bangkok via a flight from Mahajanga to Mayotte in the Comoros Islands, then on to Reunion Island and from there to Bangkok. There are no baggage scanners at the Mahajanga Airport, so this route appears to be favorable to the smugglers. They also said that small animals are much easier to smuggle. We also learned from them how they work with the villagers in Baly Bay and how little they pay for the animals there. In October 2010, the government of Malaysia sent four confiscated Ploughshare Tortoises back to Madagascar. This return was facilitated by DWCT and TRAFFIC Southeast Asia. One of the returned animals had, in fact, been stolen from DWCT's reintroduction program. This was the first case of repatriation in recent times and represents an important new step in global Ploughshare management.

To summarize, we believe that the number of *non-situ* Angonoka is on the order of hundreds, which is the same order of magnitude as the estimated size of the wild population of adults. Most of the animals known outside of Madagascar are juveniles, but there are many adults as well. Clearly the population of *non-situ* animals is potentially a major conservation resource.

#### Discussion

Currently (as of early 2013) the wild *in-situ* population of Ploughshare Tortoises is estimated to be around 600 individuals and is declining rapidly. Our estimates of both *ex-situ* and *non-situ* numbers are very rough. However, it is clear that we do not require accurate estimates of any of these numbers to know that this species is in great trouble. Without doubt, the incredible demand for this species on the international market is the primary cause of its decline in the wild. We acknowledge that this demand will continue to put extreme pressure on the Ploughshare Tortoise until ways are found to meet or decrease this demand without otherwise imperiling its survival.

Formation of the International Angonoka Working Group (IAWG). — Recognizing that the conservation of the Ploughshare Tortoise is a genuinely global problem and that all possible conservation approaches need to be synthesized for this species, DWCT, the TC, Conservation International, and the Turtle Survival Alliance have begun the process of creating an international institution to provide coordination for the many actions aimed at saving this tortoise. The initial goals of the IAWG are:

1. Support efforts to protect and restore wild populations of Ploughshare Tortoises around Baly Bay.

2. Reduce the trade in illegally harvested or bred Ploughshare Tortoises on the international market.

3. Build capacity within Madagascar to tackle wildlife trade issues and to work better with the authorities in countries confiscating tortoises to facilitate repatriation.

4. Expand and enhance the captive breeding program within Madagascar and increase capacity to manage confiscated animals.

5. Establish and manage an international breeding program for Ploughshare Tortoises based on animals already outside Madagascar that acts as a safety-net population.

6. Build capacity in Southeast Asia to manage confiscated tortoises.

7. Develop a sustained media campaign to raise funds and awareness for Ploughshare Tortoise conservation.

However, each of these goals must be further refined to lead development of an integrated strategy. The IAWG would like to see this working group take on a public face and be able to highlight cases of illegal animals coming to international market as well as the positive actions taken to save the species. It would also function as a fundraising group to support the delivery of its core objectives. The group will need representation from the government of Madagascar, TRAFFIC, and CITES, and will be open to all parties interested in conserving this tortoise. None of the goals of the IAWG are surprising: they represent conservation strategies that have been discussed, and in many cases, at least partially implemented before.

The plight of the Ploughshare Tortoise is at such a critical point that we must find new ideas and methods to add to these well-known ones. For example, the numbers of *non-situ* animals may cause the consideration of an amnesty for some illegally held animals. They simply represent too important a resource to be ignored. But figuring out how to do this in a way that works for the many government agencies involved, as well as CITES, is a challenge we believe the conservation community should take on. Another idea is having the government of Madagascar lease animals using a model similar to that of China and the Giant Panda. Again there are challenges to be met. The reasons that this is the rarest tortoise in the world are daunting indeed, but we must struggle to overcome them.

Acknowledgments. — We thank Chris Shepherd and Kaitlyn Foley of TRAFFIC Southeast Asia for much insight into the trade in Angonoka. We also thank Nantarika Chansue and Thanakhom Bundhitwongrut for information about Angonoka in Thailand. We thank Michael Lau, Paul Crowe, Gary Ades of Kadoorie Farm in Hong Kong, Kurtis Pei and Vicky Lin of the Ping Tung Rescue Center in Taiwan, Jeffrey Chen of the Taipei Zoo, and Anders Rhodin for photos of Ploughshare Tortoises for sale in Jakarta. Our work is supported by the U.S. Fish and Wildlife Service Wildlife Without Borders Program and we thank Earl Possardt for his continuing help. Andrew Terry of DWCT in Jersey has been critical to all of our work and is most deserving of our thanks. We thank Bill Zovickian and the San Antonio Zoo for providing the male for the Behler Chelonian Center breeding group. Finally, we acknowledge the memory of John Behler as a continuing source of inspiration.

#### Résumé

Nous décrivons l'histoire de la conservation de l'Angonoka, ou Tortue à Soc (Astrochelys yniphora), qui l'a conduit vers son statut actuel de tortue la plus rare du monde. A cause du niveau de braconnage qui menace cette espèce et du fait que ses individus sont vendus dans le monde entier, la conservation de cette espèce est un véritable problème planétaire. La population sauvage de 2011 à 2013 est estimée à 600 individus (longueur de carapace > 200 mm), un déclin de 33% de l'estimation de 900 individus pour les années 2006 à 2008. Nous concluons qu'au moins un nombre similaire est détenu illégalement en captivité. Nous croyons que marquer les animaux de façon significative avec une gravure aidera à diminuer ce commerce international. Nous faisons le bilan de nos efforts contre le braconnage de même que sur les nouvelles colonies ex-situ constituées d'animaux confisqués du commerce illicite. Cette espèce nécessite des mesures extraordinaires et une stratégie mondiale cohérente pour empêcher l'avancement de son déclin.

#### LITERATURE CITED

- ANDRIAMALALA, C. AND GARDNER, C. J. 2010. Le utilisation du dina comme outil de gouvernance des ressources naturelles: leçons tirés de Velondriake, sud-ouest de Madagascar. Tropical Conservation Science 3:447–472.
- ANDRIANANDRASANA, T.H. 2000. Survey of the habitat of the ploughshare tortoise *Geochelone yniphora* in the Baly Bay region,

Madagascar. Dodo 36:92.

- BURNHAM, K.P., ANDERSON, D.R., AND LAAKE, J.L. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs 72:1–202.
- DECARY, R. 1950. La Faune Malgache. Paris: Payot, 236 pp.
- DURBIN, J., RAJAFETRA, V., REID, D., AND RASANDRIZANAKANIRINA, R. 1996. Local people and Project Angonoka - conservation of the ploughshare tortoise in northwestern Madagascar. Oryx 30:113–120.
- JUVIK, J.O. AND BLANC, C.P. 1974. The angonoka of Cape Sada. Animals 16:148–153.
- JUVIK, J.O., ANDRIANARIVO, J., AND BLANC, C.P. 1981. Ecology and status of *Geochelone yniphora*: a critically endangered tortoise in Northwestern Madagascar. Biological Conservation 19:297–316.
- JUVIK, J.O., ANDRIANANARIVO, A.J., BLANC, C.P., AND BOUR, R. 1982. Species recovery plan for the endangered Madagascar angulated tortoise (*Geochelone = Asterochelys yniphora*). Unpublished manuscript.
- JUVIK, J.O., KIESTER, A.R., REID, D., COBLENTZ, B., AND HOFFMAN, J. 1997. The conservation biology of the Angonoka, *Geochelone yniphora*, in northwestern Madagascar. In: Van Abbema, J. (Ed.). Proceedings: Conservation, Restoration and management of tortoises and turtles. An International Conference. Purchase, N.Y. Turtle Recovery Program and New York Turtle and Tortoise Society. pp. 345–349.
- LEUTERITZ, T. AND PEDRONO, M. 2008. Astrochelys yniphora. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1, www.iucnredlist.org.
- LEWIS, R.E., MANDIMBIHASINA, A.R., AND WOOLAVER, L. 2009. Action Plan for the Conservation of the Ploughshare Tortoise *Astrochelys yniphora* (Angonoka). Unpublished manuscript.
- LOVE, B. 2000. Tattooed turtles. Reptiles Magazine 8:26.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu: Natural History Publications (Borneo), 147 pp.
- RAKOTOSON, L.R. AND TANNER, K. 2006. Community-based governance of coastal zone and marine resources in Madagascar. Ocean and Coastal Management 49:855–872.
- REID, D. 1996. The captive breeding project for the ploughshare tortoise *Geochelone yniphora* in Madagascar. In: Devaux, B. (Ed.) Proceedings of the International Congress of Chelonian Conservation. Gonfaron: SOPTOM, pp. 139–140.
- SMITH, J.E. 2011. Stolen World. New York: Crown Publishers, 322 pp.

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles

Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds.

Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a26p162.e • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 7 November 2013

# ERRATUM

"Conservation of the Angonoka (Ploughshare Tortoise), *Astrochelys yniphora*" by A. Ross Kiester, Angelo R. Mandimbihasina, Richard E. Lewis, Eric V. Goode, James O. Juvik, Richard Young, and Torsten Blanck, *Chelonian Research Monographs* 6:162–170 (2013).

On page 168, in the middle of the first paragraph under the heading *Non-Situ*, there were errors in the numbers of confiscated and died or disappeared *non-situ* tortoises. The corrected sentences should read: "Table 2 gives the numbers of confiscated tortoises held around the world. We estimate a total of 198 animals have been confiscated in recent years, of which 75 have died or disappeared."

The new Table 2 with updated and corrected numbers for the four Madagascar entities is now published here.

**Table 2.** Number of confiscated *non-situ* Ploughshare Tortoises held in captivity from 2008–11.

Country	Entity	Confiscated	Died or Disappeared
Madagascar	DWCT Antananarivo	88	18
e	Olaf Pronk Antananarivo	18	12
	Croc Farm	20	13
Ν	Ainistry of Environment & For	ests 5	5
Taiwan	Taipei Zoo	2	2
	Ping Tung Rescue Center	2	0
Thailand	Government	20	18
Hong Kong	Kadoorie Farm	30	1
China	Kunming	3	3
Malaysia	Government	2	2
Singapore	Singapore Zoo	3	1
United States	Fish & Wildlife Service	1	0
Germany	Frankfurt Zoo	4	0

## An Integrated Research, Management, and Community Conservation Program for the Rere (Madagascar Big-headed Turtle), *Erymnochelys madagascariensis*

JULIETTE VELOSOA<sup>1</sup>, LANCE WOOLAVER<sup>1</sup>, RANDRIAMAHITA<sup>1</sup>, ERNEST BEKARANY<sup>1</sup>, FLORIOT RANDRIANARIMANGASON<sup>1</sup>, RICHARD MOZAVELO<sup>1</sup>, GERARDO GARCIA<sup>1,2</sup>, AND RICHARD E. LEWIS<sup>1</sup>

<sup>1</sup>Durrell Wildlife Conservation Trust Madagascar, BP 851, 101 Antananarivo, Madagascar [juliette velosoa@durrell.org, ampijoroaa@yahoo.com, floriot\_dw@yahoo.com, lance.woolaver@durrell.org, richard.lewis@durrell.org]; <sup>2</sup>Present Address: Chester Zoo, Upton-by-Chester, Chester, CH2 1LH United Kingdom [g.garcia@chesterzoo.org]

ABSTRACT. - The Madagascar Big-headed Turtle (Erymnochelys madagascariensis) is Critically Endangered and endemic to eight major watersheds in western Madagascar. Major threats are loss of wetlands and turtle consumption by impoverished local communities. Both sexes and all age classes are consumed. Erymnochelys madagascariensis is on the verge of extinction; this is true at 27% of sites throughout the species' known range. At a further 31% of sites the species has been over-exploited and is in serious decline. Only eight sites, representing 7.6% of the species' historical range, currently support stable populations. Six of these are within existing protected areas. Three official New Protected Areas that support important populations are currently being established at Menabe-Antimena, Tsimembo, and Ambondrobe. A conservation program began in 1998 and has evolved to combine research on this species' distribution and ecology with captive breeding and active management of wild populations. The captive-breeding program has produced 94 hatchlings. Wild population management includes nest protection, headstarting of young turtles, and community conservation programs at key sites. Local people at Lakes Antsilomba and Ambondrobe have protected nests (1998 to 2011) that have produced more than 3000 hatchlings. In 2004, we carried out a reinforcement of E. madagascariensis at Lake Ankomakoma with 158 headstarted young that were collected as hatchlings from Lake Antsilomba and raised in captivity; 29% survived one year after release, 20% after 2 years, and 12% after 3 years. Another 180 headstarted young were released in 2009. Since 2010, we have trialed an experimental translocation of hatchlings from Antsilomba to Ankomakoma, with the transfer of 28 hatchlings in 2010 and 18 in 2011. We will continue these annual translocations for the next few years, so that we can compare survival between translocated hatchlings and headstarted juveniles. Establishment of sustainable community conservation projects is an integral component of our conservation program. We have been supporting the creation of local Associations and the legal transfer of natural resource management to these Associations. To date, community Associations have been created at four sites for turtle protection and sustainable wetland management. Our long-term goal is to support local communities to manage viable populations of E. madagascariensis within each of the eight main watersheds of western Madagascar.

## KEY WORDS. – Reptilia, Testudines, Podocnemididae, conservation, status, community-based program, *Erymnochelys madagascariensis*, headstarted juveniles, Madagascar Big-headed Turtle, nest protection, translocated hatchlings, Madagascar

The Rere, or Madagascar Big-headed Turtle (*Erymnochelys madagascariensis*), is the largest freshwater turtle in Madagascar (Fig. 1), and is the only aquatic turtle species endemic to the island. It comprises a monotypic genus and subfamily (Erymnochelyinae), and is the only Old World member of the family Podocnemididae. The Rere is Critically Endangered as assessed on the IUCN Red List, primarily from extensive habitat loss and consumption by local human populations. The species is found in eight major watersheds of western Madagascar; from north to south, these are the watersheds of Sambirano, Sofia, Mahajamba, south Mahavavy, Betsiboka, Manambolo, Tsiribihina, and Mangoky rivers (Fig. 2). Elevation for these watersheds ranges from 2 to 800 m above sea level. There are at least two genetically distinct populations of *E.madagascariensis* (Fig. 2). A northern group in Sofia, Mahajamba, and Betsiboka exhibits 0.5% divergence amongst individuals within that group. In the south, individuals within the watersheds of Manambolo, Tsiribihina, and Mangoky exhibit 1% divergence. However, when the northern and southern groups are compared, divergence ranges from 3.5 to 5%, suggesting differences at least at a subspecific level (Forstner et al., in prep.). It is still unclear whether there is a hybrid zone between the two populations and further sample collection and analysis is needed in order to determine the full extent of genetic variation for the species.

Conservation status and trends have been assessed for E. madagascariensis and are based on re-evaluations of initial



Figure 1. Adult male Rere, or Madagascar Big-headed Turtle, Erymnochelys madagascariensis. Photo by Juliette Velosoa.

site surveys and villager interviews carried out from 1991 to 1997 (Kuchling 1991, 1992, 1997). Of the 105 sites identified during the initial surveys, 88 were revisited from 1998 through 2010 (Velosoa 2001; DWCT, unpubl. data), and only eight were still healthy, with six of them within currently protected areas. The species has disappeared completely from



Figure 2. Distribution map of *Erymnochelys madagascariensis* showing location of genetically distinct northern and southern subpopulations.

27% of the original sites (Fig. 3). At a further 31% of sites, the species has been over-exploited and is in serious decline. Only eight sites, representing 7.6% of the species' historical range, currently support stable populations. The decline has been extremely rapid, with a decrease in population size averaging 70% over a ten-year period. The main causes of this massive decline have been overexploitation for human consumption and habitat loss (Kuchling and Mittermeier 1993), particularly the loss of marshlands, which are used by the turtle as refugia. Both sexes and all age classes are consumed (Garcia 2005; Garcia and Goodman 2003).

The ultimate goal for the conservation recovery of *E*. *madagascariensis* is to ensure at least one healthy population within each of the eight major watersheds that encompass the species' distribution. This is based on recommendations from a workshop held by the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group in Antananarivo in January of 2008. Our conservation activities to date have concentrated on maintaining and increasing populations at four main sites, covering five of the eight watersheds:

1. Baly Bay National Park adjacent to the Mahavavy sud watershed;

2. Ankarafantsika National Park with populations within both the Mahajamba and Betsiboka watersheds;

3. Lake Ambondrobe in the Manambolo watershed;

4. Lake Begogo-Mahombe within the Tsiribihina watershed.

Our conservation activities at all these sites have followed the same basic pattern and can be summarized as four main activities:

1. Research on the species' distribution, biology, ecology, genetics and major threats;

2. Intensive population management, including captive breeding, population restoration through release of headstarted juveniles and translocated hatchlings, and protection of wild nests;



Figure 3. Pie chart documenting extent of decline of *Erymnochelys* madagascariensis at 88 known sites throughout the species' range from 1991–2011.

3. Close collaboration and capacity building within local communities to improve local awareness of the species' importance and to facilitate the legal transfer of resource management to these communities;

4. Promotion of official National protection of important wetlands.

This paper summarizes the main conservation activities we have carried out for E. madagascariensis since 1998, with recommendations for future activities.

#### **Research and Monitoring**

Early research on *E. madagascariensis* focused on the species' distribution and basic ecology (Kuchling and Mittermeier 1987; Kuchling, 1988, 1993; Garcia 2005). Garcia (2005) documented the reproductive ecology, feeding ecology, and human impacts on *E. madagascariensis* populations in Ankarafantsika National Park. The species reproduces from September to March and, although generally omnivorous, juveniles are more carnivorous, eating insects, mollusks, and fish, while adults are more vegetarian, eating primarily fruits and leaves (Garcia 2005).

More recent research has been management-oriented with emphasis on monitoring populations and nests at key sites (Velosoa and Randriamahita 2004; Velosoa and Mozavelo 2009, 2010). Since 2001, we have been evaluating and monitoring populations using capture-mark-recapture at seven lakes (Soamalipo, Ankerika, Ambondrobe, Begogo, Mahombe, Ankomakoma, Antsilomba, and Sariaka) and three rivers (Andranohobaka, Andranomiditra, and Ampatika) within five watersheds (Manambolo, Tsiribihina, Betsiboka, Mahajamba, and Mahavavy).

Single population estimates have been made using capture-mark-recapture at Lakes Soamalipo, Ankerika, Begogo, Mahombe, Sariaka, and Ambondrobe, and in the Ampatika River (Velosoa 2007; Velosoa and Randriamahita 2005, 2011; Velosoa et al. 2007). Monitoring has been more intensive within Ankarafantsika National Park where we have been carrying out capture-mark-recapture monitoring twice yearly at Lake Ankomakoma, annually in the Andranohoboka River, and every five years for Lake Antsilomba and the Andranomiditra River (Velosoa and Randriamahita 2010). At Soamilipo, Ankerika, Begogo-Mahombe, Ankomakoma, and Andranohobaka, captures have been dominated by juveniles, suggesting that the populations there have been overexploited and depleted. Populations have remained stable (Andranomiditra River) or are increasing (Lakes Antsilomba and Ankomakoma, Andranohobaka River) within Ankarafantsika National Park (Velosoa and Randriamahita 2010), which is encouraging, as these are sites where significant long-term conservation actions have been implemented.

As a result of the monitoring we have also been able to assess the relationship between population status and habitat quality. Lakes with surrounding marshes and reed-beds tend to have the healthiest turtle populations, since these areas are used by turtles as refugia from fishing nets.

#### **Population Management**

*Captive Breeding.* — A captive breeding program was started in 1999 in collaboration with Conservation International at Ampijoroa in Ankarafantsika National Park (Kuchling 2000). The goal of the captive population is to produce animals for restoring wild populations (Kuchling 1996). As of 2011, six adult males and three adult females formed the captive population, and 94 hatchlings have been produced in captivity (2 in 2004, 52 in 2008, and 40 in 2011). The majority of eggs laid have been infertile. For example, all three nests laid in captivity in 2009–10 were infertile.

The main challenge faced by the captive breeding program has been correctly timing the placement of males with females for breeding. Males can be aggressive toward females outside of the breeding season, and the period of reproduction is likely linked to environmental factors (e.g., rainfall), that we do not yet fully understand.

*Population Restoration.* — A major component of the conservation management has been the experimental release of headstarted juveniles to Lake Ankomakoma in Ankarafantsika. In 2004, we carried out a reinforcement of *E. madagascariensis* at Lake Ankomakoma, using headstarted young that were collected as hatchlings from Lake Antsilomba and raised in captivity. Ankomakoma was an historically important lake for turtles, but they have been decimated due to over-fishing. Except for the two first years (1998–99 and 1999–2000), we collected two hatchlings from each wild nest from a healthy population at Lake Antsilomba, and raised them in captivity for 1–7 years (Table 1).

In 2004, we released 158 headstarted young (3–5 yrs old). The population in Ankomakoma has been assessed twice each year post-release; 47 (29%) had survived one year after release, 32 (20%) after 2 years, and 20 (12%) after 3 years. Although we considered this to be a success, with an overall increase in turtle numbers and the raising of the

Breeding season	Number of nests monitored	Total number of hatchlings	Number of young collected	Number of turtles released	Year of release
1998-1999	17	35	24	20	2004
				2	2009
1999-2000	15	115	115	110	2004
2000-2001	27	224	29	28	2004
2001-2002	32	250	44	31	2009
2002-2003	14	116	18	18	2009
2003-2004	19	154	26	25	2009
2004-2005	23	124	22	19	2009
2005-2006	27	214	34	34	2009
2006-2007	26	116	28	27	2009
2007-2008	20	48	10	10	2009
2008-2009	19	41	14	14	2009
2009-2010	30	90	28	28	2010
2010-2011	11	58	18	18	2011
Total	280	1585	410	384	

**Table 1.** Number of *Erymnochelys madagascariensis* nests monitored and hatchlings produced at Lake Antsilomba from 1998 to 2011. The table includes the number of hatchlings collected, the number of turtles released, and year of release at Lake Ankomakoma.

species' profile within local communities, the population was still too low to guarantee long-term survival. Another 180 young (aged 1–7 yrs) were released in 2009.

The population of E. madagascariensis in Ankomakoma has increased post-release (Fig. 4). We have also seen an improvement in habitat quality, and an increase in endemic fish populations. Much of this is due to increased motivation of the nearby local communities to protect and improve the health of the lake. As a result of the releases, a village Association was created for the conservation and sustainable resource management of the lake.



**Figure 4.** Graph of population trend of *Erymnochelys madagascariensis* at Lake Ankomakoma from 2002–2011. Population estimates are derived from mark-recapture surveys.

Since 2010, we have been trialing an experimental translocation of hatchlings from Antsilomba to Ankomakoma, with the transfer of 28 hatchlings in 2010 and 18 in 2011. Similar to the collection of young for headstarting, two hatchlings were collected from each nest protected in Antsilomba. The hatchlings were then kept in captivity for 2–4 weeks prior to release in Ankomakoma. We will continue these annual translocations for the next few years, so that we can compare survival between these translocated hatchlings and the headstarted juveniles.

*Nest Protection.* — We have been carrying out intensive nest monitoring and protection at Lakes Antsilomba and Ambondrobe. Since 1998, we have protected 280 nests at Antsilomba (Table 1), with a total of 1585 hatchlings produced over a 13-year period. Nest protection at Ambondrobe has been a more recent activity, with 146 nests protected in 2008 and 2009, producing 1316 hatchlings during those two years alone.

#### Community Involvement in Conservation

Involving local communities within all aspects of the conservation recovery of *E. madagascariensis* is absolutely critical, since the main threats to the species are anthropogenic (habitat conversion and overexploitation). In general, our approach of engaging local communities has followed three main steps (Fig. 5).

1. Public awareness and community motivation.

2. Village meetings and discussions for the creation of local conservation Associations responsible for implementing traditional environmental laws.

3. Support for the legal transfer of local resource management to local communities and support the creation of protected areas.

Motivation of local communities begins with demonstrating the connection between a healthy wetland ecosystem and sustainable benefits to local communities (e.g. fish, clean water, marsh products like *Raphia*) that provide a better quality of life for people living near the wetland. This is done through the organization and support of local festivals with an environmental theme, and in celebrating national and international events such as World Environment Day, which is very popular in Madagascar. Although this process begins with village meetings and celebrations to promote awareness, tangible benefits need to follow, such as the creation of local Associations and real improvements in fish stocks or local incomes.

Local communities already have traditional and cultural laws or *Dinas* to prevent the overexploitation of natural resources, including regulations on catching turtles, conserving fish stocks (e.g., closed fishing seasons or *Loadranos*) and sustainable use of marshlands. These *Dinas* can be implemented by local conservation Associations to protect turtles and improve habitat quality. Within the management plans of these Associations, there are provisions for strict conservation of fish stocks and for the restoration of habitat. However, local communities need financial and logistical support from NGOs in order to create and maintain these Associations until they become sustainable. With the support of local and regional authorities, we have assisted with the legal transfer of local resource management from the National government to the local community Associations. Within the resulting management plans, there are zones set aside for strict conservation and for habitat restoration.

Four community conservation Associations have been created to date specifically for conservation of *E. madagascariensis*: two in Ankarafantsika, one in Ambondrobe, and one in Begogo-Mahombe. The latter two have already received legal management rights through a Gestion Locale Securisé (GELOSE). Figure 6 is an example of resource zonage within the local management plan of Begogo-Mahombe.

At the National level, *E. madagascariensis* is currently found within three National Parks (Baly Bay, Bemaraha, and Ankarafantsika) and five New Protected Areas (Menabe-Antimena, Mangoky, Tsimembo, Mahavavy-Kinkony, and Ambondrobe). Ambondrobe is the first New Protected Area being created primarily for the conservation of the Madagascar Big-headed Turtle.

#### Recommendations for Future Actions

Future actions for the conservation of *E. madagascariensis* will be guided by some of the results of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group workshop held in Antananarivo in 2008, and will build on past conservation efforts. The main overall goal will be to



Figure 5. Flow diagram of steps used to engage local communities in conservation recovery of *Erymnochelys madagascariensis*.



**Figure 6.** Map of Gestion Locale Securisé (GELOSE) including zonage for local community management of Lakes Begogo-Mahombe; the strict conservation zone is in dark green.

achieve the protection of at least one healthy population of *Erymnochelys* in each of the eight major watersheds within the species' distribution. Conservation recovery will continue within a framework of research, population management, and local community conservation for sustainable wetland management.

Key future research needs and goals for *E. madagascariensis* will be to:

1. Identify priority sites for conservation in the northern watersheds of Sambirano and Sofia.

2. Determine the full extent of genetic variation throughout the entire range of the species. We know that there is significant divergence among populations at the northern and southern limits of the range. However we do not yet have genetic samples from all major sites, and there is a particular gap for the central west coast populations between Besalampy and Antsalova, and for some populations in the north (Sofia).

3. Monitor population trends at Lakes Antsilomba, Begogo-Mahombe, and Sariaka, and the rivers in Ankarafantsika.

4. Evaluate the survival of released animals at Lake Ankomakoma and compare the survival of the headstarted juveniles with translocated hatchlings.

5. Continue nest monitoring at Lakes Antsilomba and Ambondrobe.

Future management of the captive population of *E*. *madagascariensis* will focus on:

1. Improving the Ampijoroa captive breeding program to produce animals for restoring wild populations.

2. Studying the possibility of establishing another captive breeding population in the south of the species' range.

3. Establishing an *ex-situ* captive breeding population outside of Madagascar.

Future restoration of wild populations will involve:

1. Continuation of the experimental translocation of hatchlings from Lake Antsilomba to Ankomakoma.

2. Release of headstarted juveniles produced in captivity to nearby Lake Ravelobe in Ankarafantsika National Park.

3. Continuation of the village-implemented nest protection projects at Lakes Antsilomba and Ambondrobe, and extension of nest protection to include Lakes Begogo-Mahombe in the near future.

Future community conservation programs will continue to:

1. Promote awareness at priority sites.

2. Support the creation of village Associations, and assist them to sustainably manage their resources, and enforce strict conservation zones for turtle and fish conservation.

3. Promote and facilitate the official conservation status designation (e.g. Ramsar, New Protected Area, and GELOSE) of key sites within the eight major watersheds.

In conclusion, conservation actions since 1998 for *E.* madagascariensis have focused on restoring and protecting at least one healthy population in five of the eight major watersheds within the species' distribution. There has been some success with captive breeding, and intensive management to restore populations using headstarting, hatchling translocations, and nest protection.

Community involvement in all levels of the work, from assisting research to protecting nests, and sustainably managing key wetlands through transfer of resource management to local Associations, has been critically important.

Acknowledgments. — We would like to take this opportunity to thank the major partners and donors that have been part of this long-term conservation recovery project: Behler Chelonian Center and Turtle Conservancy, British Chelonia Group, Chelonian Research Foundation, Conservation International, EAZA, Fota Wildlife Park, Harcroft Foundation, IUCN Tortoise and Freshwater Turtle Specialist Group, Liz Claiborne Art Ortenberg Foundation, Turtle Conservation Fund, Turtle Survival Alliance, Madagascar National Parks, and the government of Madagascar. We would like to extend a special thank you to Gerald Kuchling for his outstanding contribution toward Rere conservation.

Résumé

La podocnémide de Madagascar (Erymnochelys madagascariensis), endémique de huit bassins versants majeurs de l'ouest de Madagascar, est Gravement Menacée. Les principales menaces sont la perte des zones humides et la consommation par des communautés locales appauvries. La consommation concerne autant les mâles que les femelles et toutes les classes d'âge sont touchées. Erymnochelys madagascariensis est au bord de l'extinction, telle est la réalité dans 27% des sites de l'aire de répartition de l'espèce. De plus, dans 31% des sites, l'espèce a été surexploitée et décline sérieusement. Seuls huit sites, faisant 7,6% de l'aire de répartition initiale de l'espèce présentent des populations stables. Six desdits sites se trouvent à l'intérieur de zones protégées. Trois Nouvelles Aires Protégés à populations importantes sont en cours de création à Menabe-Antimena, Tsimembo, et Ambondrobe. Un programme de conservation a été initié en 1998 et s'est développé par la suite en une combinaison des travaux de recherche sur la distribution et l'écologie de l'espèce avec l'élevage en captivité et la gestion active des populations sauvages. Un total de 94 bébés tortues ont été produites en captivité. La gestion des populations sauvages comprend la protection des nids, "headstarting" des jeunes tortues et programmes de conservation communautaire dans les sites-clés. La population locale des lacs Antsilomba et Ambondrobe possèdent des nids protégés (1998 à 2011) ayant produit plus de 3000 petites tortues. En 2004, au Lac Ankomakoma, a été effectué un renforcement de E. madagascariensis en utilisant des individus issus du "headstarting". Ceux-ci ont été collectés au Lac Antsilomba lorsqu'ils étaient encore très petits et élevés par la suite en captivité. Par le passé, Ankomakoma était un important lac pour les tortues, mais elles ont été décimées suite à une surpêche. En 2004, 158 jeunes tortues (3 à 5 ans) ayant bénéficié du programme de "headstarting" ont été relâchées. 47 tortues (soit 29%) ont survécu l'année d'après le lâcher, 32 (20%) après 2 ans et 20 (12%) après 3 ans. Même si nous considérons ceci comme un succès, avec un accroissement global du nombre de tortues et une amélioration du profil de l'espèce au niveau communautés locales, la population de E. madagascariensis était encore trop faible pour garantir sa survie à long terme. 180 nouvelles jeunes tortues ont été relâchées en 2009. Depuis 2010, nous essayons une translocation expérimentale de bébés tortues de Antsilomba vers Ankomakoma, avec le transfert de 28 individus en 2010 et 18 en 2011. Nous allons continuer ces translocations dans les prochaines années pour pouvoir, dans le futur, comparer la survie des petites tortues translocalisées avec la survie des jeunes issus du "headstarting". La mise en place de projets communautaires de conservation durables est une composante à part entière de notre programme de conservation. Nous avons soutenu la création d'Associations locales et le transfert de gestion légal des ressources naturelles à ces Associations. Jusqu'à présent, des Associations communautaires ont été créées dans quatre sites pour la protection des tortues et pour la gestion durable des zones humides. Notre objectif à long terme est d'aider les communautés locales à gérer des populations viables de E. madagascariensis au sein de chacun des huit grands bassins-versants de l'ouest de Madagascar.

#### LITERATURE CITED

- GARCIA, G. 2005. Ecology, human impact and conservation for the Madagascan side-necked turtle (*Erymnochelys madagascariensis* Grandidier 1867) at Ankarafantsika National Park. Ph.D. Thesis, University of Kent, Canterbury, UK.
- GARCIA, G. AND GOODMAN, S.M. 2003. Hunting of protected animals in the Parc National d'Ankarafantsika, north-western Madagascar. Oryx 37(1):115–118.
- KUCHLING, G. 1988. Population structure, reproductive potential and increasing exploitation of the freshwater turtle *Erymnochelys mada*gascariensis. Biological Conservation 43:107–113.
- KUCHLING, G. 1991. Biology and status of *Erymnochelys madagas-cariensis*. Unpublished report to MPAEF, Perth, Australia, 27 pp.
- KUCHLING, G. 1992. Distribution and status of *Erymnochelys mada-gascariensis*. Unpublished report to MPAEF and Conservation International, 34 pp.
- KUCHLING, G. 1993. Possible biennial ovarian cycle of the freshwater turtle *Erymnochelys madagascariensis*. Journal of Herpetology 27(4):470–472.

- KUCHLING, G. 1996. Feasibility of the propagation of *Erymnochelys madagascariensis* in Madagascar. Unpublished report to the Madagascar Fauna Group, Ministère des Eaux et Forêts, Ministère de l'Agriculture et du Développement Rural de Madagascar, and Conservation International, 28 pp.
- KUCHLING, G. 1997. Patterns of exploitation, decline, and extinction of *Erymnochelys madagascariensis*: implications for conservation. In: Van Abbema, J. (Ed.). Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles – An International Conference. N.Y. Turtle and Tortoise Society, pp. 113–117.
- KUCHLING, G. 2000. Concept and design of the Madagascar sidenecked turtle *Erymnochelysmadagascariensis* facility at Ampijoroa, Madagascar. Dodo 36:62–74.
- KUCHLING, G. AND MITTERMEIER, R.A. 1987. Biologie et statut d'Erymnochelys madagascariensis et commentaire sur les autres cheloniens de Madagascar. In: Mittermeier, R.A., Rakotovao, L.H., Andrianasolo, V., Sterling, E.J., and Devitre, D. (Eds.). Priorités en matière de conservation des espèces à Madagascar.IUCN/SSC Occasional Papers 2:121–124.
- KUCHLING, G. AND MITTERMEIER, R.A. 1993. Status and exploitation of the Madagascan big-headed turtle *Erymnochelys madagascariensis*. Chelonian Conservation and Biology 1(1):13–18.
- VELOSOA, J. 2001. Contribution à l'étude de l'habitat, de la population et la mise à jour de statut de conservation d'*Erymnochelys madagascariensis* (Grandidier 1867), dans la région ouest de Madagascar. D.E.A. Thesis, Université d'Antananarivo, Madagascar.
- VELOSOA, J. 2007. Étude de la population de Rere dans le lac Sariaka, Parc National de Baie de Baly. Unpublished report to Madagascar National Parks and Durrell Wildlife Conservation Trust, 9 pp.
- VELOSOA, J. AND MOZAVELO, R. 2009. Suivi de nid Ambondrobe 2009. Unpublished report to Durrell Wildlife Conservation Trust, 12 pp.
- VELOSOA, J. AND MOZAVELO, R. 2010. Suivi de nid Ambondrobe 2010. Unpublished report to Durrell Wildlife Conservation Trust, 19 pp.
- VELOSOA, J. AND RANDRIAMAHITA. 2004. Suivi des 4 sites de bonne population de Rere. Unpublished report to Durrell Wildlife Conservation Trust, 14 pp.
- VELOSOA, J. AND RANDRIAMAHITA. 2005. Étude de la population d'*Erymnochelys madagascariensis* dans le lac Ambondrobe. Unpublished report to Durrell Wildlife Conservation Trust, 20 pp.
- VELOSOA, J. AND RANDRIAMAHITA. 2010. Evaluation de la population d'*Erymnochelys* dans le lac Antsilomba. Unpublished report to Durrell Wildlife Conservation Trust, 12 pp.
- VELOSOA, J. AND RANDRIAMAHITA. 2011. Evaluation de la population d'*Erymnochelys* et des poissons dans les rivières Andranomiditra et Ampatika, Parc National d'Ankarafantsika. Unpublished report to Durrell Wildlife Conservation Trust, 16 pp.
- VELOSOA, J., RANDRIAMAHITA, AND MOZAVELO, R. 2007. Étude de la population d'*Erymnochelys* dans les lacs Begogo et Mahombe. Unpublished report to Durrell Wildlife Conservation Trust, 20 pp.

## Tortoise Breeding and 'Re-wilding' on Rodrigues Island

## **OWEN GRIFFITHS<sup>1</sup>, AURELE ANDRE<sup>2</sup>, AND ARNAUD MEUNIER<sup>3</sup>**

<sup>1</sup>Autard Street #6, Souillac, Mauritius [owen@bcm.intnet.mu]; <sup>2</sup>Anse Quitor, Rodrigues [arpege@orange.mu]; <sup>3</sup>Fond la Digue, Port Mathurin, Rodrigues [arnaud@torti.intnet.mu]

ABSTRACT. – Rodrigues Island in the western Indian Ocean had the highest density of giant tortoises known in historic times. The two endemic tortoise species (*Cylindraspis vosmaeri* and *C. peltastes*) provided vital ecosystem services for the endemic flora. By 1795 they had been rendered extinct as a result of commercial exploitation. In 2006, a private protected area, the François Leguat Giant Tortoise and Cave Reserve, was established on Rodrigues with the aim of introducing two species of tortoises (*Aldabrachelys gigantea* from the Seychelles and *Astrochelys radiata* from Madagascar) as ecological analogues to replace the extinct species, as well as re-establishing the native endemic habitat. Since then over 600 tortoises have been released and 186,000 endemic and native trees have been re-planted. Such ecosystem reconstruction using analogues is known as 're-wilding', and appears preliminarily to be working on Rodrigues. The program could potentially serve as a model for re-wilding of giant tortoises to Madagascar by using *Aldabrachelys gigantea* as an analogue for the extinct *Aldabrachelys abrupta*.

### KEY WORDS.-Reptilia, Testudines, Testudinidae, Astrochelys radiata, Aldabrachelys gigantea, Aldabra Giant Tortoise, Radiated Tortoise, Cylindraspis vosmaeri, Cylindraspis peltastes, captive breeding, ecological analogues, re-wilding, Mauritius, Reunion Island, Rodrigues Island, Indian Ocean

At the time of its discovery in 1528, Rodrigues Island in the Indian Ocean had one of the highest densities of land tortoises found anywhere on planet Earth, with two species occurring there: the Rodrigues Giant Saddleback Tortoise, Cylindraspis vosmaeri, and the smaller Rodrigues Domed Tortoise, C. peltastes (North-Coombes 1986; Checke and Hume 2008) (Fig. 1). Following the settlement of the Mascarenes by the French and the commercial extinction of land tortoises on Reunion Island and Mauritius, the tortoise trade from Rodrigues was established. This trade supplied Rodrigues tortoises to settlements on Reunion and Mauritius as well as to passing ships. Tortoises were either exported alive or rendered down for oil. From 1732 to 1771, it is estimated that 280,000 giant tortoises were removed from Rodrigues (North-Coombes 1986). The last record of someone seeing Rodriguan tortoises alive was in 1795 by Philibert Marragon (North-Coombes 1986).

In parallel with the destruction of the tortoises (and most of Rodrigues' terrestrial fauna), the plant communities were also being devastated. The island, once covered in luxuriant forest, was already by 1874 'a dry and barren spot' (Balfour 1877, in Strahm 1989).

In 2006, the François Leguat Giant Tortoise and Cave Reserve (Leguat Reserve) was established on 20 ha at Anse Quitor, Rodrigues. This land was obtained under a longterm lease from the Government of Rodrigues (Rodrigues Regional Assembly). The aim of the Leguat Reserve was to promote conservation awareness in Rodrigues and help protect Indian Ocean land tortoises, and to recreate, as far as possible, the original forest ecosystem of Rodrigues on its southwest limestone (calcarinite) plains. And this has included the early stages of introduction of two non-native tortoise species (Aldabra Giant Tortoises, *Aldabrachelys gigantea*, and Madagascar Radiated Tortoises, *Astrochelys radiata*) to the island as potential ecological replacements for the two extinct tortoise species that had occurred there originally.

The Leguat Reserve project was a private initiative by the company that also runs La Vanille Réserve des Mascareignes (La Vanille) in the south of Mauritius. The project had as a secondary aim the breeding of a sufficient number of Aldabra Tortoises to be able to also consider their possible eventual introduction to Madagascar as a 're-wilding' initiative on that island as well.

The Leguat Reserve was established in the southwest of Rodrigues using captive-bred tortoises from La Vanille (Fig. 2). The project had as a primary aim to establish giant land tortoises in the wild in a managed natural reserve on Rodrigues. Since then over 186,000 native and endemic Rodriguan trees (of 39 species) have been planted on the site. The whole concept is to re-create a virtually extinct ecosystem and to introduce 'ecological analogue species' to replace extinct species from that ecosystem, a concept and process that is known as 're-wilding' (Burney 2010). The two chosen species were the Aldabra Giant Tortoise, (Aldabrachelys gigantea) as an analogue for the extinct Rodrigues Giant Saddleback Tortoise (C. vosmaeri) (Fig. 3), and the Madagascar Radiated Tortoise (Astrochelys radiata) as an analogue for the extinct Rodrigues Domed Tortoise (C. peltastes) (Fig. 4).


Figure 1. Depiction of two species of extinct giant tortoises, *Cylindraspis vosmaeri* (larger, saddlebacked) and *C. peltastes* (smaller, domed) in their native habitat on Rodrigues Island in the late 1600s when accounts indicate the herds of tortoises were so dense that it was possible to walk on their backs without touching the ground. Painting by Julian Pender Hume.

La Vanille has been breeding these analogue species over the last 20 years and in so doing has built up large breeding herds. It is expected that in the next few years 1000 subadult and adult tortoises will be released into the Reserve (Fig. 5). This would represent a stocking density of around 50 tortoises/ ha, which is close to the density occurring on the Aldabra Atoll (Coe et al. 1979). From 2006 to 2009 tortoises were successfully shipped from Mauritius to Rodrigues by boat without any problems. By mid-2013, over 480 subadult and adult Aldabra and 100 Radiated Tortoises had been released at the Reserve.

The Aldabra Giant Tortoises now seen on Mauritius are mostly derived from stock imported to Mauritius from the Seychelles in the 1880s, following the recommendation of Charles Darwin and other eminent scientists, that was set out in a letter sent in April 1874 to Gordon Hamilton, the Governor General of Mauritius and Dependencies at the time, which then included the Seychelles (a copy of the letter is located at the Mauritian National Archives). Darwin was concerned that the Aldabra Tortoise would become extinct, and he wanted to have populations on other islands as security against extinction; he was the first to recommend captive breeding of endangered species as a conservation measure. Following Darwin's intervention, the governor of Mauritius and the Seychelles agreed to the introduction of Aldabra Tortoises to Pamplemousses Botanic Gardens and Le Reduit in Mauritius. Radiated Tortoises, since the French days prior to 1810 and continuing into the 1930s, have been exported to Reunion and Mauritius from Madagascar in huge numbers, principally for food. However, large numbers were kept as pets and have been bred on those Mascarene Islands ever since. This includes those that were sent to Rodrigues from La Vanille.

Once the tortoises arrived at the Leguat Reserve, the larger ones (above 10 kg in weight) were released into the large limestone valley known as Canyon Tiyel, approximately 330 m long and 20 to 35 m wide, that dominates the site (Fig. 6). The valley is surrounded by limestone ramparts of approximately 10 to 20 m. The tortoises graze on the grass, and fallen leaves and fruits found on the valley floor. They are also supplied daily with additional food in the form of seasonal fodders and vegetables and fruits. Smaller tortoises were maintained in a specially built nursery building, featuring indoor and outdoor sections, until they reached the 10 kg release size. As the native vegetation that has been replanted throughout the Reserve grows, tortoises will be gradually released throughout the entire Reserve. Tortoises are allowed to nest naturally in the valley and eggs are left to incubate in-situ. Hatchlings are collected when found, normally just after emerging, although some hatchlings have been picked up after what would appear to be many months later. Hatching events take place between December and March each



**Figure 2.** Entrance to the François Leguat Giant Tortoise and Cave Reserve on Rodrigues Island. The reserve was established to help protect Indian Ocean land tortoises, promote awareness for their conservation, and recreate the original forest ecosystem. Photo by Jim Pether.

year and are usually triggered and facilitated by heavy rain. The hatchlings are transferred to a nursery building where they are maintained for up to four years prior to release on the Reserve (Fig. 7). The length of the nursery is about 24 m and the width 20 m. It is composed of an open area and a closed area that can be locked at night. Both of them are divided into four compartments.

Giant tortoise re-wilding has also been carried out on Mauritius by the Mauritian Wildlife Foundation in conjunction with Government authorities at two sites: Ile aux Aigrettes in the East and Round Island in the North. As on Rodrigues, both of these projects comprise the re-introduction of the same two analogue tortoise species along with forest restoration through weeding and replanting.

There is a growing scientific school of thought that the Aldabra Tortoise may be a surviving lineage of *Aldabrachelys abrupta* (Grandidier 1868) – the smaller of the two extinct Madagascan giant tortoise species (Pedrono 2008). It is likely



**Figure 3.** The Aldabra Giant Tortoise (*Aldabrachelys gigantea*) is considered to be an analogue species for the now extinct Rodrigues Giant Saddleback Tortoise (*Cylindraspis vosmaeri*). Photo by Jim Pether.

that these giant tortoises occurred in huge numbers before the arrival of man and their subsequent extinction. As such they would have been a significant force shaping the ecology and evolution of Madagascar's west coast floral communities. With the extinction of giant tortoises on Madagascar, plants that required them for seed dispersal, or for creating the right conditions for germination and growth, would have declined. There is a growing belief that this process is indeed occurring (S. Goodman, pers. comm.).

It is part of the philosophy of our breeding program for Aldabra Tortoises to ultimately produce enough individuals to consider their re-introduction (or translocation) to suitable



**Figure 4.** The Radiated Tortoise (*Astrochelys radiata*) (shown here copulating) is considered to be an analogue species for the now extinct Rodrigues Domed Tortoise (*Cylindraspis peltastes*). Photo by Jim Pether.



**Figure 5.** Young Aldabra Tortoises that are part of the release program. Photo by Jim Pether.



Figure 6. An enclosure at the Leguat Reserve used to rear juvenile Aldabra Tortoises is at the center of a large, limestone valley called Canyon Tiyel. Photo by Jim Pether.

areas in Madagascar where they may once have occurred – areas like the Tsingy Beanka Reserve east of Maintirano. Any introduction program would require careful and detailed feasibility and impact assessments. However, the hard part of such a program – the availability of tortoises to re-introduce – should not be a limitation within the next few years.

As of mid-2013, 1114 Radiated Tortoises and 568 Aldabra Tortoises have hatched at the Leguat Reserve. Survival rates have been satisfactory overall. The baby Aldabras suffer from very few problems. The Radiated babies, however, require much more intensive care in their first few years.



**Figure 7.** Hatching tortoises that emerge in the outdoor enclosure are transferred to a nursery building where they are maintained for up to four years prior to release. Photo by Jim Pether.

As tortoise numbers increase and the plant restoration work progresses in the upper part of the Reserve, more and more tortoises will be allowed free access to that area. Increasingly, tortoises are making their own way up from the canyon to these restored areas anyway. Long-term there is the hope that it will be possible to allow tortoises access to the much larger remnant native forest area of Anse Quitor Reserve which borders the Leguat Reserve to the west.

Our tortoise breeding project in Rodrigues appears so far to be a successful model for tortoise translocation, breeding, and potential re-wilding. The two tortoise species are thriving and breeding at a very high rate with only limited human intervention. Their interaction with vegetation seems to be having the desired effects of controlling invasive weeds and facilitating the regeneration of the site. The project has transformed this area of southwest Rodrigues from a previously barren and degraded area into a successful mix of natural biodiversity conservation along with a popular and sustainable economic and social enterprise. This is now allowing Rodrigues to claim back its past glory as a 'Giant Tortoise Island' for the benefit and enjoyment of humanity.

#### Résumé

L'île de Rodrigues à l'ouest de l'Océan Indien était jadis connue pour le nombre élevé de tortues géantes qui l'habitaient. Les deux espèces de tortues endémiques (Cylindraspis vosmaeri et C. peltastes) jouaient un rôle-clé dans l'écosystème pour la flore endémique. En 1795, elles ont disparu suite à leur exploitation commerciale. En 2006 fut créée à Rodrigues une réserve privée, le Francois Leguat Giant Tortoise and Cave Reserve, dans le but d'introduire deux espèces de tortues (Aldabrachelys gigantea des Seychelles et Astrochelys radiata de Madagascar) comme analogues pour remplacer les espèces éteintes, et de replanter l'habitat naturel et endémique. Depuis lors, plus de 600 tortues ont été liberées, et plus de 186,000 arbres indigènes et endémiques ont été replantés. Une telle reconstruction de l'écosystème utilisant des espèces analogues est connue sous le terme réensauvagement, et apparait préliminairement de fonctionner à Rodrigues. Le program pouvait eventuellement servir comme modèle pour le réensauvagement des tortues géantes au Madagascar en utilisant Aldabrachelys gigantea comme une analogue pour le tortue éteinte Aldabrachelys abrupta.

### LITERATURE CITED

- BURNEY, D.A. 2010. Back to the Future in the Caves of Kaua'I A Scientist's Adventures in the dark. New Haven, CT: Yale University Press, 216 pp.
- CHEKE, A. AND HUME, J. 2008. Lost Land of the Dodo: The Ecological History of Mauritius, Reunion, and Rodrigues. New Haven, CT: Yale University Press, 480 pp.
- COE, M.J., BOURN, D., AND SWINGLAND, I.R. 1979. The biomass, production and carrying capacity of giant tortoises on Aldabra. Philosophical Transactions of the Royal Society of London B 286:163–176.
- NORTH-COOMBES, A. 1986. Histoire des tortues de terre de Rodrigues et le movement maritime de l'ile de 1601 à 1808. Port-Louis Service Bureau, 75 pp.
- PEDRONO, M. 2008. The Tortoises and Turtles of Madagascar. Kota Kinabalu, Sabah: Natural History Publications, Borneo, 147 pp.
- STRAHM, W. 1989. Plant Red Data Book for Rodrigues. Konigstein, Germany: Koeltz Scientific Books for IUCN.



### Turtles on the Brink in Madagascar • Chelonian Research Monographs, No. 6 - 2013

Turtles on the Brink in Madagascar: Proceedings of Two Workshops on the Status, Conservation, and Biology of Malagasy Tortoises and Freshwater Turtles Christina M. Castellano, Anders G.J. Rhodin, Michael Ogle, Russell A. Mittermeier, Herilala Randriamahazo, Rick Hudson, and Richard E. Lewis, Eds. Chelonian Research Monographs (ISSN 1088-7105) No. 6, doi: 10.3854/crm.6.a29p184 • © 2013 by Chelonian Research Foundation, Lunenburg, MA, USA • Published 30 October 2013

This poem and original commentary reprinted from *Chelonian Conservation and Biology* 3(3):534 (1999), and the poem also reprinted from *A Global Action Plan for Conservation of Tortoises and Freshwater Turtles*, presented by the Turtle Conservation Fund and co-published by Conservation International and Chelonian Research Foundation (2002).

### **Ancient Chelonians**

### ANDERS G.J. RHODIN<sup>1</sup>

<sup>1</sup>Chelonian Research Foundation, 168 Goodrich St., Lunenburg, Massachusetts 01462 USA [rhodincrf@aol.com]

> Ancient chelonians of lineage primeval Their survival now threatened by man's upheaval

We gather together to celebrate our perception Of turtles and their need for preservation and protection

For turtles forever to play their part ecological To prosper and maintain their diversity biological

For turtle and tortoise, terrapin and kin Their kind to preserve, their future to win

We must work together, I tell you from the heart Whether we work together, or apart.

*Comment.* — I wrote this poem for my opening address at the Powdermill Conference on Freshwater Turtle Biology and Conservation in Laughlin, Nevada, in August 1999. Honoring the style of Robert Frost's "The Tuft of Flowers" I tried to capture the essence of how we must all work together to help save these chelonians that we care for with such passion. I read the poem again during my closing address at the Florida Conference on Freshwater Turtles in St. Petersburg, Florida, in October 1999. At each reading I sensed from the positive responses of listeners that there is a need for all of us in the conservation world to not only expound on our scientific knowledge, but also to openly express our passion and love for turtles. In expressing that passion, by whatever reasonable means possible, we may reach beyond our tight-knit scientific chelonian circles to start influencing, at least on an emotional level, those unconverted people with whom we must interact if we are to succeed in preserving the turtles of the world. We must all be ambassadors for turtle conservation at all levels of human interaction.

*Updated 2013 Comment.* — As I finished formatting and editing and putting the final touches on this monograph on *Turtles on the Brink in Madagascar*, I felt that I wanted to once again express my feelings about how important it is for all of us who love turtles to work together for their preservation and protection. By working together — among individuals, organizations, and institutions — and by demonstrating and sharing the passion that we all have for these endeavors and their importance, we are more likely to ultimately be successful, and to gradually build a collaborative and increasingly influential broadbased coalition of like-minded people and organizations and governments that share our vision of a world that values biodiversity and ecosystem services and the sustainable wealth of a healthy and richly diverse natural environment. The critically endangered turtles and tortoises of Madagascar are an integral and important part of that environment — indeed, they are radiant jewels in its crown — and more than worthy of and in desperate need of our utmost efforts to secure their future. I believe it is our moral imperative to work for the conservation of these amazing species.

# **CHELONIAN RESEARCH FOUNDATION**

www.chelonian.org

Chelonian Research Foundation is a nonprofit organization founded in 1992 for the production, publication, and support of worldwide turtle and tortoise research, with an emphasis on the scientific basis of chelonian diversity and conservation biology.

# **Regular Publications**

Chelonian Conservation and Biology International Journal of Turtle and Tortoise Research (ISSN 1071-8443) • Published since 1993 Volumes 1 through 12 (current through 2013) Co-published with Allen Press since 2006 www.chelonian.org/ccb; www.chelonianjournals.org

## Chelonian Research Monographs

Contributions in Turtle and Tortoise Research (ISSN 1088-7105) • Published since 1996 Numbers 1 through 6 (current through 2013) www.chelonian.org/crm

Conservation Biology of Freshwater Turtles and Tortoises Chelonian Research Monographs, No. 5

Published since 2008, Annual Looseleaf Installments Numbers 1 through 5 (current through 2012) Co-published with IUCN/SSC Tortoise and Freshwater Turtle Specialist Group *www.iucn-tftsg.org/cbftt* 

## Turtle and Tortoise Newsletter

The Newsletter of Chelonian Conservationists and Biologists (ISSN 1526-3096) • Published 2000 through 2011 Issues 1 through 15 (no longer current) Co-published with Allen Press 2006 through 2011 www.chelonian.org/ttn; www.chelonianjournals.org

# **Special Publications**

A Global Action Plan for Conservation of Tortoises and Freshwater Turtles: Strategy and Funding Prospectus 2002–2007 Presented by the Turtle Conservation Fund Co-Published 2002 by Conservation International and Chelonian Research Foundation www.turtleconservationfund.org

Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles—2011 Presented by the Turtle Conservation Coalition

Co-Published 2011 by IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Turtle Conservation Fund, Turtle Survival Alliance, Turtle Conservancy, Chelonian Research Foundation, Conservation International, Wildlife Conservation Society, and San Diego Zoo Global www.iucn-tftsg.org/trouble (ISSN 1088-7105) CHELONIAN RESEARCH MONOGRAPHS Number 6 – October 2013





CASTELLANO ET AL. • TURTLES ON THE BRINK IN MADAGASCAR

CHELONIAN RESEARCH MONOGRAPHS - No. 6 • 2013