

The diversity of Indian Ocean Heterotardigrada

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ABSTRACT

Information about Indian Ocean tardigrades is quite scarce and in most cases refers to species in coastal coralline sediment and occasionally in abyssal mud. The present data concern species found in the intertidal sand of Coco and La Digue Islands in the Seychelles, previously unsampled for tardigrades, as well as species in subtidal sediment found at depths ranging between 1 and 60 m off the shores of the Maldivic Atolls. These sediments are all very similar and consist of heterogeneous coralline sand, moderately or scarcely sorted. Sixteen species (three new to science) were found in the Seychelles, belonging to Renaudarctidae, Stygarctidae, Halechiniscidae, Batillipedidae and Echiniscoididae. Diversity and evenness data are also interesting, with maximum values of $H' = 2.59$ and of $J = 0.97$. In the Maldives 25 species were found (two new to science) belonging to Neostygarctidae, Stygarctidae, Halechiniscidae and Batillipedidae. Such a number of species, despite the low percentage of tardigrade fauna (only 0.6% of the total meiofauna), contributes to the high values of both diversity and evenness, with H' ranging between 1.5 and 2.6 and J between 0.6 and 1. The Indian Ocean tardigrade fauna currently numbers 31 species of Arthrotardigrada and 2 species of Echiniscoidida. In the present study, Arthrotardigrada are the most abundant and all the families are present except Neoarctidae. Halechiniscidae is present with all the sub-families (except Euclavartinae), thus contributing to the high diversity values. Furthermore, 18 species, representing more than 50% of the total marine tardigrade fauna, are new records for the Indian Ocean, including five species new to science.

Keywords: Tardigrada, Heterotardigrada, Seychelles, Maldives, biodiversity

1. INTRODUCTION

Although the overall bibliography of marine tardigrades is quite limited, references on the species found in the Indian Ocean are numerous and mainly related to Arthrotardigrada from abyssal mud and coastal coralline sand from Madagascar, the Mozambique Channel, the Comoros Islands, Mauritius and the Maldives (Renaud-Debyser 1965a, b; Renaud-Mornant 1974, 1975, 1979a, b, 1981, 1984, 1987; Kristensen & Renaud-Mornant 1983; Grimaldi de Zio *et al.* 1987; de Zio Grimaldi *et al.* 1999).

Our new findings of several tardigrade species in the intertidal sand of the Seychelles Islands and in subtidal sand along coral reefs of the Maldives Archipelago add further information to previous data.

2. METHODS

The Seychelles sediment studied for the tardigrade fauna was sampled from the intertidal zone in 1 site at Coco and 4 sites at La Digue Islands (Banane, Cocos, La Réunion, La Source à Jean) in March 2004. In the Maldives most of the samples were collected by SCUBA diving from 14 sites, during the April 2004 Scientific cruise "Albatros", at depths ranging from 1 to 60 m along the external coral reefs and in 2 caves of four atolls (South Male, North Ari, South Ari, and Felidhoo). Figure 1 shows the whole sampling area.

Sediment meiofauna samples were immediately fixed with 5% formalin/seawater and the animals extracted from sand using the multiple decantations technique and retained on a 42 μm mesh sieve.

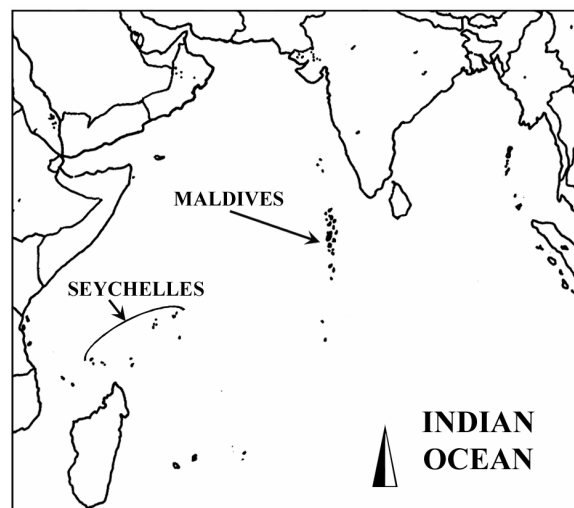


Fig. 1. Location map of Indian Ocean.

Following slow dehydration in alcohol-glycerol solutions, permanent mounts were made either in Kaiser's glycerol-gelatin or Hoyer's fluid (Higgins & Thiel 1988). Contrast phase and interference contrast micros-

Tab. 1. Tardigrada species, number of specimens, density and diversity per site of the Seychelles Islands. CS = coarse sand; MS = medium sand; MFS = medium fine sand; FS = fine sand; H' = Shannon-Wiener index; J = Pielou's index.

	Cocos Island		La Digue Island		
		Anse Banane	Anse Cocos	Anse La Réunion	Anse La Source à Jean
Site	1	2	3	4	5
Depth (m)	0	0	0	0	0
Mean Grain Size (Φ)	0.5	2	1.5	2.5	1.5
Sediment type	CS	MFS	MS	FS	MS
Taxon					
Stygarctidae					
<i>Stygarctus lambertii</i> Grimaldi de Zio <i>et al.</i> 1987					1
Renaudarctidae					
<i>Renaudarctus psammocryptus</i> Kristensen & Higgins 1984					3
<i>Renaudarctus n. sp.</i>					1
Halechiniscidae					
<i>Dipodarctus subterraneus</i> (Renaud-Debyser 1959)	2				
<i>Florarctus antillensis</i> Van der Land 1968	22				4
<i>Florarctus hulingsi</i> Renaud-Mornant 1976		3			
<i>Florarctus n. sp.</i>		11			
<i>Wingstrandarctus intermedius</i> Renaud-Mornant 1967			1		3
<i>Halechiniscus greveni</i> Renaud-Mornant & Deroux 1976	1				
<i>Styraconyx nanoqsunguak</i> Kristensen & Higgins 1984	1				
<i>Styraconyx sardiniae</i> D'Addabbo Gallo <i>et al.</i> 1989	2				
<i>Styraconyx tyrrhenus</i> D'Addabbo Gallo <i>et al.</i> 1989	1				
Batillipedidae					
<i>Batillipes pennaki</i> Marcus 1946		2	1	3	1
<i>Batillipes n. sp.</i>		1		2	6
Echiniscoididae					
<i>Anisonyches diakidius</i> Pollock 1975	2	1			3
<i>Anisonyches mauritanus</i> Grimaldi de Zio <i>et al.</i> 1987	1				
Total	32	18	2	5	22
Species number	8	5	2	2	8
Total Density (n. ind. · 10 cm ²)	52	29	3	8	35
H'	1.75	1.68	1	0.97	2.74
J	0.58	0.72	1	0.97	0.91

copy (Leica DM 2500) were used to perform identification and taxonomic studies on tardigrades. Shannon-Wiener diversity index (H') and Pielou's index (J) of equitability (evenness) were calculated. Sediment samples were analysed for particle size.

3. RESULTS

The sediment consists of white coralline sand, ranging between 0.25 and 2.5 Φ , usually moderately and poorly sorted (Tabs 1 and 2).

Tardigrades always represent a very modest fraction of the meiofauna; nevertheless, they show interesting values of diversity and evenness at the studied sites.

Sediment from the Seychelles Islands, the first ever sampled for tardigrades, contained 16 species, belonging mainly to Halechiniscidae but also to Renaudarctidae, Stygarctidae, Batillipedidae and Echiniscoididae (Tab. 1). The highest density was recorded at Cocos Island (site 1) with 52 individuals 10 cm². Diversity (H') and Evenness (J) indices are remarkably high at Anse La Source à Jean, 2.74 and 0.9 respectively (Fig. 2). At the same site, all the collected and identified specimens (22) belong to five families.

The finding of 3 specimens, two females, and one 2nd stage larva, of *Renaudarctus psammocryptus*, and 1 male specimen of *Renaudarctus n. sp.* is quite remarkable. Only one adult female of *Stygarctus lambertii* and of *Anisonyches mauritanus* were found, for the first time on the island of Mauritius, from "Belle Mer" beach. Only two adult females of *Styraconyx sardiniae* and one 2nd stage larva of *Styraconyx tyrrhenus* were recorded. Both species were previously known only from the Mediterranean Sea. The Halechiniscidae family is present with 9 species, among which one is new to science (*Florarctus n. sp.*). The Batillipedidae family has representatives only in fine sand, with 7 specimens (one adult female, three 2nd stage larvae, three 1st stage larvae) of *Batillipes pennaki*, collected in 4 sites and 9 specimens of a new *Batillipes* species (two adult female, five 2nd stage larvae, and two 1st stage larvae) collected in 3 sites. The family Echiniscoididae is represented by two species, one previously found on Mauritius (*A. mauritanus*), as noted above, and *Anisonyches diakidius*, with one 1st stage larva and three 2nd stage larvae, already known for the Atlantic and the Pacific Ocean.

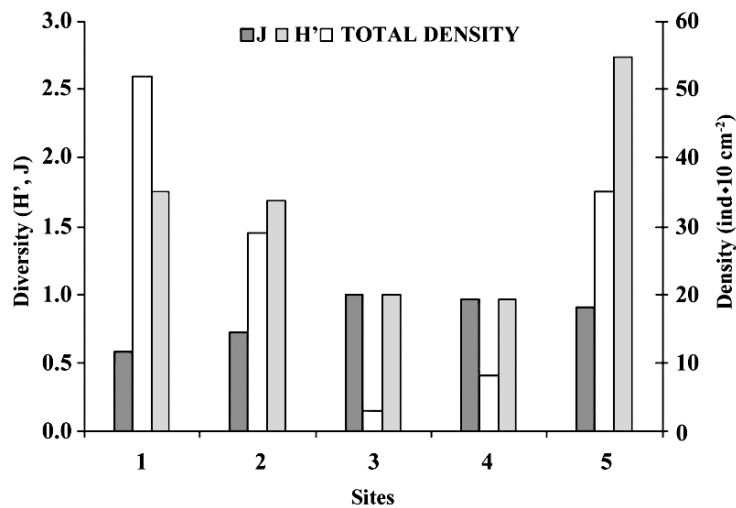


Fig. 2. Density and diversity of Seychelles marine tardigrade fauna.

Tab. 2. Tardigrada species, number of specimens, density and diversity per site of the Maldivian Islands. CS = coarse sand; MS = medium sand; H' = Shannon-Wiener index; J = Pielou's index.

Localities	Male Sud					Ari Sud			Ari Nord		Felidhoo			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Site														
Depth (m)	41	6	5	37	9	15	58	23	22	37	19	1	2	2
Mean Grain Size (Φ)			0.25				0.25	1.5		0.25			1.5	
Sediment type			CS				CS	MS		CS			MS	
Taxon														
Neostygarctidae														
<i>Neostygarctus acanthophorus</i> Grimaldi de Zio <i>et al.</i> 1982	2		4	1						3				
Stygarctidae														
<i>Parastygarctus renaudae</i> Grimaldi de Zio <i>et al.</i> 1987						1		2	1					
<i>Megastygarctides</i> n. sp.														1
Halechiniscidae														
<i>Archechiniscus minutus</i> Grimaldi de Zio & D'Addabbo Gallo 1987			2											
<i>Dipodarctus anaholiensis</i> Pollock 1995		3		1										
<i>Dipodarctus subterraneus</i> (Renaud-Debyser 1959)			2	1	5	1	1	5	2					
<i>Florarctus antillensis</i> Van der Land 1968				1										
<i>Florarctus heimi</i> Delamare Deboutteville & Renaud-Mornant 1965							1							
<i>Florarctus hulingsi</i> Renaud-Mornant 1976					18	1	3	5	2		3			
<i>Florarctus pulcher</i> de Zio Grimaldi <i>et al.</i> 1999							1		1				2	
<i>Wingstrandarctus corallinus</i> Kristensen 1984												2		5
<i>Halechiniscus greveni</i> Renaud-Mornant & Deroux 1976	10	10	13	16	3			2	1	1	1			
<i>Halechiniscus paratuleari</i> Grimaldi de Zio <i>et al.</i> 1988														2
<i>Halechiniscus perfectus</i> Schulz 1955			1											
<i>Halechiniscus tuleari</i> Renaud-Mornant 1979	1													
<i>Orzeliscus belopus</i> Du Bois Reimond Marcus 1952					1									
<i>Raiarctus variabilis</i> D'Addabbo Gallo <i>et al.</i> 1986			2					3			1			
<i>Styraconyx nanoqsunguak</i> Kristensen & Higgins 1984								2		1	1			
<i>Styraconyx qivitoq</i> Kristensen & Higgins 1984										1				
<i>Styraconyx tyrrhenus</i> D'Addabbo Gallo <i>et al.</i> 1989		2									1			
<i>Tholoarctus natans natans</i> Kristensen & Renaud-Mornant 1983		1						7		1				
<i>Tanarctus gracilis</i> Renaud-Mornant 1980								38	1		1			
<i>Tanarctus velatus</i> Mc Kirdy <i>et al.</i> 1976									1					
Batillipedidae														
<i>Batillipes pennaki</i> Marcus 1946					1	1				1				
<i>Batillipes</i> n. sp.	6	7		3	4	1	43	13		8	3			1
Total	19	24	23	23	32	4	7	107	22	16	11	2	2	9
Species number	4	6	5	6	6	4	5	9	8	7	7	1	1	4
Total Density (n. ind. · 10 cm ²)	31	39	37	37	52	6	11	173	35	26	18	3	3	15
H'	1.6	2.1	1.8	1.5	1.9	2	2.1	2.2	2.1	2.2	2.6	0	0	1.7
J	0.8	0.8	0.8	0.6	0.7	1	0.9	0.7	0.7	0.8	0.9	0	0	0.8

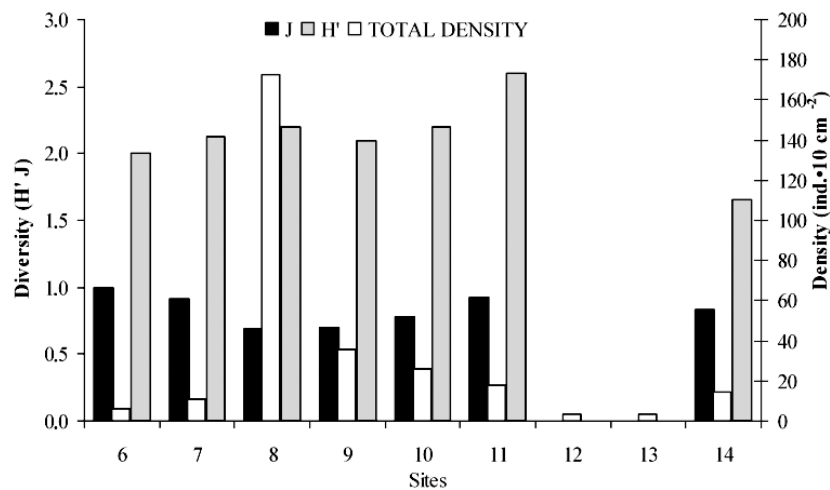


Fig. 3. Density and diversity of Maldivian marine tardigrade fauna.

In the Maldives Islands, 25 species were found from 4 families: Neostygarctidae (1 species), Stygarctidae (2 species), Halechiniscidae (20 species) and Batillipedidae with 2 species, one of which is new to science (Tab. 2). The highest density was recorded at the Bulhaa Lhohi cave (South Ari atoll, site 8) with 173 individuals $\cdot 10 \text{ cm}^{-2}$ (Fig. 3). The highest values of H' (2.6) and J (1) were respectively recorded at site 11 and site 6 (Fig. 3).

Neostygarctus acanthophorus (Neostygarctidae) is present in 4 sites with two adult males, three adult females, four 2nd stage larvae, and one 1st stage larva. The Stygarctidae were present in 4 sites with only 4 specimens (one adult male, one adult female, one 1st stage larva and one 2nd stage larva), of *Parastygarctus renaudae*, previously recorded on Mauritius, and with only one specimen (2nd stage larva) of *Megastygarctides* n. sp., at site 14 of Fotteyo Finolhu (Felidhoo Atoll), collected at 2 m depth. In the present study, the Halechiniscidae family markedly contributes to the high values of diversity, being present with several species and with all its sub-families (except Euclavartinae). This family is present in all sites studied, and is the exclusive taxon in site 12 and 13. Only one specimen (adult female) of *Tanarctus velatus* was collected in the cave of site 9, and only one specimen (adult female) of *Florarctus heimi* was sampled at site 7. The family Batillipedidae, represented by 2 species at 11 sites, is also a dominant component of the tardigrade fauna. One of them, found at 10 sites with 89 specimens, is a new species still to be described.

4. DISCUSSION

The present data add faunistic and biogeographic information about the distribution of marine tardigrade fauna. The number of species in the Indian Ocean to date represents more than 1/3 of the known species of marine Heterotardigrada with both the Arthrotardigrada

and Echiniscoidea orders. In the present study, the Arthrotardigrada show the highest densities, with Halechiniscidae strongly contributing to the high values of the diversity. Excluding the Neoarctidae family, all the other known families are present in the Indian Ocean. The finding of *R. psammocriptus*, previously recorded in the Atlantic and Pacific Oceans, *Renaudarctus* n. sp., *T. velatus*, and of *F. heimi*, previously found only in the Pacific Ocean, and, finally, of *N. acanthophorus*, *Archechiniscus minutus*, *Halechiniscus paratuleari*, *S. sardiniae* and *S. tyrrhenus*, previously known only in the Mediterranean Sea, is very remarkable.

The total number of known marine heterotardigrade species to date is 170; 65 found in the Indian Ocean (38% of world marine tardigrade fauna), 79 in the Mediterranean Sea (46%), 76 in the Atlantic Ocean (45%), and 61 in the Pacific Ocean (36%). There are several species in common in various basins; for example, the Mediterranean Sea and Indian Ocean share 40 species (about 50% of total Mediterranean tardigrade fauna, and more than 60% of total Indian Ocean tardigrades), and the Atlantic Ocean and Mediterranean Sea share 37 species. Furthermore, the theory of plate tectonics might partly explain the existence of a rather high number of cosmopolitan species such as *Parastygarctus sterreri* Renaud Mornant, 1970, *Stygarctus bradypus* Schulz, 1951, *Archechiniscus marci* Schulz, 1953, *Florarctus antillensis* Van der Land, 1968, *Wingstrandarctus corallinus*, *Halechiniscus perfectus*, *Halechiniscus remanei* Schulz, 1955, *Orzeliscus belopus*, *Styraconyx craticulus* (Pollock 1983), *Styraconyx sargassi* Thulin, 1942, *Tholoarctus natans natans*, *Batillipes mirus* Richters, 1909, *B. pennaki* and *A. diakidius*.

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