

## Chapter 4.1

# Giant Pill-Millipedes (Diplopoda: Sphaerotheriida) in the Littoral Forest Fragments of Southeastern Madagascar

Thomas Wesener and Johann-Wolfgang Wägele

### Abstract

An inventory of giant pill-millipede species was conducted during March and April of 2003 in the three remaining littoral forest fragments around Tolagnaro (Fort Dauphin). Three small blocks at Petriky, Mandena, and Sainte Luce represent the last vestiges of littoral forest on sandy ground in southern Madagascar. Three species of the Genus *Zoosphaerium*, and two of the enigmatic Genus *Sphaeromimus* were found in these areas. Only one species was found in more than one of the forest patches, and only one was found more than 10 kilometers outside the littoral forest ecosystem. The known distributions of three species are restricted to one forest fragment. Although the littoral forest holds a smaller number of giant pill-millipedes than other Malagasy ecosystems, its faunal composition is very unique and most species are endemic to this ecosystem. No millipedes were found in *Eucalyptus* plantations.

### Résumé

**Cloportes géants (Diplopoda: Sphaerotheriida) dans les fragments de la forêt littorale du sud-est de Madagascar.** Un inventaire des espèces de cloportes géants a été mené en mars et en avril 2003 dans les trois parcelles restantes de forêt littorale aux environs de Tolagnaro (Fort Dauphin). Ces trois petites parcelles que sont Petriky, Mandena et Sainte Luce représentent les derniers vestiges de la forêt littorale du sud de Madagascar sur substrat sableux. Trois espèces du genre *Zoosphaerium* et deux espèces du genre énigmatique *Sphaeromimus* ont été récoltées dans ces régions. Seule une espèce a été récoltée dans plus d'une parcelle forestière et l'a d'ailleurs été en dehors de l'écosystème de forêt littorale. La distribution connue des quatre autres espèces est limitée à un seul fragment forestier.

Quatre de ces espèces ont été décrites récemment. Même si la forêt littorale n'abrite qu'un petit nombre de cloportes par rapport à d'autres écosystèmes de Madagascar, la composition faunique y est unique et la plupart des espèces sont endémiques à dans cet écosystème donné. Aucun mille-pattes n'a été répertorié dans les plantations d'*Eucalyptus*.

### Introduction

Generally, chilognath diplopods can be divided into two groups, the Pentazonia and the Helminthomorpha. The giant pill-millipedes of the Order Sphaerotheriida belong, like the Order Glomerida and the Order Glomeridesmida, to the pentazonid diplopods. These three orders have no more than 600 described species, which makes this group small in comparison to the over 9000 species of the helminthomorph millipedes. The Sphaerotheriida have a highly developed ability to roll into a perfect sphere in which the ventral side, legs, head, and first segment are completely covered (Fig. 1). The Sphaerotheriida are distributed in the southern hemisphere - Madagascar, India, South Africa, southeast Asia, the east coast of Australia, Tasmania, and New Zealand. This pattern demonstrates, with the exception of South America, a Gondwana distribution (Jeekel 1974). The Malagasy Sphaerotheriida of the tribe Zoosphaeriini are placed with the Indian taxa in the subfamily Arthrosphaerinae, based on the female hypoproct stridulation structure apomorphy. The Malagasy and some of the Indian giant pill-millipedes have an additional male stridulation organ on the anterior

---

Research Institute and Museum Alexander Koenig,  
Adenauerallee 160, 53113 Bonn, Germany. Email:  
Thomas.Wesener@ruhr-uni-bochum.de

telopods, the ‘harp,’ as an apomorphy. Those stridulation organs, in both males and females, are unique in the entire class of Diplopoda. Some Malagasy pill-millipedes have developed gigantism with a body length of 100 mm, a width of 55 mm, and a weight of more than 50 g. They are much larger than those from other areas, and possibly the heaviest Diplopoda in the world. Like so many other groups, Madagascar hosts a unique diversity and assemblage of giant pill-millipede species (de Saussure and Zehntner 1897, 1902, Jeekel 1974, 1999, Enghoff 2003, Wesener and Sierwald 2005a, 2005b). This was recently documented with the description of four new species from the littoral forest ecosystem of the island (Wesener and Sierwald 2005a, 2005b).

The objective of the present study is to provide distribution data on millipede species in the threatened, southern littoral forests of Madagascar. The millipede species of this area may play a crucial role in forest regeneration, specifically associated with the decomposition cycle, as has been documented in Kenya, coastal dune forests in South Africa, and tropical habitats (Schaefer 1990, Crawford 1992, Curry 1994, Haller and Baer 1995, Van Aarde *et al.* 1996, Wolters and Ekschmitt 1997, Smit and Van Aarde 2001, Lawrence and Samways 2003). Also, sphaerotheriid species are known to enrich the soil (Ashwini and Sridhar 2002).

Because of their cryptic habitats and limited means of dispersal, a large number of diplopod species have a very small distributional range. Within the well studied millipede fauna of South Africa, 50% of species are only known from one col-



Figure 1. *Zoosphaerium alluaudii* (de Saussure and Zehntner, 1897). Medium-sized, (up to 40 mm long) giant pill-millipede species, endemic to Petriky. Like all pill-millipedes from Madagascar, both sexes possess a stridulation organ.

lection site (Hamer and Slotow 2002). The same pattern seems to apply to the millipede fauna of Madagascar (Wesener 2006). Furthermore, no single Malagasy pill-millipede genus has been recorded outside Madagascar. Although more research is necessary, all these results suggest that millipedes are crucial tools for finding ‘hotspots’ of invertebrate endemism, which comprises the major part of the fauna in most terrestrial ecosystems.

Table 1. Distribution of sphaerotheriid diplopod species in littoral forest fragments.

Species	Petriky	Mandena	Sainte Luce	Lavaso Mountain	Also in other ecosystems	Source of specimens
<i>Zoosphaerium alluaudi</i> (de Saussure and Zehntner, 1897)	x			x		CAS, MNHN, ZFMK
<i>Zoosphaerium arborealis</i> Wesener and Sierwald, 2005a		x	x		x	ZFMK, FMNH
<i>Zoosphaerium</i> sp. ‘ <i>Sainte-Lucé</i> ’ <i>Sphaeromimus inexpectatus</i> Wesener and Sierwald, 2005b			x			ZFMK
<i>Sphaeromimus splendidus</i> Wesener and Sierwald, 2005b		x				ZFMK
			x			ZFMK

CAS: California Academy of Sciences, San Francisco; MNHN: Muséum national d’Histoire naturelle, Paris, France; FMNH: Field Museum of Natural History, Chicago; ZFMK: Zoologisches Forschungsmuseum Alexander Koenig, Bonn, Germany.

## Methods

The majority of the specimens used in this study were sampled during a field expedition in March and April of 2003. Hand collecting was used to obtain the specimens (Mesibov *et al.* 1995, 2002). The amount of time spent searching for specimens was eighteen days and some nights in the forest fragment of Mandena, two half-days in Petriky, and one half-day in Sainte Luce. A second expedition was conducted in May and June 2007. During this expedition usually 4-5 researchers and local assistants participated in collecting. Two half-day were each spent searching for specimens in the forest fragment of Mandena and Sainte Luce. Additionally, two half-day searches were conducted in the Petit Lavaso forest with seven collectors. Furthermore, one half-day searches were conducted in the Eastern rainforest fragments of Enato, Ivorona, Mananantely, Malio, Isaka-Ivondro and Ebosika. The millipede fauna of the dry and gallery forests at Faux Cap, Mangatsiaka, Tsimelahy and Andrahomana were also inventoried.

Additional material for comparison was loaned by the Field Museum of Natural History (FMNH), Chicago, Illinois, and the California Academy of Sciences (CAS), San Francisco, California. This material was collected in the late 1990s by Steven M. Goodman and Brian L. Fisher from about 36 sites in eight Malagasy ecosystems during general fauna inventories (Wesener 2006). Additional material was collected at sites west of Tolagnaro by Ken Emberton, and was studied at the Zoologisk Museum, Copenhagen, Denmark.

## Results

Five species of giant pill-millipedes were collected in the forest fragments of Petriky, Mandena, and Sainte Luce. In spite of intensive searching, no pill-millipede was found in the *Eucalyptus* plantations, *Erica* secondary vegetation, or in the pseudo-steppe surrounding the remaining forest.

All specimens were located in humid places within forested zones. Although species of giant pill-millipedes were found in every fragment, their distributions were very irregular (Table 1). Four of the five species were restricted to a single forest fragment. Only the species *Zoosphaerium arborealis* was detected in more than one forest fragment.

## Littoral forest of Petriky

Petriky is the southernmost extension of the littoral forest ecosystem in southeastern Madagascar. It represents a transition between humid forest and spiny forest (Dumetz 1999), making this zone unique in the world. This forest receives less rainfall than the more northern littoral forests of Mandena and Sainte Luce (Donque 1972, see Vincelette *et al.* Chapter 2.1). The closest existing forest is the humid forest of the Lavaso-Mountain, 4 kilometers South of Petriky. The Petriky forest is now completely isolated from other patches of natural forests by vast areas of pseudo-steppe (Ramanamanjato *et al.* 2002, Dufils 2003). Even though it covers a large area, the forest has been severely damaged by anthropogenic pressures, and the mining project will have its largest impact on this forest, leaving some hundred hectares unaffected (de Gouvenain and Silander 2003, Vincelette *et al.* 2003).

One giant pill-millipede species, *Zoosphaerium alluaudi*, was discovered in the Petriky forest (Fig. 1). This species was collected in average numbers (5-10 specimens) from wet leaf litter under large trees with understory. Not many large trees still exist in this forest. No juvenile or small (<10 mm) millipedes were collected, but one female contained over 1500 eggs. Specimens of this species occur in the



Figure 2. *Zoosphaerium arborealis* Wesener and Sierwald, 2005. This recently discovered giant pill-millipede has suspiciously red-colored legs. Surprisingly, it is often found climbing on trees. This species was the only pill-millipede which could be found in more than one forest fragment, it was quite common in both Mandena and Sainte Luce.



Figure 3. Immature specimen of *Sphaeromimus splendidus* Wesener and Sierwald, 2005. On a Malagasy standard, this is a small-sized millipede species (adults up to 30 mm long). Adults are completely black with a very smooth and shiny surface. This species is only known from Sainte Luce. It belongs to a genus which may represent a missing link between Malagasy and Indian Sphaerotheriida, highlighting the close relationship between the faunas.

collections of the MNHN and CAS, all stating ‘Petriky’ or ‘South of Fort Dauphin’ as locality information. Numerous additional specimens could be collected at the humid forest of Petit Lavasoa. *Z. alluaudi* was not found in other littoral forest fragments, which are only 20 km away, nor was it found in surrounding ecosystems like the spiny forest, gallery forest, or more inland eastern rainforest. This species can thus be considered as micro-endemic (<10 km<sup>2</sup> area of distribution) to the highly threatened forests in Petriky and the Lavasoa Mountain. The importance of the unique Petriky forest is furthermore highlighted by the presence of two micro-endemic *Spirobolida* helminthomorph millipede species. Both species belong to an undescribed genus, one of them was also found at Petit Lavasoa, the second can only be found in Petriky.

#### Littoral forest of Mandena

The littoral forest of Mandena is highly fragmented. The largest remaining patch is divided into two parts by a river and a swamp. Forest fragments of Mandena have no remaining connection to other forests, and have suffered considerably from tree extraction and fires over the last decade (Ramanamanjato *et al.* 2002, Vincelette *et al.* 2003).

Two species of pill-millipedes were found in the Mandena forest, *Zoosphaerium arborealis* (Fig. 2) and *Sphaeromimus inexpectatus* (Fig. 4), and the former was common. Numerous adults were found feeding in wet leaf litter, piles of dead wood, and climbing on trees. Juveniles and small individuals were common inside the dead stems of *Pandanus*. Even with intensive inventory efforts, only two mature specimens of *S. inexpectatus* were found in Mandena. This remarkably pink colored species could only be found approximately six kilometers West to Mandena, between Mandena and Enato. *S. inexpectatus* can thus be considered micro-endemic around the littoral forest of Mandena, for which blocks M15 and M16 have been declared a conservation area. In 2007, an endemic, helminthomorph millipede belonging to the order Spirobolida was collected in Mandena. This species belongs to an undescribed genus.

#### Littoral forest of Sainte Luce (S9)

This block represents one of the last remaining and relatively intact, large parcels of eastern littoral forest. It receives more rainfall per year than the more southern zones (Donque 1972). The fragment S9, and an adjacent fragment, S8, were declared conservation zones in 2006.

Three species of giant pill-millipedes were collected in the Sainte Luce fragment, the highest species richness of any of the three littoral forest sites. All three species, *Zoosphaerium arborealis*, *Z. sp.* ‘Sainte-Lucé’, and *Sphaeromimus splendidus* (Fig. 3), were found in wet leaf litter and under dead wood. Juvenile and small specimens of all three species were obtained as well. *Zoosphaerium arborealis* was common in this forest, like in Mandena, as was *S. splendidus*. In 2007 *S. splendidus* was very common in Sainte Luce, around 1000 specimens could be counted on a single afternoon. For *Zoosphaerium sp.* ‘Sainte-Lucé’, only one female and one juvenile could be collected in 2003, circa 15 additional individuals in 2007. All collected specimens were females, therefore the description of this largely unknown species awaits further material. Neither species, *S. splendidus* and *Z. sp.* ‘Sainte-Luce,’ was found in any other millipede samples, so both are probably best considered endemic to the Sainte Luce forest. The high diversity of giant pill-millipedes in Sainte Luce was also reflected in the diversity of Spirobolida millipedes found. No less than six genera of Spirobolida could be collected in the forest of Sainte Luce, making it the most Spirobolida genus-rich forest of the planet.

## Discussion

Although the eastern littoral forest ecosystem has no vertebrate species restricted to its habitat (Ganzhorn *et al.* 2000), several micro-endemic invertebrate species are present (e.g., Lourenço 2005). Every littoral forest fragment studied in the context of this project contained micro-endemic giant pill-millipede species. Studies show that *Eucalyptus* plantations, which are a prominent feature of the landscape in southeastern Madagascar, do not form a suitable environment for indigenous vertebrate species (Ramanamanjato and Ganzhorn 2001). It has been reported that *Eucalyptus* plantations form barriers to the dispersal of native millipede species in the coastal forests of South Africa (Van Aarde *et al.* 1996). Around Mandena, these plantations lack a layer of leaf litter and wet refuges. Even after 30 years, regenerated “natural forests,” planted in South Africa after a large-scale mining project, contained less than 50% of soil invertebrate species found in the soil of similar, non-mined forests (Kumssa *et al.* 2004). The slow colonization ability of millipedes, their levels of micro-endemism, and their role in litter decomposition call for the conservation of as many natural forest fragments as possible.

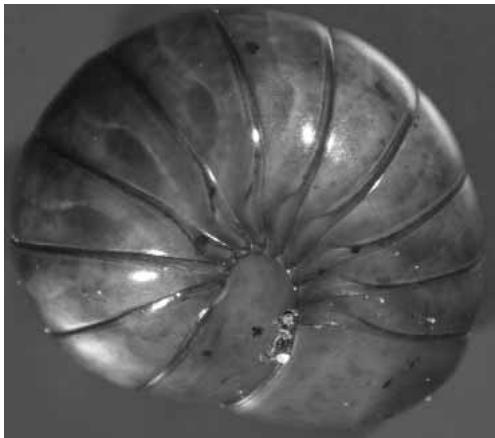


Figure 4. *Sphaeromimus inexpectatus* Wesener and Sierwald, 2005. This species has a unique pink coloration. The species belongs with around 20 mm body length to the smallest pill millipede species on Madagascar. This species is only known in a six kilometer radius around the littoral forest of Mandena and was just described and named in 2005.

## Acknowledgements

This project is part of the dissertation “*Biodiversity, Evolution, Biogeography and ecological Specialization of Malagasy Diplopoda*” of TW conducted at the Rheinische Friedrich-Wilhelms Universität in Bonn under the supervision of Prof. Dr. J.-W. Wägele. We would like to thank Jörg U. Ganzhorn (University of Hamburg) for his help in the organization of the Madagascar expedition where the materials for this study were collected. Thanks go to the Direction des Eaux et Forêts and the Committee “CAFF-CORE” as well, for their authorizations to carry out this work. Excellent support was provided by QIT Madagascar Minerals and their environmental and conservation team headed by Manon Vincelette and Jean-Baptiste Ramanamanjato. This research is based on the “Accords de Collaboration” between the Université d’Antananarivo (Département de Biologie Animale and Département d’Anthropologie et Biologie Evolutive), QIT Madagascar Minerals, and the University of Hamburg. The support of O. Ramilijaona and D. Rakotondravony is gratefully acknowledged. We would like to thank Petra Sierwald (Field Museum of Natural History, Chicago) and Charles Griswold (California Academy of Science) for the loan of materials. The study of TW was supported by Studienstiftung des Deutschen Volkes with a monthly grant. A ten-day stay at the Zoologisk Museum, Copenhagen, was made possible by a European Union Synthesys grant Dk-1167.

## References

- Ashwini, K.M. and K.R. Sridhar. 2002. Towards organic farming with millipede *Arthrosphaera magna*. *Current Science (Bangalore)* 82:20-22.
- Crawford, C. S. 1992. Millipedes as model detritivores. *Berichte des Naturwissenschaftlich-Medizinischen Verein Innsbruck* 10:277-288.
- Curry, J.P. 1994. *Grassland Invertebrates*. Chapman and Hall, London, 437 pp.
- de Gouvenain, R.C. and J.A. Silander. 2003. Littoral forest. Pp. 103-109 in: Goodman, S.M. and J.P. Benstead, eds., *The Natural History of Madagascar*. University of Chicago Press, Chicago.
- de Saussure, H. and L. Zehntner. 1897. Atlas de l’histoire naturelle des Myriapodes. In: Grandidier, G., ed., *Histoire physique, naturelle et politique de Madagascar* 27:pl.1-12.
- de Saussure, H. and L. Zehntner. 1902. Myriapodes de

- Madagascar. In: Grandidier, G., ed., *Histoire physique, naturelle et politique de Madagascar*, 27:i-viii, 1-356, pl.13-15.
- Donque, G. 1972. The climatology of Madagascar. Pp. 87-145 in: R.Battistini and G. Richard-Vindard, eds., *Biogeography and Ecology in Madagascar*. W. Junk, The Hague.
- Dufils, J.-M. 2003. Remaining Forest Cover. Pp. 88-96 in: Goodman, S.M. and J.P. Benstead, eds., *The Natural History of Madagascar*. University of Chicago Press, Chicago.
- Dumetz, N. 1999. High plant diversity of lowland rain-forest vestiges in eastern Madagascar. *Biodiversity and Conservation* 8:273-315.
- Enghoff, H. 2003. Diplopoda, millipedes. Pp. 617-627 in: Goodman, S.M. and J.P. Benstead, eds., *The Natural History of Madagascar*. University of Chicago Press, Chicago.
- Ganzhorn J.U., S.M. Goodman, J.-B. Ramanamanjato, D. Rakotondravony, B. Rakotosamimanana and D. Vallan. 2000. Vertebrate species in fragmented littoral forests of Madagascar. Pp. 155-164 in: Lourenço, W.R. and S.M. Goodman, eds., *Diversité et endemisme à Madagascar*. Mémoires de la Société de Biogéographie, Paris.
- Haller, R. and S. Baer. 1995. *From Wasteland to Paradise*. Kohlhammer und Wallishauser, Hechingen.
- Hamer, M.L. and R.H. Slotow, 2002. Conservation applications of existing data for South African millipedes (Diplopoda). *African Entomology* 10:29-42.
- Jeekel, C.A.W. 1974. The group taxonomy and geography of the Sphaerotheriida (Diplopoda). *Symposium of the Zoological Society in London* 32:41-52.
- Jeekel, C.A.W. 1999. A new pill-millipede from Madagascar, with a catalogue of the species hitherto described from the island (Diplopoda, Sphaerotheriida). *Myriapod Memoranda* 1:5-20.
- Kumssa, D. B., R.J. Van Aarde and T.D. Wassenaar. 2004. The regeneration of soil micro-arthropod assemblages in a rehabilitating coastal dune forest at Richards Bay, South Africa. *African Journal of Ecology* 42:346-354.
- Lawrence, J.M. and M.J. Samways. 2003. Litter breakdown by the Seychelles giant millipede and the conservation of soil process on Cousine Island, Seychelles. *Biological Conservation* 113:125-132.
- Lourenço, W.R. 2005. Scorpions from Mandena east coastal rain forest in Madagascar, and description of a new species of *Grosphus* SIMON (Scorpiones, Buthidae). *Boletín Sociedad Entomológica Aragonesa* 37:83-87.
- Mesibov, R., R.J. Taylor and R.N. Brereton. 1995. Relative efficiency of pitfall trapping and hand-collecting from plots for sampling of millipedes. *Biodiversity and Conservation* 4:429-439.
- Mesibov, R., K.J. Bonham, N. Doran, J. Meggs, S. Munks, H. Otle and K. Richards. 2002. Single-species sampling in Tasmania: an inefficient approach to invertebrate conservation? *Invertebrate Systematics* 16:655-663.
- Ramanamanjato, J.-B. and J.U. Ganzhorn. 2001. Effects of forest fragmentation, introduced *Rattus rattus* and the role of exotic tree plantations and secondary vegetation for the conservation of an endemic rodent and a small lemur in littoral forest of southeastern Madagascar. *Animal Conservation* 4:175-183.
- Ramanamanjato, J.-P., P.B. McIntyre and R.A. Nussbaum. 2002. Reptile, amphibian, and lemur diversity of the Malahelo Forest, a biogeographical transition zone in southeastern Madagascar. *Biodiversity and Conservation* 11:1791-1807.
- Schaefer, M. 1990. The soil fauna on a beech forest on limestone: trophic structure and energy budget. *Oecologia* 82:128-136.
- Smit, A.-M. and R.J. Van Aarde. 2001. The influence of millipedes on selected soil elements: a microcosm study on three species occurring on coastal sand dunes. *Functional Ecology* 15:51-59.
- Van Aarde, R.J., S.M. Ferreira and J.J. Kritzing. 1996. Millipede communities in rehabilitating coastal dune forests in northern KwaZulu/Natal, South Africa. *Journal of Zoology*, London 238:703-712.
- Vincelette, M., L. Randrihasipara, J.-B. Ramanamanjato, P.P. Lowry II and J.U. Ganzhorn. 2003. Mining and environmental conservation: The case of QIT Madagascar Minerals in the southeast. Pp. 1535-1537 in: Goodman S.M. and J.P. Benstead, eds., *The Natural History of Madagascar*. University of Chicago Press, Chicago.
- Wesener, T. 2006. Giant pill-millipede diversity on Madagascar [Diplopoda: Sphaerotheriida]. *Peckiana* 4:189-193.
- Wesener, T. and P. Sierwald. 2005a. New giant pill-millipede species from the littoral forest of Madagascar (Diplopoda, Sphaerotheriida, *Zoosphaerium*). *Zootaxa* 1097:1-60.
- Wesener, T. and P. Sierwald. 2005b. The giant pill-millipedes of Madagascar: Revision of the genus *Sphaeromimus*, with a review of the morphological

terminology (Diplopoda, Sphaerotheriida, Sphaerotheriidae). *Proceedings of the California Academy of Sciences*, 4<sup>th</sup> series, 29:557-599.  
Wolters, V. and K. Ekschmitt. 1997. Gastropods,

isopods, diplopods, and chilopods: neglected groups of the decomposer food web. Pp. 265-306 in: Benckiser, G., ed., *Fauna in Soil Ecosystems*. Marcel Dekker, Inc., New York, Basel, Hong Kong.

