Editorial Comment. – This section presents research reports based on support provided by Chelonian Research Foundation through the Linnaeus Fund, its annual turtle research awards program. Named after CAROLUS LINNAEUS [1707–1778], the Swedish creator of binomial nomenclature, the fund honors the first turtle taxonomist and father of all modern systematics. Linnaeus Fund awards are granted annually to individuals for specific turtle research projects, with either partial or full support as funding allows. Priority is generally given to projects concerning freshwater turtles, but tortoise and marine turtle research proposals are also funded. Priority is given to the following general research areas: taxonomy and systematic relationships, distribution and zoogeography, ecology, natural history, and morphology, but other topics are also considered. Priority is also given to projects that demonstrate potential relevance to the scientific basis and understanding of chelonian diversity and conservation biology. The generally preliminary and summary reports in this section are not formally peer-reviewed, but are nonetheless subjected to editorial review.

Chelonian Conservation and Biology, 2003, 4(3):730–732

Distribution, Status, and Biology of the Radiated Tortoise, *Geochelone radiata*, in Southwest Madagascar. Linnaeus Fund Research Report

THOMAS E.J. LEUTERITZ[1,3]
AND ROLLANDE RAVOLANAIVO[2]

[1]*Department of Biology, George Mason University, Fairfax, Virginia 22030 USA;*
[2]*Department of Animal Biology, University of Antananarivo, Antananarivo, 101 Madagascar;*
[3]*Present Address: Department of Zoology, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa [E-mail: tleuteritz@uwc.ac.za]*

The radiated tortoise or sokatra (*Geochelone radiata*) is one of four tortoises endemic to Madagascar where its natural distribution is limited to the southwest (Iverson, 1992) in the regions of the Mahafaly and Karimbola plateaus. *Geochelone radiata* have also been introduced on the islands of Mauritius and Reunion (Gonzalez Gonzalez, 1993). The tortoise's habitat consists of xeric, spiny forest characterized by Didieraceae and *Euphorbia* sp. (Juvik, 1975; Durrell et al., 1989; Ernst and Barbour, 1989).

The IUCN Red List (Hilton-Taylor, 2000) classified the radiated tortoise as Vulnerable (defined as "not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future"). Specifically, this classification is based either on a past 20% reduction or a projected future 20% reduction over 10 years. Such reductions are often caused by exploitation, decline in habitat quality, severe fragmentation of habitat as indicated by direct observation, a decline in area of occupancy, or a decline in the extent of occurrence. The two main threats to the radiated tortoise's survival, as with many reptiles, are over-collection, and habitat loss (Durrell et al., 1989; Nussbaum and Raxworthy, 2000; Gibbons et al., 2000).

Several studies have been published on captive radiated tortoises (Schweizer, 1965; Peters, 1969; Affenberg, 1978; Burchfield et al., 1980; Behler and Iaderosa, 1991), but few published data gathered in natural habitats exist (Andriamampiandry, 1987; Bloxam, 1988). We conducted research on *G. radiata* in southern Madagascar from November 1998 to May 1999 and from January to June 2000 with the following goals: 1) to examine the status and distribution of *G. radiata* in southwest Madagascar, 2) to examine the extent of variation in tortoises occurring across the range, 3) to examine, via a field study, the reproductive biology of *G. radiata*, 4) to gather ancillary data on growth, diet, movements, external parasites, and thermal ecology, and 5) to use this information to help improve conservation efforts.

Methods. — Cap Sainte Marie, a Special Nature Reserve (established in October 1962; 1750 ha, 110 to 199 m above sea level) in the extreme south of Madagascar (Nicoll and Langrand, 1989), was chosen as the main study site and the location of the reproductive study (UTM Location: 38J 0514156 7169215).

To determine the status and distribution of *G. radiata*, line transect sampling was conducted across the species' range. Seven sites were located and sampled during the 1998–99 and 2000 field seasons. These included: 1) Cap Sainte Marie, 2) Lavanono, 3) Ankirikirika, 4) Nisoa-Ambony, 5) Lavavolo, 6) Vohombe, and 7) Lake Tsimanampetsotsa (Fig. 1). In addition, two sites (Beheloka and Mahaleotse) were found to have too few tortoises to survey. Andohahela (Ihazafotsy), the national park near Fort Dauphin, was already being surveyed by an ANGAP student.

To collect more comprehensive data on clutch size, clutch frequency, egg size, and duration of interval between clutches, a MinXray HF 80+ portable x-ray machine (Gibbons and Greene, 1979; Turner et al., 1986; Hinton et al., 1997) was used during the second field season. In 1998–99 several tortoises were radiotracked to gather data on movement, home range, feeding behavior, and foods.

Results and Discussion. — The Cap Sainte Marie radiated tortoise population appeared to be doing well. In two field seasons we marked and collected data on 1435 tortoises in an area no greater than 2 km^2. During our second field season 442 of the 1030 total tortoises were recaptured. The transect data for the seven sites located through out the tortoise range have not yet been analyzed.

No significant morphological variation was detected in the tortoises across the range. The Ankirikirika tortoises

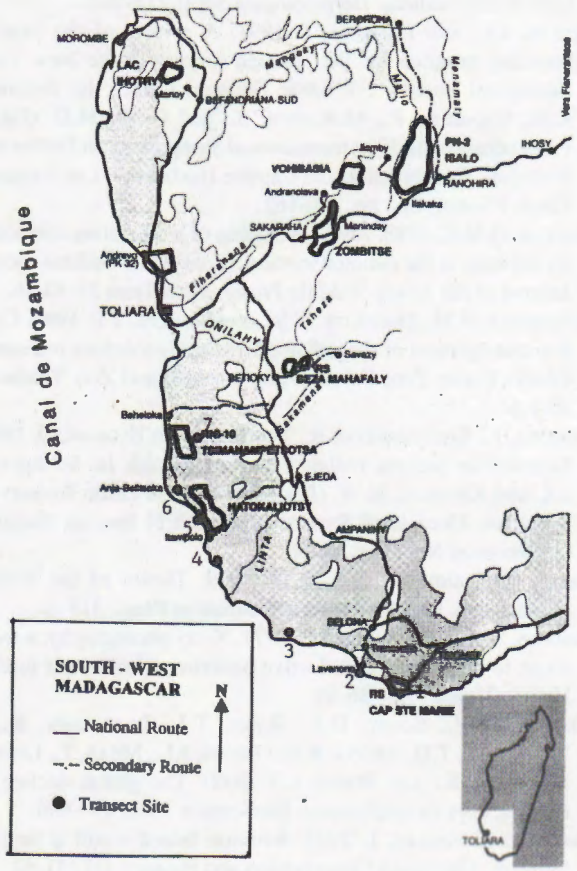

Figure 1. Map showing location of 7 transect sites for *Geochelone radiata* 1998–2000 surveys in southern Madagascar.

population did, however, seem to be slightly larger in size than tortoises in other populations. Blood samples were collected at each site to obtain information on the species' intraspecific phylogeography using mitochondrial DNA (Osentoski and Lamb, 1995). These analyses are currently on-going. There do not seem to be any significant physical barriers that prevent gene flow across the range. The Onilahy, Linta, and Menarandra rivers are dry during portions of the year and therefore do not hinder tortoise movement. Radiated tortoises are very good climbers and are capable of moving up and down the cliffs (*falaise*) found in southern Madagascar, especially movement between populations on the Mahafaly and Karimbola plateaus, and those along the coast.

This study concentrated on reproductive biology. Over the two field seasons we collected data on 24 nests, and in the second field season we took over 200 radiographs and obtained data on 80 gravid females. The adult male to female ratio at Cap Sainte Marie in 1998–99 was 1.07:1.00 (n = 307).

Mating occurred from November to May with 45% of all observations occurring in December. The frequency of mating slowed down considerably by March (Fig. 2). Based on a total of 24 nests, oviposition occurred from February to May with 38% of all records in April. However, based on x-rays taken of 11 radiotelemetered females, the nesting season extended longer. There are two nesting periods within a longer 6 or 7-month nesting season from February to July or the beginning of August. Of the 11 tortoises we radiotracked biweekly, 2 did not produce eggs, 6 had detectable eggs in February, but 3 did not show eggs until April or May.

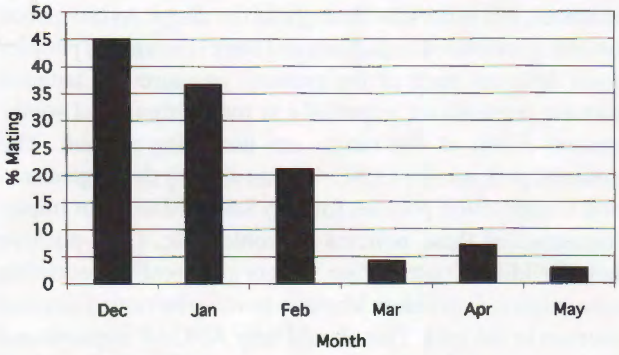

Figure 2. Frequency of occurrence of mating events.

Radiated tortoises at Cap Sainte Marie produced from 1–5 eggs per clutch with a mean clutch size of 2.54 ± 1.13 (n = 62) eggs. The mean total mass per clutch was 114.8 ± 42.40 g (n = 19). Individual females were multiparous, producing 1–3 clutches per season (1.67 ± 1.07, n = 12). The interval between egg deposition and shelling (when eggs are visible in radiographs) of the next clutch was between 10–15 days. The eggs were generally spherical with a brittle calcareous shell, had a mean mass of 38.95 ± 5.84 g (n = 56), a mean length of 41.8 ± 2.4 mm (n = 58), and a mean width of 38.4 ± 2.2 mm (n = 58). Egg size and mass decreased as clutch size increased (Fig. 3).

The only parasites found on the tortoises were ticks of the species *Amblyomma chabaudi*. Ticks were less common on radiated tortoises than on spider tortoises (*Pyxis arachnoides*) in the area, and, if found on radiated tortoises, were generally on hatchlings or young juveniles.

Since much of the data gathered have not been completely analyzed, especially that on population densities, it is premature to make any conservation recommendations. Although Cap Sainte Marie is a stronghold for radiated

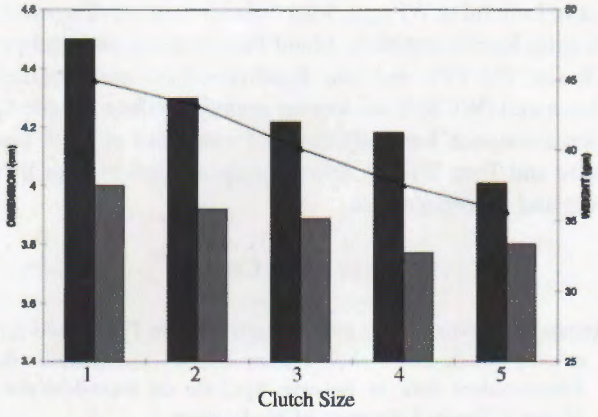

Figure 3. Radiated tortoise egg dimensions by clutch size. Dark bars = mean egg length, light bars = mean egg width, line = mean egg mass.

tortoises, this is not true throughout the range. As old taboos on eating tortoises break down and there is mixing of peoples from different parts of the country, pressures on radiated tortoise populations, especially at the northern and southeastern limits of the range, are becoming evident. The national park service (ANGAP) has already developed several conservation policies for Cap Sainte Marie, but implementation of these policies is problematic. On a positive note, Wildlife Conservation Society is currently conducting a program at Cap Sainte Marie to develop infrastructure and tourism in the area. This should help ANGAP improve and implement its already existing program for the special reserve.

Acknowledgments. - I would like to thank Russell A. Mittermeier (Conservation International), Gerard Arnhold (FOCAL), Claudia Hamblin-Katnick and the Dept. of Biology (George Mason University), John 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 professors at George Mason University and Hofstra University were instrumental in reviewing proposals and offering information: Carl H. Ernst, Lee Talbot, Geoffrey Birchard, and Russel Burke. Many thanks to the people who gave me valuable insight and preparatory advice for working in Madagascar: Ron Nussbaum (University of Michigan), John Behler (Wildlife Conservation Society), Steve Goodman (Chicago Field Museum), Gerald Kuchling (University of Western Australia), James O Juvik (University of Hawaii), Joanna Durbin (Durrell Wildlife), Lee Durrell (Durrell Wildlife), Isabel Constable and Chris Raxworthy (University of Kansas). I greatly appreciated the hospitality and assistance of Yves Etienne Rakotoarison, Chef de Reserve Special de Cap Sainte Marie and his staff. I especially would like to thank Jean Claude Limberaza and Andry Serge Randrianandrasana for their hard work and enthusiasm with this research. I appreciate the advice regarding field x-rays I received from Jeff Lovich and Cathy Myer. Much logistic and technical help was provided in Madagascar by Martin Nicole (ANGAP), Mark Fenn (WWF), Steve Lellelid (LWF_{DMD}), Jean Gabriel Ratalata (Engineer), Brigitte Randrianaridera, Maud Plancheneau, and Philippe Chorier (AFVP), Herilala Randriamahazo and Matthew Hatchwell (WCS). I am forever grateful to these people for their assistance. Last but not least I would like to thank Tom Akre and Tom Wilson, fellow graduate students, for their help and encouragement.

LITERATURE CITED

ANDRIAMAMPIANDRY, R.L. 1987. Contribution a l'etude bio-eco-ethologique de *Geochelone radiata* (Shaw 1802)(Famille des Testudinidae) dans la Reserve Speciale de Beza-Mahafaly. Master's Thesis, University of Madagascar.

AUFFENBERG, W. 1978. Courtship and breeding behavior in *Geochelone radiata*. Herpetologica 34(3):277-287.

BEHLER, J.L. AND IADEROSA, J. 1991. A review of the captive breeding program for the radiated tortoise at the New York Zoological Society's Wildlife Survival Center. In: Beaman, K.R., Caporaso, F., McKeown, S., and Graff, M.D. (Eds.). Proceedings of the First International Symposium on Turtles and Tortoises: Conservation and Captive Husbandry. Los Angeles: Circle Printing Co., pp. 160-162.

BLOXAM, Q.M.C. 1988. An investigation of temperature and activity rhythms in the radiated tortoise, *Geochelone radiata*. Dodo, Journal of the Jersey Wildlife Preservation Trust 25:30-36.

BURCHFIELD, P.M., DOUCETTE, C.S., AND BEIMLER, T.F. 1980. Captive management of the radiated tortoise *Geochelone radiata* at Gladys Porter Zoo, Brownsville. International Zoo Yearbook 20:1-6.

DURRELL, L., GROOMBRIDGE, B., TONGE, S., AND BLOXAM, Q. 1989. *Geochelone radiata*, radiated tortoise, sokake. In: Swingland, I.R. and Klemens, M.W. (Eds.). The Conservation Biology of Tortoises. Occasional Papers of the IUCN Species Survival Commission No. 5, pp. 96-98.

ERNST, C.H. AND BARBOUR, R.W. 1989. Turtles of the World. Washington, DC: Smithsonian Institution Press, 313 pp.

GIBBONS, J.W. AND GREENE, J.L. 1979. X-ray photography: a technique to determine reproductive patterns of freshwater turtles. Herpetologica 35(1):86-89.

GIBBONS, J.W., SCOTT, D.E., RYAN, T.J., BUHLMANN, K.A., TUBERVILLE, T.D., METTS, B.S., GREENE, J.L., MILLS, T., LEIDEN, Y., POPPY, S., AND WINNE, c.T. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50(8):653-666.

GONZALEZ GONZALEZ, J. 1993. Réunion Island - still a land of tortoises. Chelonian Conservation and Biology 1(1):51-52.

HILTON-TAYLOR, C. (Compiler.). 2000. 2000 IUCN Red List of Threatened Species. Gland, Switzerland: IUCN, 61 pp.

HINTON, T.G., FLEDDERMAN, P.D., LOVICH, J.E., CONGDON, J.D., AND GIBBONS, J.W. 1997. Radiographic determination of fecundity: is the technique safe for developing turtle embryos? Chelonian Conservation and Biology 2(3):409-414.

IVERSON, J.B. 1992. A Revised Checklist with Distribution Maps of the Turtles of the World. Richmond, IN: Privately printed, 363 pp.

JUVIK, J.O. 1975. The radiated tortoise of Madagascar. Oryx 13(2):145-148.

NICOLL, M.E. AND LANGRAND, O. 1989. Madagascar: Revue de la Conservation et des Aires Protegeees. Gland: WWF.

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(1):6-14.

OSENTOSKI, M.F. AND LAMB, T. 1995. Intraspecific phylogeography of the gopher tortoise, *Gopherus polyphemus*: RFLP analysis of amplified mtDNA segments. Molecular Ecology 4:709-718.

PETERS, U. 1969. Some observations on the captive breeding of the Madgascan tortoise, *Testudo radiata*, at Sydney Zoo. International Zoo Yearbook 9:29.

SCHWEIZER, H. 1965. Ei-Zeitigung, Aufzucht und Entwicklung einer Strahlenschildkröte (*Testudo radiata* Shaw). Salamandra 1:67-73.

TURNER, F.B., HAYDEN, P., BURGE, B.L., AND ROBERSON, J.B. 1986. Egg production by the desert tortoise (*Gopherus agassizii*) in California. Herpetologica 42(1):93-104.

Received: 5 February 2001
Accepted: 1 December 2003