

# Endemicity and Altitudinal Stratification in Distribution of Megascolecid Earthworms in the Centro-western Taiwan

## 台灣中西部地區蚯蚓之特有性及其垂直分布

Chu-Fa Tsai, Huei-Ping Shen and Su-Chen Tsai

蔡住發 沈慧萍 蔡素蟾

Endemic Species Research Institute, Chichi, Nantou, Taiwan

行政院農業委員會特有生物研究保育中心 南投縣集集鎮民生東路1號

### Abstract

Earthworm surveys were conducted in the centro-western Taiwan from the coastal plain at 50m in elevation near the Tatu Estuary to Mt. Hohuan at 3,200m in the Central Mountain Range in 1999, 2000 and 2003. A total of 34 species of megascolecid earthworms were collected, consisting of 19 native species and 15 exotic species. Most of the native species were woodland earthworms, dwelling primarily in the mountain range and its peripheral hills. They showed altitudinal stratification in the distribution; each species had its specific geographical area with the highest and the lowest altitudinal ranges. Apparently, elevation defines the distributional ranges, and is one of the important factors for autochthonous speciation of the native species. In contrast most of the exotic species were farmland earthworms commonly found in the coastal plain and at the foot of peripheral hills, and showed the altitudinal stratification only in the highest altitudinal ranges. Apparently, their species-specific adaptability to climatic and environmental conditions in the hill and mountain regions defines the highest altitudinal ranges of their distribution. With the decrease in elevation, number of native species decreased while number of exotic species increased, suggesting the presence of species shift from native forms to exotic forms in the earthworm communities, and the shift was higher at low elevations than at high elevations.

---

\* This paper was presented at "International symposium on impacts of soil biodiversity on biogeochemical processes in ecosystems & workshop on molecular methods in soil biological and biochemical diversity in terrestrial ecosystems" held in Taipei, Taiwan, April 18-24, 2004.

## 摘 要

自1999年至2000年於中央山脈西側集集至合歡山區以及2003年於集集至大肚溪口共採得34種蚯蚓，其中特有種19種、外來種15種。特有種在海拔高度上有其特定之分布上下限，形成不同物種垂直分層的現象；外來種則自平地至山區皆有分布，僅分布上限因物種而有所不同。高海拔處之特有性較低海拔處為高。海拔高度下降，則蚯蚓特有種數隨之減少，而外來種數隨之增加，顯見物種組成有自特有種轉換成外來種之趨勢，此趨勢又以低海拔處較高海拔處明顯。

**Key words :** earthworm, native species, exotic species, species diversity, elevation

**關鍵詞 :** 蚯蚓、特有種、外來種、物種多樣性、海拔

Received: February 13, 2004

Accepted: April 12, 2004

收件日期：93年2月13日

接受日期：93年4月12日

## Introduction

Megascolecid earthworms are one of the dominant terrestrial macro-invertebrates in the eastern and southeastern Asia, and their altitudinal distributions have been reported sporadically. The highest elevation that has been recorded so far is for *Amyntas asiaticus* (Michaelsen), which occurs at 3,415 to 4,268m in Tibet (Michaelsen 1902). It is followed in decreasing order by *Amyntas corticis* (Kinberg) at 3,659m in Sichuan of China (Gates 1972); *Perionyx hingstoni* Stephenson at 3,354m at Mt. Everest (Stephenson 1925); *Amyntas wulinensis* Tsai, Shen and Tsai and *Amyntas tessellatus* Shen, Tsai and Tsai at 3,200m at Mt. Hohuan of Taiwan (Tsai *et al.* 2001; Shen *et al.* 2002); *Amyntas omeimontis kinabalu* Sims and Easton and *Pheretima darnleiensis* (Fletcher) at 3,100m, and *Pheretima saba* Sims and Easton and

*Metapheretima elongata* (Perrier) at 2,750m at Mt. Kinabalu of Borneo (Sims and Easton 1972); *Metapheretima bulmeri* (Gates), *Amyntas kaironkensis* (Gates), and *Amyntas schraderi* (Gates) at 2,530 to 2,560m in New Guinea (Gates 1970); *Metaphire langbiangi* (Michaelsen) and *Amyntas dactylicus* (Chen) at 2,400m, respectively, in Vietnam (Michaelsen 1934) and at Mt. Omei in Sichuan of China (Chen 1946); and *Amyntas yamizoyamensis* (Ohfuchi) at 1,022m at Mt. Yamizo of Japan (Ohfuchi 1935). According to literature there is a decreasing trend in highest altitudinal ranges with the increase in latitude in the distribution of megascolecid earthworms in the eastern and southeastern Asia. Also, there are evidences of high endemism and altitudinal stratification in their distribution in highlands (Sims and Easton 1972).

Taiwan is an island situated between the

tropical zone and the subtropical zone in the western Pacific. The Central Mountain Range runs from north to south, and is cut deeply by valleys and mountain peaks of 3,000m to nearly 4,000m in elevation. It is the area of highly diverse habitat with rich flora and fauna, and homes of most of native animals. Prior to the 1970s most of the areas of the mountain range were not easily accessible to man, and earthworms that had been studied were only those collected from coastal plains and peripheral hills (Kobayashi 1938a, 1938b; Gates 1959; Tsai 1964). In the past few decades, cross-island highways were constructed across the mountain range, from where some earthworms have been reported (Chen and Shih 1996; Tsai *et al.* 1999, 2000b, 2000c, 2001, 2002, 2004; Shen *et al.* 2002, 2003b).

This study was intended to relate the distribution of terrestrial earthworms to elevations with respects to native and exotic species, and to determine their altitudinal stratification in the centro-western Taiwan.

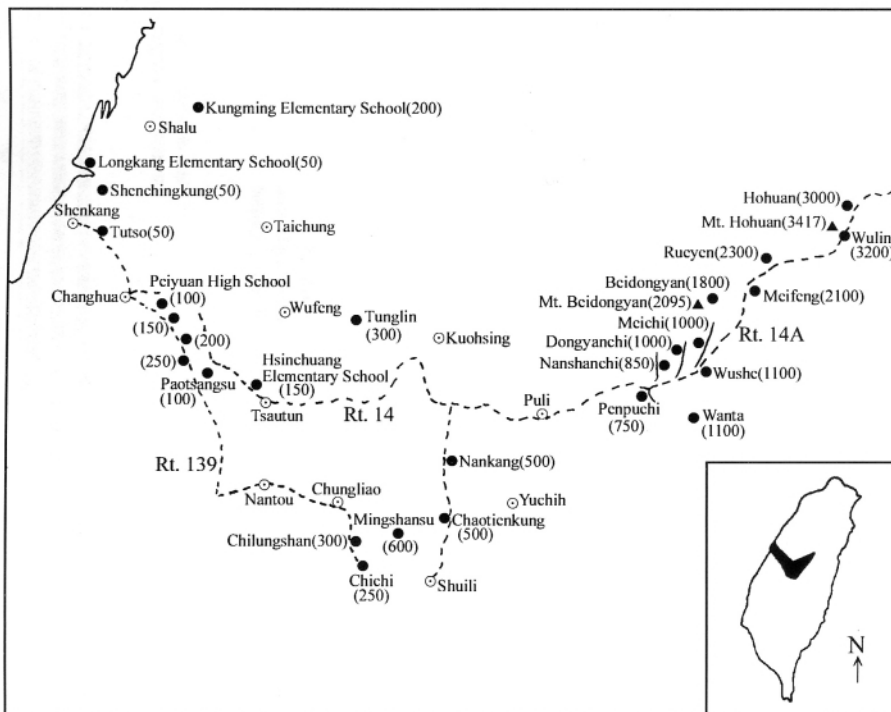
## Materials and Methods

In 1999 and 2000 we conducted earthworm surveys on the western slope of the Central Mountain Range and its peripheral hills from Chichi at 250m in elevation to the peak Wulin of Mt. Hohuan at 3,200m along Rt. 14 A in the central Taiwan (Tsai *et al.* 2001; Shen *et al.* 2003b). This highway was only primary road that reaches to Mt. Hohuan in the Nantou County. With its secondary mountain roads it was only place accessible for earthworm collection in the mountains. The earthworms were collected from mountain slopes wetted by

spring waters, and from the piles of soil and detritus at road sides and in roadside rainwater drainage ditches. The earthworms collected in the latter were those apparently washed down from the mountains by heavy rainwater, trapped in the ditches and aggregated in the piles of soils and detritus. They were easily collected and might be good representatives of the earthworm communities in the mountains above.

In 2003 we made another survey along Rts. 14 and 139 on the coastal plain from Chichi to the area around 50m in elevation near the mouth of the Tatu River flowing into the Taiwan Strait (Fig. 1). As there was no natural forest in the coastal plain, we collected earthworms on dry lands and drainage ditches in betel nut plantations, fruit orchards, bamboo plantations, schools, villages, and parks.

The coastal plain region was mostly flat farmlands (rice paddies, vegetable gardens, fruit orchards, bamboo plantations, and some betel nut plantations) at elevations of 50 to 200m. It was an area of intensive agricultural activities and human disturbances. The peripheral hill region was at elevations from 250 to 700m, and covered mostly by betel nut plantations, fruit orchards, and sparsely distributed broadleaf forests. The mountain region started from 700m in elevation at the east of Puli to 3,200m at the peak Wulin. The region was covered with mixing broadleaf and coniferous forests at lower elevations and coniferous forests and Yushan cane (*Yushania nitakayamensis* (Hayata)) forests at higher elevations, with sparsely distributed fruit orchards and vegetable gardens. The climates in the study area were subtropical condition in the coastal plain and the peripheral hills, warm temperate condition at low



**Fig. 1.** Localities of earthworm collections (solid circles) in the centro-western Taiwan (open circles with black center dots, urban centers; solid triangles, mountains; elevations in meter in parentheses).

elevations of the mountain range, and cold temperate condition with snowfall in winter at high elevations. The elevations were measured by an altimeter and corrected by a map with elevations. Earthworms collected were fixed in a 10% formalin-water solution for two days to a week, and then preserved in a 75% ethyl alcohol-water solution. Each individual was identified to species.

A native species is a species that occurs naturally in a restricted geographical area, and thus, it is certainly speciated locally and autochthonous (= endemic, indigenous) (Gates 1972). In contrast, an exotic species is a foreign species introduced to a particular geographical area. It is equivalent to a peregrine species, that

is a species of wide distribution in Michaelsen's term (Edwards and Bohlen 1996), but it is more commonly characterized as an anthropochorous species, defined as a species transported by humans, usually unintentionally (Gates 1972). In this study the native species is one that occurs only in Taiwan, while the exotic species is one that occurs not only in Taiwan but also in other parts of the world, particularly, in the neighboring Mainland China and Southeast Asia (Tsai *et al.* 2000a).

The number of species of earthworms collected at an elevation was used as a species-diversity indicator for that particular elevation. Its altitudinal trend was determined using the linear regression analysis for each of the three

groups of the earthworms: native species, exotic species, and total species (native + exotic). For each group, cumulative numbers of species were established with the increase in elevation. The numbers were converted to percent cumulative numbers and then to probits (Finney 1971). The probit-elevation regressive equation was established using the linear analysis. The constant and slope of the equation was compared among the three groups with the *t*-test (Zar 1984). For examining the changes in the earthworm community structure in relation to elevation, the similarity matrix was established at each of the elevations for total species, using Sorensen's similarity coefficient (S) (Krebs 1989). It was calculated with the formula  $S = 2a / (2a+b+c)$ , where a is the number of the same species occurring at the two elevations x and y, b is the number of species occurring only at elevation x, and c is the number of species only at elevation y. Based on the similarity coefficients, a dendrogram was established using UPGMA clustering (Everitt 1980).

## Results

A total of 2,163 specimens were collected from 43 collections at 27 localities and 17 elevations. They were consisted of 19 native species and 15 exotic species (Table 1). Their distributions in relation to elevations are shown in Fig. 2.

### Native species

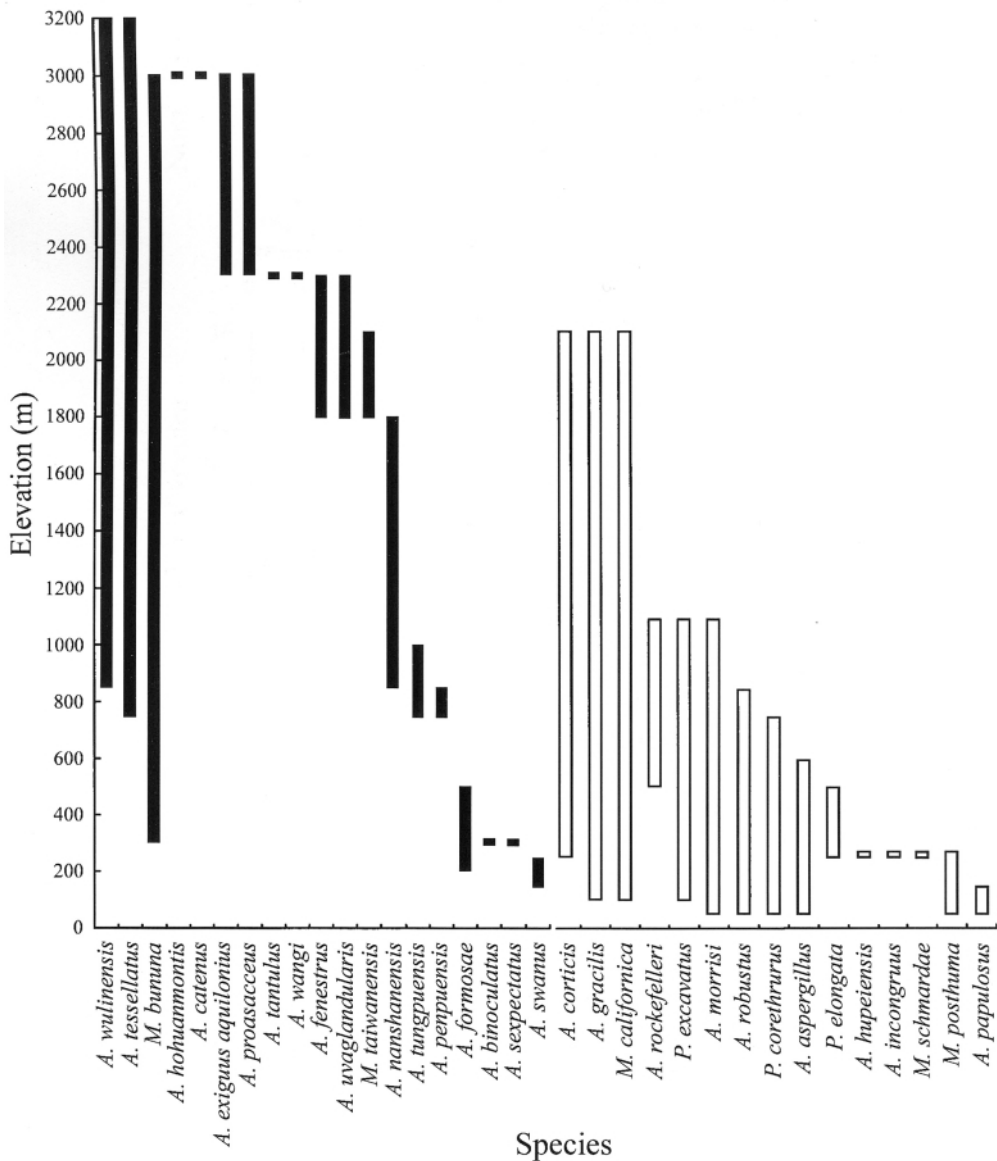
Native species were widely distributed from the coastal plain at 150m in elevation to the peak Wulin of Mt. Hohuan at 3,200m in the Central Mountain Range (Fig. 2). Each species occupied

a species-specific geographical area with the highest altitudinal range and the lowest altitudinal range, indicating the presence of altitudinal stratification in the distribution. According to the patterns of the altitudinal distribution, the native species were divided into five groups as follows:

Group 1: elevations 300 to 3,200m, common and widely distributed in the peripheral hills (subtropical climate) and the Central Mountain Range (warm and cold temperate climates). It was consisted of *Amyntas wulinensis* (Tsai *et al.* 2001), *Amyntas tessellatus* (Shen *et al.* 2002), and *Metaphire bununa* (Tsai *et al.* 2000b). *A. wulinensis* and *A. tessellatus* were found in elevations from 700-800 to 3,200m. They showed an increasing altitudinal cline in the characters of body length, segment number and setal numbers for the former species (Tsai *et al.* 2001), and of genital papillae and associated accessory glands for the latter species that had two distinct subspecies, *A. t. tessellatus* and *A. t. paucus*, at the boundary elevations of 1,000 to 1,100m (Shen *et al.* 2002). *M. bununa* was one of the large earthworms (86-352 mm in length) in the peripheral hills (300 to 600m) of Chungliao, Kuohsing, and Chichi. It was not found in the coastal plain and at the foot of the peripheral hills (250m) in Chichi, where large exotic *Amyntas aspergillus* (Perrier) was common. *M. bununa* made large piles of casts on roadsides, grasslands and woodlands, and was a common species of earthworm walking or killed on highways. At Mt. Hohuan it was a common dweller in the Yushan cane (*Yushania niitakayamensis* (Hayata)) forest. Although the number of specimens collected was small, they tended to show a V-shaped vertical cline in total

**Table 1.** Species and numbers of native and exotic megascolecid earthworms collected at 17 elevations in the centro-western Taiwan, 1999, 2000 and 2003

Species	Elevation(m)																Total	
	3200	3000	2300	2100	1800	1100	1000	850	750	600	500	300	250	200	150	100		50
<b>Native</b>																		
<i>A. wulinensis</i>	9			12	1			41										63
<i>A. tessellatus</i>	1	2	8		32	1	1	19	2									66
<i>M. bumuna</i>		15		6		2		1	10	13	1	6						54
<i>A. hohuanmontis</i>		8																8
<i>A. catenus</i>		12																12
<i>A. exiguus aquilonius</i>		2	10															12
<i>A. proasacceus</i>		25	2															27
<i>A. tantulus</i>			19															19
<i>A. wangi</i>			1															1
<i>A. fenestrus</i>			8		2													10
<i>A. uvaglandularis</i>			10	53	28													91
<i>M. taiwanensis</i>				1	2													3
<i>A. nanshanensis</i>					3			71										74
<i>A. tungpuensis</i>							8	13	1									22
<i>A. penpuensis</i>								12	34									46
<i>A. formosae</i>											1	5	5	2				13
<i>A. binoculatus</i>												1						1
<i>A. sexpectatus</i>												6						6
<i>A. swanus</i>													2		5			7
Number of species (N)	2	6	7	4	6	2	2	6	4	1	2	4	2	1	1	0	0	19
Number of individuals	10	64	58	72	68	3	9	157	47	13	2	18	7	2	5	0	0	535
<b>Exotic</b>																		
<i>A. corticis</i>				104	9	15	1					5	16	16				166
<i>A. gracilis</i>				9		35	6	2	37	49	27	58	75	2	1	9		310
<i>M. californica</i>				38		4			1	11		3	19		5	38		119
<i>A. rockefelleri</i>						1	1				2							4
<i>P. excavatus</i>						7				1		1	51	5		10		75
<i>A. morrisi</i>						1				1		3	1		5	4	4	19
<i>A. lautus</i>								7		6	8	1	19	3	4		6	54
<i>P. corethrurus</i>									1	55	11	136	455	2	22	38	4	724
<i>A. aspergillus</i>										4	7	23	15		5		2	56
<i>P. elongata</i>											1	15	30					46
<i>A. hupiensis</i>													1					1
<i>A. incongruus</i>													2					2
<i>M. schmardae</i>													3					3
<i>M. posthuma</i>													2		7		30	39
<i>A. papulosus</i>															1		9	10
Number of species (E)	0	0	0	3	1	6	3	2	3	7	7	9	13	4	8	5	6	15
Number of individuals	0	0	0	151	9	63	8	9	39	127	61	256	689	12	50	99	55	1628
<b>Total (N+E)</b>																		
Number of species	2	6	7	7	7	8	5	8	7	8	9	13	15	5	9	5	6	34
Number of individuals	10	64	58	223	77	66	17	166	86	140	63	274	696	14	55	99	55	2163
Number of localities	1	1	1	1	1	2	2	1	1	1	2	2	2	2	2	2	3	24
Number of collections	1	4	1	1	3	2	2	1	1	1	3	8	6	2	2	2	3	43



**Fig. 2.** Altitudinal ranges in distribution of the native species (solid columns) and the exotic species (open columns) of megascolecid earthworms in the centro-western Taiwan.

length and segment number: lowest at 1,100m and highest at 300-600m and 3,000m, while its setal number decreased with the increase in elevation (Table 2).

Group 2: elevations 2,300 to 3,200m in the

Central Mountain Range with cold temperate climate. It was consisted of *Amyntas hohuanmontis* (Tsai *et al.* 2002), *Amyntas catenus*, *Amyntas exiguus aquilonius*, and *Amyntas proasacceus* (Tsai *et al.* 2001). The

**Table 2.** Total length, segment number and setal number of *Metaphire bununa* at different elevations in the western slope of the Central Mountain Range of Taiwan

Elevation (m)	Specimen number	Total length (mm)	Segment number	Setal number		
				VII	XX	XVIII <sup>a</sup>
3000 (Hohuan)	15	196-286	103-154	79-112	82-111	10-21
2100 (Meifeng)	6	107-136	109-183	99-124	105-116	21-28
1100 (Wushe)	2	86-190	96-101	107-115	110-114	19-20
750 (Penpuchi)	10	202-246	128-182	100-104	91-107	20-26
300-600 (Chichi)	20	255-352	189-221	114-158	119-145	19-29

<sup>a</sup>Between male pores.

former two species occurred only at Mt. Hohuan (3,000m), while the latter two species were also found at the Rueyen Nature Reserve (2,300m).

Group 3: elevations 1,800 to 2,300m in the Central Mountain Range with warm temperate climate. It was composed of *Amyntas tantulus*, *Amyntas wangi*, *Amyntas fenestrus*, *Amyntas uvaglandularis* (Shen *et al.* 2003b), and *Metaphire taiwanensis* (Tsai *et al.* 2004). *A. fenestrus* and *A. uvaglandularis* were found from Mt. Beidongyan (1,800m) to Rueyen Nature Reserve (2,300m). They were small- to moderate-sized earthworms, living in grass roots or shallow soil on wet mountain slopes. *M. taiwanensis* was the largest megascolecoid earthworm in Taiwan with a size up to 860 mm in length. It was found only in the areas of Mt. Beidongyan and the National Taiwan University's High-Altitude Horticulture Experimental Station in Meifeng (2,100m). *A. tantulus* and *A. wangi* were collected only in the Rueyen Nature Reserve at an elevation of 2,300m, an intermediate in the distribution between Group 2 and Group 3.

Group 4: elevations 750 to 1,800m in the lower mountain region associated with warm

temperate climate and the upper hill region associated with subtropical climate. It was consisted of *Amyntas tungpuensis* (Tsai *et al.* 1999), *Amyntas penpuensis* and *Amyntas nanshanensis* (Shen *et al.* 2003b). *A. tungpuensis* was found on the mountain slopes along the Penpu Creek (750m), Nanshan Creek (850m) and Dongyan Creek (1,000m), and *A. penpuensis* along Penpu Creek and Nanshan Creek. *A. nanshanensis* was distributed comparatively widely from Nanshan Creek (850m) to Mt. Beidongyan (1,800m), an intermediate in the distribution between Group 3 and Group 4.

Group 5: elevations 150 to 500m associated with the subtropical climate of lower peripheral hills and the coastal plain. It was consisted of *Amyntas formosae* (Michaelsen), *Amyntas binoculatus* (Tsai *et al.* 1999), *Amyntas sexpectatus* (Tsai *et al.* 1999), and *Amyntas swanus* (Tsai 1964). *A. formosae* was a large earthworm like *M. bununa*, and widely distributed in the peripheral hills from Chiahsien of Kaohsiung (Michaelsen 1922) to Neihu of Taipei (= *Pheretima yushi* Tsai, 1964). *A. binoculatus* was found in Wufeng, Taichung at an elevation of 300m, and *A. sexpectatus* was

collected only at Chilungshan near Chungliao, Nantou (Tsai *et al.* 1999). Two specimens of *A. swanus* were collected at the plain area of Chichi and 5 specimens were from the plain near Tsautun, Nantou. Except *A. formosae* that was common, *A. binoculatus*, *A. sexpectatus* and *A. swanus* were extremely rare in the lower peripheral hills and the coastal plain. They may be considered as the endangered species at the edge of extinction.

### Exotic species

The exotic species differed greatly from the native species in their altitudinal distribution. They were common in the coastal plain (subtropical climate) and peripheral hills, and were found in the mountain range only up to an elevation of 2,100m (warm temperate climate). Altitudinal stratification in the distribution was found for the highest altitudinal ranges, but not for the lowest altitudinal ranges (Fig. 2). The above evidences suggest that the exotic species are coastal plain dwelling species and their highest altitudinal ranges in the distribution in Taiwan depend on their species-specific adaptability to altitudinal climates and environmental conditions in the Central Mountain Range and its adjacent peripheral hills.

The highest range of the altitudinal distribution of the exotic species was 2,100m for *Amyntas corticis* (Kinberg), *Amyntas gracilis* (Kinberg) and *Metaphire californica* (Kinberg). They were followed by *Amyntas rockefelleri* (Chen), *Perionyx excavatus* Perrier and *Amyntas morrisoni* (Beddard) at 1,100m, *Amyntas robustus* (Perrier) at 850m, *Pontoscolex corethrurus* (Müller) at 750m, *A. aspergillus* at 600m, and *Polypheretima elongata*

(Perrier) at 500m. *Amyntas hupeiensis* (Michaelsen), *Amyntas incongruus* (Chen), *Metaphire schmardae* (Horst), *Metaphire posthuma* (Vaillant), and *Amyntas papulosus* (Rosa) occurred only in the coastal plain at 250m or lower.

*A. corticis*, *A. gracilis* and *M. californica* were the most common farmland earthworms in the coastal plain, peripheral hills and the Central Mountain Range. *A. corticis* has been found at 2,134m at Mt. Everest (Stephenson 1925) and 3,659m in China (Gates 1972). It was common in the central China (= *Pheretima heterochaeta* (Michaelsen)) (Chen 1933) and in Japan as north as to Hokkaido (Easton 1981). *A. corticis* has been considered as a temperate species of Chinese origin (Tsai *et al.* 2000a). *A. gracilis* was found at 1,829m in the eastern Himalayas, and has been considered to evolve in the temperate zone (Gates 1972). The above three common exotic species share a fairly similar habitat requirement and adaptability to wide ranges of climatic conditions in the coastal plain, peripheral hill and mountain regions.

*A. rockefelleri* was found from Meichi and Wushe (950 to 1,100m) in the Central Mountain Range and the peripheral hills (500m) near Kuohsing. It has been reported from the plains of Hsinchu (Kobayashi 1938a, 1938b) and Taipei (Tsai 1964). Apparently, it is more or less a coastal plain dweller in the northern Taiwan but a hill and mountain dweller in the central Taiwan. In contrast to *A. rockefelleri*, *A. papulosus* was found from coastal plain near the Tatu Estuary to the plain near Tsautun, Nantou at an elevation of 150m (Table 1), but it was found in the mountain near Chiahhsien of Kaohsiung at an elevation of 400m (Michaelsen 1922). *A.*

*papulosus* is a hill-dwelling species in the southern Taiwan but a plain dweller in the central Taiwan. *A. rockefelleri* is a warm temperate species perhaps introduced from the central China (Shen *et al.* 2003a), while *A. papulosus* is a tropical species from Southeast Asia (Rosa 1896; Gates 1939).

*P. excavatus* was found from the plain area at an elevation of 100m to the hill and mountain regions at an elevation of 1,100m (Table 1). In Southeast Asia it is widely distributed from tropical lowlands to the Himalayas at elevations up to 2,744m (Gates 1972). *A. morrisoni* was found from the coastal plain near the Tatu Estuary to an elevation of 1,100m in the central Taiwan. It has been found at elevations up to 2,439m in Sichuan, China and at the sea level near Bombay, India to 1,982m in the Himalayas (Gates 1972).

*P. elongata* was found at 250 to 500m in the peripheral hill region of the central Taiwan. It was found at elevations of 1,650 to 2,750m at Mt. Kinabalu in the tropical Borneo (Sims and Easton 1972), from the sea level to 1,067m in Burma (Gates 1972), and on lowlands of the Riukiu islands (Ohfuchi 1956). Apparently, *P. elongata* is a tropical species originated from Southeast Asia (Gates 1972), and its altitudinal range decreases with the increase in latitude.

The remaining 7 species of the exotic species were commonly found in the coastal plain and the foot of its peripheral hills at elevations of 250m or lower. Like *A. corticis*, *A. gracilis* and *M. californica*, they are well known exotic (= peregrine) species associated with environments disturbed by human activities, such as banana plantations, betel nut plantations, fruit orchards, bamboo plantations, and city

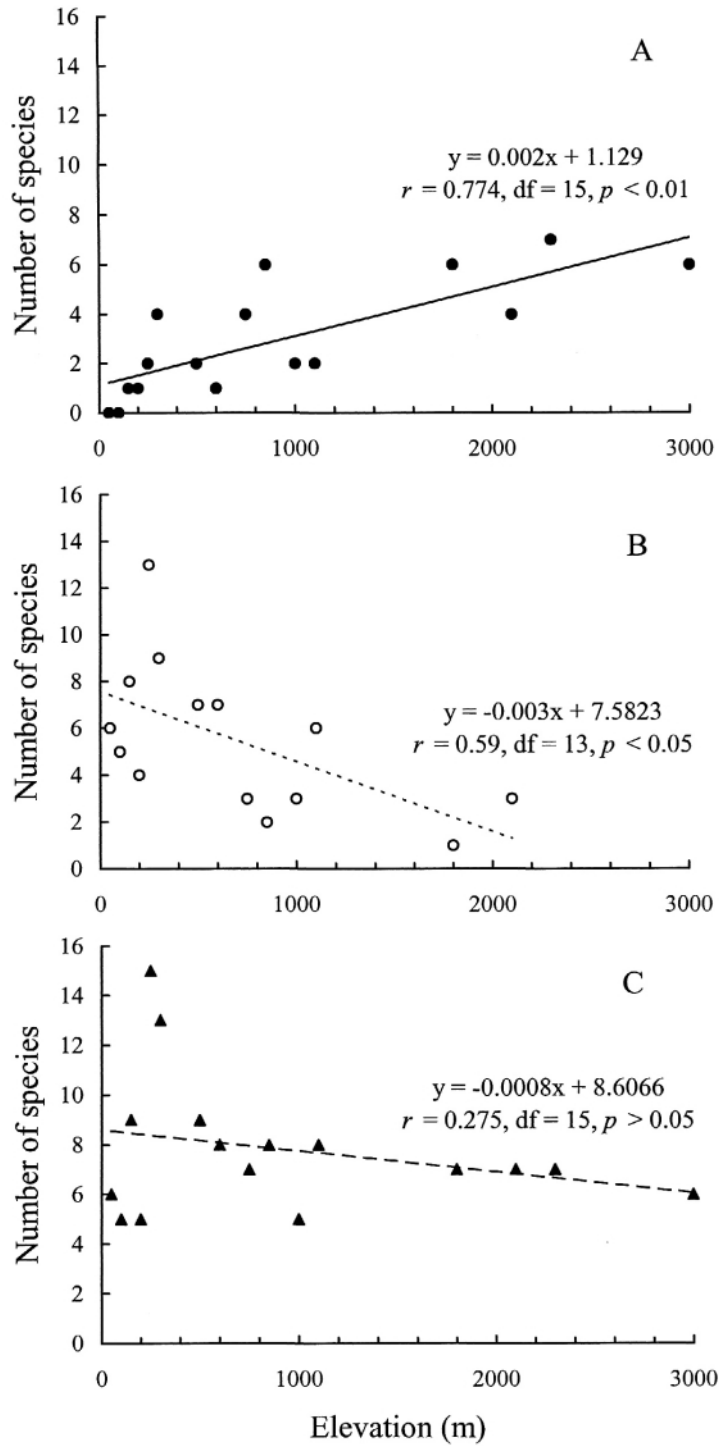
parks (Tsai *et al.* 2000a).

### Number of species

Native species were extremely rare in the coastal plain; only 2 species were found at 150 to 250m in elevations (Table 1). In the peripheral hills and the Central Mountain Range, the number of native species increased with elevation, and showed a significantly, positively linearly regressive relationship (Fig. 3A). The maximum number of 7 species was found at 2,300m. Apparently, there was high endemism of megascolecid earthworms in the Central Mountain Range at elevations of 1,800 to 3,000m.

In contrast to the native species, exotic species were fairly common in the coastal plain; a total of 9 species were collected at elevations of 200m and lower (Table 1). The maximum number of 13 species was found at 250m at the foot of the peripheral hills. With the increase in elevation in the hill and mountain regions, the number decreased to only 3 species at 2,100m. No exotic species were found at elevations at and above 2,300m. In contrast to the positively regressive relationship between the number of native species and elevation (Fig. 3A), the number of exotic species showed a significantly but negatively regressive relationship with elevation (Fig. 3B).

For the total species (native + exotic), the number showed a slightly but insignificantly negative regressive relationship to elevations (Fig. 3C). This suggested that there was a fairly constant number of 8.6 species in average of the earthworms at each elevation in the coastal plain, peripheral hills and Central Mountain Range in the central Taiwan.



**Fig. 3.** Relationships between the numbers of species and elevations for the native species (A), the exotic species (B), and the total species (native + exotic)(C) of megascolecid earthworms in the centro-western Taiwan.

**Table 3.** Probits converted from percentages of cumulative numbers of native species, exotic species and total species (native + exotic) of megascolecid earthworms at 17 elevations in the centro-western Taiwan

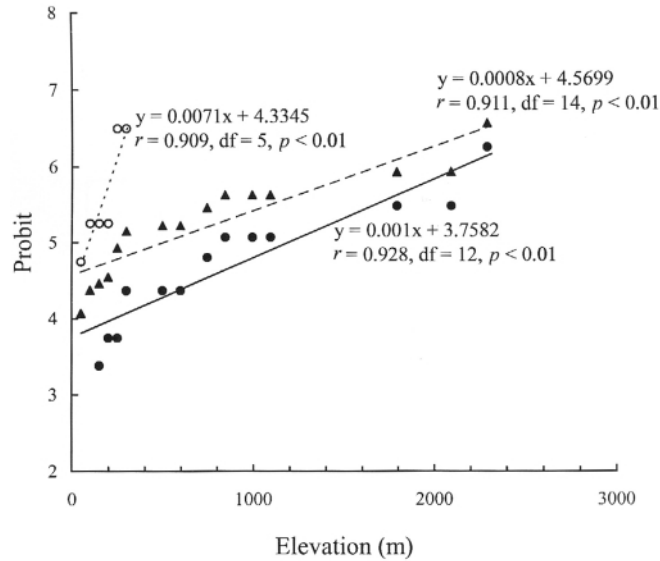
Species	Elevation (m)																
	50	100	150	200	250	300	500	600	750	850	1000	1100	1800	2100	2300	3000	3200
<b>Native</b>																	
Number	0	0	1	2	2	5	5	5	8	10	10	10	13	13	17	19	19
%	0	0	5.3	10.5	10.5	26.3	26.3	26.3	42.1	52.6	52.6	52.6	68.4	68.4	89.5	100	100
Probit	–	–	3.38	3.75	3.75	4.37	4.37	4.37	4.8	5.07	5.07	5.07	5.48	5.48	6.25	–	–
<b>Exotic</b>																	
Number	6	9	9	9	14	14	15	15	15	15	15	15	15	15	15	15	15
%	40	60	60	60	93.3	93.3	100	100	100	100	100	100	100	100	100	100	100
Probit	4.75	5.25	5.25	5.25	6.5	6.5	–	–	–	–	–	–	–	–	–	–	–
<b>Total (N+E)</b>																	
Number	6	9	10	11	16	19	20	20	23	25	25	25	28	28	32	34	34
%	17.6	26.5	29.4	32.4	47.1	55.9	58.8	58.8	67.6	73.5	73.5	73.5	82.4	82.4	94.1	100	100
Probit	4.07	4.37	4.46	4.54	4.93	5.15	5.22	5.22	5.46	5.63	5.63	5.63	5.93	5.93	6.56	–	–

### Cumulative number of species

Probits of the percent cumulative numbers of native species, exotic species and total species are shown in Table 3. For each of the three groups, the probit showed a positively, linearly regressive relationship to elevation (Fig. 4). When the probit-elevation regressive equations were compared between the native species and the exotic species, the exotic species had the constant of 4.3345 and the slope of 0.0071, that were, respectively, significantly higher than 3.7582 ( $t$ -value = 6.547,  $p < 0.01$ ) and 0.001 ( $t$ -value = 3.938,  $p < 0.01$ ) of the equation of the native species. These differences between the two equations suggested that the exotic species were highly dominant in the coastal plain and had more rapid increment in the number of species with the elevation in the coastal plain and the lower peripheral hills, while the native species were rare in the coastal plain and occurred in the entire hill and mountain regions with much slower increment rate in the number

of species.

The slope of the probit-elevation regressive equation of total species was 0.0008, that was significantly lower than 0.0071 of the exotic species ( $t$ -value = 4.280,  $p < 0.01$ ), but not significantly different from 0.001 of the native species ( $t$ -value = 0.0005,  $p > 0.05$ ). At the same time the constant of the equation of the total species was 4.5699 that was significantly higher but closer to 4.3345 of the exotic species ( $t$ -value = 3.884,  $p < 0.01$ ) than 3.7582 of the native species ( $t$ -value = 5.573,  $p < 0.01$ ) (Fig. 4). In other words the total species that represents earthworm community had the equation with the constant closer to that of exotic species but with the slope similar to that of native species. These facts suggest that the changes in the earthworm community with elevation in terms of the increment in cumulative number of species was strongly affected by exotic species in the coastal plain but by native species in the hill and mountain regions.



**Fig. 4.** Probit-elevation relationships for the native species (solid circles and solid line), the exotic species (open circles and dotted line), and the total species (native + exotic, solid triangles and dashed line) of megascolecid earthworms in the centro-western Taiwan.

**Table 4.** A matrix of Sorensen's similarity coefficients among the megascolecid earthworm communities at 17 elevations in the centro-western Taiwan

Elevation (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3200	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3000	0.250	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2300	0.222	0.462	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2100	0.222	0.154	0.143	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-
1800	0.444	0.154	0.429	0.571	1.000	-	-	-	-	-	-	-	-	-	-	-	-
1100	0.200	0.286	0.133	0.533	0.267	1.000	-	-	-	-	-	-	-	-	-	-	-
1000	0.286	0.182	0.167	0.333	0.333	0.615	1.000	-	-	-	-	-	-	-	-	-	-
850	0.400	0.286	0.133	0.400	0.400	0.375	0.462	1.000	-	-	-	-	-	-	-	-	-
750	0.222	0.308	0.143	0.429	0.143	0.533	0.500	0.667	1.000	-	-	-	-	-	-	-	-
600	0.000	0.143	0.000	0.400	0.000	0.625	0.154	0.375	0.533	1.000	-	-	-	-	-	-	-
500	0.000	0.133	0.000	0.375	0.125	0.471	0.429	0.353	0.375	0.588	1.000	-	-	-	-	-	-
300	0.000	0.105	0.000	0.400	0.100	0.571	0.222	0.286	0.400	0.762	0.727	1.000	-	-	-	-	-
250	0.000	0.000	0.000	0.273	0.091	0.435	0.200	0.174	0.273	0.609	0.583	0.714	1.000	-	-	-	-
200	0.000	0.000	0.000	0.167	0.000	0.308	0.200	0.308	0.333	0.615	0.571	0.556	0.500	1.000	-	-	-
150	0.000	0.000	0.000	0.250	0.000	0.353	0.143	0.235	0.375	0.706	0.444	0.545	0.667	0.429	1.000	-	-
100	0.000	0.000	0.000	0.333	0.000	0.615	0.200	0.154	0.500	0.769	0.286	0.556	0.500	0.600	0.571	1.000	-
50	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.143	0.154	0.571	0.400	0.421	0.476	0.364	0.800	0.364	1.000

### Community structure

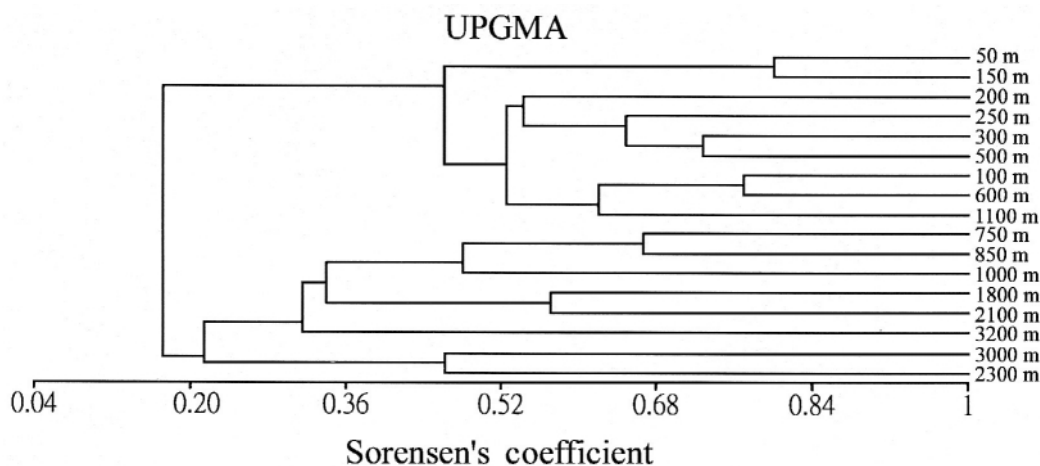
Sorensen's similarity coefficients expressing the levels of similarity in the community structure of the earthworms in terms of species composition among 17 elevations are shown in Table 4. The community structure at an elevation tended to show certain similarity with those of its neighboring or nearby elevations, but complete difference (coefficient = 0) from those at elevations of farther distances. For examples, the earthworm community at 3,200m in elevation had some similarity to those at 3,000 to 750m, but completely different from those at 600m and lower, while the community at 50m had some similarity to those at 100 to 1,100m, but completely different from those at 1,800m and higher. At 1,100m the community showed some similarity with those at all elevations above and below. There was a certain trend that the similarity in the earthworm community decreased with the increase in elevation.

A dendrogram expressing the result of the

cluster analysis based on Sorensen's similarity coefficients showed that the earthworm communities in the centro-western Taiwan were able to divide into two groups according to their altitudinal distributions (Fig. 5). They were the earthworm communities dominated by native species at high elevations of 750 to 3,200m in the Central Mountain Range, and the communities dominated by exotic species at low elevations of 50 to 1,100m in the coastal plain and peripheral hills.

### Discussion

The species of native earthworms were found only in Taiwan and thus, they were certainly speciated within the island. They were found in the Central Mountain Range and its peripheral hills, and rarely found in the coastal plain. Their distributions showed altitudinal stratification; each species had its own specific highest range and lowest range of elevation (Fig.



**Fig. 5.** A dendrogram based on the Sorensen's similarity coefficients among the earthworm communities at 17 elevations in the centro-western Taiwan.

2). Apparently, climatic and environmental conditions associated with elevations define the distribution ranges of the native species, and are one of the important factors for their autochthonous speciation.

The distribution pattern of the exotic species differed greatly from that of the native species (Fig. 2). They are anthropochorous, and likely originated primarily from the southern China and Southeast Asia (Tsai *et al.* 2000a). Apparently, most of them were accidentally introduced to Taiwan with soils and roots of plants brought from abroad. It is reasonable to speculate that they first populated in disturbed lands (farmlands) associated with the human settlements in the coastal plain, and then gradually spread into the peripheral hill and mountain regions along with expansion of human activities, particularly agriculture and horticulture. The highest elevations for their dispersion reached to the elevation of 2,100m, and differed among the species, depending on their adaptability to mountain environments, such as climatic, soil and biotic conditions.

The presence of a positive trend for the native species, a negative trend for the exotic species, but the neutral trend for the total species in the number-elevation relationship equations (Fig. 3) suggested that there was a shift from native species to exotic species in the earthworm communities with the decrease in elevation. The shift was higher at lower elevations than higher elevations. In other words the introduction of exotic species to Taiwan caused the replacement of native species by exotic species rather than the addition of exotic species to the native species for Taiwan's earthworm fauna.

According to the probit-elevation

relationship equations (Fig. 4), the cumulative number of the exotic species was estimated to reach to 100% (probit = 10) at an elevation of 798m. In other words, all species of the exotic earthworms were found in the coastal plain and peripheral hills, and thus, those found in the Central Mountain Range were merely an expansion of their distribution (Fig. 2). For the native species the cumulative number to reach to 100% was estimated at an elevation of 6,242m. As the highest peak in the Central Mountain Range is Mt. Yushan of 3,952m, it is predicted that megascolecid earthworms may occur in the entire Central Mountain Range in Taiwan.

Native species have lived in natural environments for their evolutionary history. Each of the species has developed its own particular ranges of habitat and environment requirements that were expressed as their altitudinal stratification in distribution in this study. It is reasonable to speculate that the entire island of Taiwan was once covered with tropical forests prior to the massive immigration of Chinese a few centuries ago, and thus, the native earthworms are woodland earthworms. When the woodlands were converted to farmlands, the natural habitat was destroyed, resulting in the extinction of the native earthworms, while the farmlands became favorable places for propagation of exotic species, which are the so-called farmland earthworms. Therefore, the species shift from native species to exotic species found in this study is attributable primarily to the replacement of natural woodland habitat to farmland habitat. Furthermore, intensive use of insecticides and herbicides is another factor contributing to the present scarcity of earthworms in many parts of the island,

particularly in the coastal plain.

## Acknowledgements

We are grateful to Ms. C. H. Hsieh, a teacher of Hsinchuang Elementary School, who collected earthworms in Hsinchuang and Kungming elementary schools, and Messrs. R. C. Jang, H. P. Chen, J. W. Luo, M. H. Shen, J. L. Lai, T. J. Lin, C. Y. Chang, C. T. Yao, and P. H. Ho who assisted in field collections.

## Literature Cited

- Chen, J. H. and H. T. Shih. 1996. A preliminary study of earthworms in Fushan Botanical Garden. *Chinese Bioscience* 39: 52-59. (in Chinese)
- Chen, Y. 1933. A preliminary survey of the earthworms of the lower Yangtze Valley. *Contributions from the Biological Laboratory of the Science Society of China (Zoology)* 9: 177-295.
- Chen, Y. 1946. On the terrestrial oligochaeta from Szechwan III. *Journal of the West China Border Research Society* 16: 83-141.
- Easton, E. G. 1981. Japanese earthworms: A synopsis of the megadrile species (Oligochaeta). *Bulletin of the British Museum of Natural History (Zoology)* 40: 33-65.
- Edwards, C. A. and P. J. Bohlen. 1996. *Biology and ecology of earthworms*. 3<sup>rd</sup> edition. Chapman and Hall, New York.
- Everitt, B. 1980. *Cluster analysis*. 2<sup>nd</sup> edition. Gower Publishing Co., Hampshire.
- Finney, D. J. 1971. *Probit analysis*. 3<sup>rd</sup> edition. Cambridge University Press, London.
- Gates, G. E. 1939. Thai earthworms. *The Journal of the Thailand Research Society* 12: 65-114.
- Gates, G. E. 1959. On some earthworms from Taiwan. *American Museum Novitates* 1941: 1-19.
- Gates, G. E. 1970. On some New Guinea earthworms. *Australian Zoologist* 15(3): 386-390.
- Gates, G. E. 1972. Burmese earthworms: An introduction to the systematics and biology of megadrile oligochaetes with special reference to Southeast Asia. *Transactions of the American Philosophical Society* 62(7): 1-326.
- Kobayashi, S. 1938a. Earthworms found in Shinchiku, Formosa I. *Zoological Magazine (Tokyo)* 51: 659-660. (in Japanese)
- Kobayashi, S. 1938b. Earthworms found in Shinchiku, Formosa II. *Zoological Magazine (Tokyo)* 51: 777-779. (in Japanese)
- Krebs, C. J. 1989. *Ecological methodology*. Harper Row, New York.
- Michaelsen, W. 1902. Neue Oligochaeten und neue Fundorte alt-bekannter. *Jahrbuch der Hamburgischen Wissenschaftlichen Anstalten* 19: 1-54.
- Michaelsen, W. 1922. Oligochäten aus dem Rijks Museum van Natuurlijke Historie zu Leiden. *Capita Zoologica* 1: 1-67.
- Michaelsen, W. 1934. Oligochäten von Französisch-Indochina. *Archives de Zoologie Experimentale et Generale* 76: 493-546.
- Ohfuchi, S. 1935. On some new species of earthworms from north-eastern Hondo, Japan. *Science Report of the Tohoku University* 10: 409-415.
- Ohfuchi, S. 1956. On a collection of the

- terrestrial Oligochaeta obtained from the various localities in Riu-kiu Islands, together with the consideration of their geographical distribution (Part I). *Journal of Agricultural Science Tokyo Nogyo Daigaku* 3: 131-176.
- Rosa, D. 1896. I Lombrichi raccolti a Sumatra dal Dott. Elio Modigliani. *Annali del Museo Civico di Storia Naturale di Genova Serie 2.<sup>a</sup>* 16: 502-532.
- Shen, H. P., C. F. Tsai and S. C. Tsai. 2002. Description of a new earthworm belonging to the genus *Amyntas* (Oligochaeta: Megascolecidae) from Taiwan and its infraspecific variation in relation to elevation. *The Raffles Bulletin of Zoology* 50(1): 1-8.
- Shen, H. P., C. F. Tsai and S. C. Tsai. 2003a. *Amyntas hsinpuensis* (Kuo, 1995) as a synonym of *Amyntas rockefelleri* (Chen, 1933) (Megascolecidae: Oligochaeta). *Endemic Species Research* 5(1): 41-44.
- Shen, H. P., C. F. Tsai and S. C. Tsai. 2003b. Six new earthworms of the genus *Amyntas* (Oligochaeta: Megascolecidae) from central Taiwan. *Zoological Studies* 42(4): 479-490.
- Sims, R. W. and E. G. Easton. 1972. A numerical revision of the earthworm genus *Pheretima* auct. (Megascolecidae: Oligochaeta) with the recognition of new genera and an appendix on the earthworms collected by the Royal Society North Borneo Expedition. *Biological Journal of the Linnean Society* 4: 169-268.
- Stephenson, J. 1925. Oligochaeta from various regions, including those collected by the Mount Everest Expedition 1924. *Proceedings of the Zoological Society of London* 1925: 879-907.
- Tsai, C. F. 1964. On some earthworms belonging to the genus *Pheretima* Kinberg collected from Taipei area in north Taiwan. *Quarterly Journal of the Taiwan Museum* 17: 1-35.
- Tsai, C. F., H. P. Shen and S. C. Tsai. 1999. On some new species of the pheretimoid earthworms (Oligochaeta: Megascolecidae) from Taiwan. *Journal of the National Taiwan Museum* 52(2): 33-46.
- Tsai, C. F., H. P. Shen and S. C. Tsai. 2000a. Native and exotic species of terrestrial earthworms (Oligochaeta) in Taiwan with reference to Northeast Asia. *Zoological Studies* 39(4): 285-294.
- Tsai, C. F., S. C. Tsai and G. J. Liaw. 2000b. Two new species of protandric pheretimoid earthworms belonging to the genus *Metaphire* (Megascolecidae: Oligochaeta) from Taiwan. *Journal of Natural History* 34: 1731-1741.
- Tsai, S. C., H. P. Shen and C. F. Tsai. 2000c. A new pheretimoid earthworm with latero-dorsal genital papillae. *Journal of the National Taiwan Museum* 53: 7-13.
- Tsai, C. F., H. P. Shen and S. C. Tsai. 2001. Some new earthworms of the genus *Amyntas* (Oligochaeta: Megascolecidae) from Mt. Hohuan of Taiwan. *Zoological Studies* 40(4): 276-288.
- Tsai, C. F., H. P. Shen and S. C. Tsai. 2002. A new athecate earthworm of the genus *Amyntas* Kinberg (Megascolecidae: Oligochaeta) from Taiwan with discussion on phylogeny and biogeography of the *A. illotus* species-group. *Journal of Natural History* 36: 757-765.
- Tsai, C. F., S. C. Tsai and H. P. Shen. 2004. A

new gigantic earthworm of the genus *Metaphire* Sims and Easton (Megascolecidae: Oligochaeta) from Taiwan with reference to evolutionary trends in body sizes and segment numbers of the *Pheretima* genus-group. *Journal of Natural History* 38(7): 877-887.

Zar, J. H. 1984. *Biostatistical analysis*. 2<sup>nd</sup> edition. Prentice-Hall, Inc., New Jersey.