Four new species of terrestrial earthworms belonging to the genus *Amynthas* (Megascolecidae: Oligochaeta) from Taiwan with discussion on speculative synonyms and species delimitation in oligochaete taxonomy

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Abstract

This paper describes four new species of earthworms, *Amynthas shinanmontis* sp. nov., *Amynthas chilanensis* sp. nov., *Amynthas bilineatus* sp. nov., and *Amynthas cruxus* sp. nov. from Taiwan. *Amynthas shinanmontis* is sexthecate and parthenogenetic with individuals with various levels of degeneration of spermathecae and male reproductive organs. It occurs at elevations of 1700–2700 m in the Central Mountain Range in southern Taiwan. *Amynthas bilineatus* and *A. chilanensis* are athecate and also parthenogenetic. They occur, respectively, at elevations of 1000 m in the central region and 1325 m in the northeastern region of Taiwan. *Amynthas cruxus* is octothecate, amphimictic, and occurs at elevations of 900–1700 m in southern Taiwan. This paper also discusses confusion and dilemma caused by uncertain, speculative synonyms and parthenogenetic morphs in species delimitation in oligochaete taxonomy, and recommends the use of absolute synonyms and phylogenetic species concept.

Keywords: Oligochaeta, Megascolecidae, Amynthas, earthworm, new species, Taiwan, taxonomy

Introduction

Since Goto and Hatai (1898) described two species of earthworms over a century ago, megadrile oligochaetes in Taiwan have been continuously investigated, but particularly intensively in the past 15 years (Michaelsen 1922; Kobayashi 1938, 1939a, 1939b; Gates 1959; Tsai 1964; Kuo 1995; Shih et al. 1999; Tsai CF et al. 1999, 2000a, 2000b, 2000c, 2001, 2002, 2003, 2004a, 2004b; Tsai SC et al. 2000; Chuang and Chen 2002; Shen and Tsai, 2002a, 2002b, 2007; Shen et al. 2002, 2003, 2005a, 2005b; Chen and Chuang 2003; Chang and Chen 2004, 2005a, 2005b; James et al. 2005). The number of nominal species and subspecies that contributed to the earthworm fauna (natural constituents of earthworm biodiversity) of Taiwan has increased to 65 species. This paper describes four additional new species, *Amynthas shinanmontis* sp. nov., *Amynthas chilanensis* sp. nov., *Amynthas
bilineatus sp. nov., and Amynthas cruxus sp. nov. from Taiwan. The earthworms collected were anaesthetized in 10% ethyl alcohol–water solution, fixed in 10% formalin–water solution, and preserved in 75% ethyl alcohol–water solution. They are deposited at the Taiwan Endemic Species Research Institute, Chichi, Nantou, Taiwan. This paper also discusses confusion and dilemma for species delimitation of parthenogenetic morphs and by uncertain, speculative synonyms (with question marks) in oligochaete taxonomy.

**Amynthas shinanmontis** Tsai and Shen, sp. nov. (Figure 1)

Figure 1. *Amynthas shinanmontis* sp. nov. (A) Ventral view of right male pore region (p, male porophore); (B) dorsal view of spermathecae of a 110-mm specimen (coll. no. 2000-77-Shen) (amp, ampulla; dv, diverticulum); (C) dorso-lateral view of right testis sacs (ts) and seminal vesicles (sv) of a 178-mm specimen (coll. no. 2000-21-Shen) (dl, dorsal lobe; vd, vas deferens; ve, vas efferens); (D) dorso-lateral view of right testis sacs and seminal vesicles of holotype; (E) large prostate gland (pg) of a 106-mm specimen (coll. no. 2000-77-Shen) (pd, prostatic duct); (F) vestigial prostate gland of a 178-mm specimen (coll. no. 2000-21-Shen); (G) nodule-like prostate gland of a 110-mm specimen (coll. no. 2000-77-Shen); (H) prostate gland absent for a 122-mm specimen (coll. no. 2000-21-Shen).
Type material

Holotype: a clitellate (mature) specimen (dissected) collected 16 June 1999 at Mt Shinan (elevation 2000 m) along Shihshan Forest Road in natural forest near the Middle Altitude Experimental Station, Taiwan Endemic Species Research Institute, Kaohsiung County by C. F. Tsai, S. C. Tsai, R. C. Jang, and S. T. Chang (coll. no. 1999-2-Shen). Paratypes: two clitellates (dissected) collected 25 October 2000 at the same mountain road (elevation 1700 m) where holotype was collected by H. P. Shen, S. T. Chang, H. P. Yang, and C. Y. Chang (coll. no. 2000-75-Shen).

Other material

Seven clitellates (three dissected) and 11 aclitellates collected 15 March 2000 along Rt 20 (elevation 2500 m) near Kuaigu, Kaohsiung County by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Shen, S. T. Chang, H. P. Yang, and T. J. Lin (coll. no. 2000-19-Shen); seven clitellates (two dissected) collected 15 March 2000 along Rt 20 near Takuanshan Tunnel (elevation 2700 m) in Kaohsiung County near the border with Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Shen, S. T. Chang, H. P. Yang, and T. J. Lin (coll. no. 2000-20-Shen); five clitellates (two dissected) collected 15 March 2000 from Yakou, Taitung County (elevation 2700 m) by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Shen, S. T. Chang, H. P. Yang, and T. J. Lin (coll. no. 2000-21-Shen); four clitellates (all dissected) and two aclitellates collected 15 March 2000 from Hsiangyang (elevation 2100–2300 m), Taitung County by C. F. Tsai, S. C. Tsai, H. S. Fang, H. P. Shen, S. T. Chang, H. P. Yang, and T. J. Lin (coll. no. 2000-22-Shen); four clitellates (one dissected) collected 25 October 2000 along Shihshan Forest Road in natural forest (elevation 2100 m) near the Middle Altitude Experimental Station, Taiwan Endemic Species Research Institute, Kaohsiung County by H. P. Shen, S. T. Chang, H. P. Yang, and C. Y. Chang (coll. no. 2000-72-Shen); 13 clitellates (five dissected) and seven aclitellates collected 26 October 2000 along a forest road in the Chuyunshan Nature Reserve (elevation 2150 m) in Kaohsiung County near the border with Taitung County by H. P. Shen, S. T. Chang, H. P. Yang, and C. Y. Chang (coll. no. 2000-77-Shen); four clitellates collected 26 October 2000 along a forest road in the Chuyunshan Nature Reserve (elevation 1850 m) in Kaohsiung County near the border with Taitung County by H. P. Shen, S. T. Chang, H. P. Yang, and C. Y. Chang (coll. no. 2000-78-Shen).

Diagnosis

Medium earthworm; length (clitellates) 86–187 mm, segments numbering 75–114. Setae 31–43 in VII, 38–55 in XX, 6–11 between male pores. Spermathecal pores invisible. Male pores 0.20–0.28 body circumferences ventrally apart; each on an oval or round papilla-like or disc-like porophore, surrounded by three to five skin folds, often with a horizontal groove anteriorly, so that it looks like an eye. Spermathecae three pairs to absent; normal (large) size to nodule. Prostate glands paired and normal size to absent. Seminal vesicles two pairs, normal size to nodule. Genital papillae and accessory glands absent. Parthenogenetic.

External characters

Total length (clitellates) 86–187 mm. Clitellum length 1.74–5.27 mm and width 2.53–5.19 mm. Prostomium epilobous. Segments numbering 75–114. Setae minute, 31–43 in
VII, 38–55 in XX, and 6–11 between male pores in XVIII. First dorsal pore in 11/12–13/14. Spermathecal pores invisible externally. Female pore single, medio-ventral in XIV.

Male pores paired in XVIII, ventro-lateral, 0.20–0.28 body circumferences ventrally apart; each on an oval or round papilla-like or disc-like porophore, surrounded by three to five oval skin folds, often with a horizontal groove anteriorly, so that it looks like an eye (Figure 1A). Genital papillae absent in both preclitellar and postclitellar regions. Preserved specimens greyish brown on head and dorsum, dark grey on mid-dorsum, and light brown on ventrum. Clitellum light to dark grey in colour.

**Internal characters**

Septa 5/6–7/8 and 10/11–13/14 thickened, 8/9/10 missing. Nephridial tufts thick, on anterior faces of 5/6/7 septa. Gizzard large in IX–X. Oesophageal hearts enlarged in XI–XIII. Intestine starting enlarged in XV or XVI. Intestinal caeca paired in XXVII, simple, slender, extending anteriorly to XXII–XXV.

Spermathecae varied in number from three pairs (sextethecate) to absent (atheteate). For 20 clitellate specimens dissected, three pairs in VI–VIII for four specimens and one of them with degenerated spermathecae in VIII (Figure 1B); three spermathecae on one side in VI–VIII and a single one on the other side in VI or VII for three specimens; two in each of VI, VII and VII, VIII for one specimen; one pair in VI for one specimen; single one in VII for one specimen; and completely absent for 10 specimens (Table I). Sizes and structure of spermathecae also varied from large (normal), vestigial, nodule to absent: large spermatheca with a peach-shaped ampulla with a very short, stout stalk or almost no stalk, and a diverticulum with a small, oval-shaped seminal chamber and a slender stalk (Figure 1B); vestigial spermatheca with a small degenerated ampulla and stalk, and no diverticulum; nodule-like spermatheca with a small, degenerated ampulla without stalk and no diverticulum.

Holandry: testis sacs small, two pairs in X and XI or both in XI. Vas efferens connected in XII or XIII in each side to form a large, straight vas deferens and then to prostatic duct in XVIII. Seminal vesicles two pairs in XI and XII, variable in size: large (normal) seminal vesicle with pink, follicular surface, and a small, reddish brown dorsal lobe, occupying an entire segmental compartment (Figure 1C); medium vesicle with highly folliculated surface and a large dorsal lobe, occupying about half of the segmental compartment (Figure 1D); vestigial vesicle and its dorsal lobe highly folliculated, occupying less than half of the compartment; and nodule-like vesicle, a small, irregular nodule without dorsal lobe. For 20 specimens dissected, large seminal vesicles for 12 specimens, medium for two specimens, vestigial for five specimens, and one specimen with large seminal vesicles on one side and medium on the other side (Table I).

Prostate glands also variable in size from normal to absent (aprostastic) (Table I): normal in XVI–XVIII for two specimens (Figure 1E), vestigial only in XVIII or XVII to XVIII for three specimens (Figure 1F), nodule-like for 12 specimens (Figure 1G), and absent for three specimens (Figure 1H). Prostatic duct thick, swollen, U-shaped or coiled (Figure 1E–H). One of the aprostastic paratypes has no left prostatic duct and left male porophore. Accessory glands absent in both preclitellar and postclitellar regions.

**Etymology**

The name *shinanmontis* is given to this species with reference to its type locality (elevation 2000 m) at Mt Shinan in southern Taiwan.
Amynthas shinanmontis sp. nov. is a parthenogenetic earthworm, consisting of individuals that have a continuous spectrum in degeneration of spermathecae and male reproductive organs (prostate glands, prostatic ducts, and seminal vesicles) (Table I). Most of the specimens examined have certain levels of degeneration of at least one of the organs. It is reasonable to consider that the specimens of A. shinanmontis studied are I₄ morph, an intermediate between Hp morph (with full reproductive organs but parthenogenetic) to ARZ morph (athecate, anarsenosomphic, and lacking all male reproductive organs) (Gates 1956, 1972). The rates of the degeneration vary among organs and also among individuals. Some of the individuals degenerated to or over A morph (athecate), R morph (aprostatic and no male terminalia), or AR morph (athecate and no male terminalia), but none reached ARZ morph. Generally, the rate of degeneration is faster for spermathecae (10 of 20 specimens, athecate) than that of prostate glands (three specimens, aprostatic). Seminal vesicles have the slowest rate of degeneration (all specimens with seminal vesicles). For spermathecae, the degeneration is faster for those in VIII than VII and VI, and those in VI are the final ones to be lost.

Table I. Individual variations in number of spermathecae and size of prostate glands and seminal vesicles of dissected specimens of Amynthas shinanmontis sp. nov.

| Specimens                   | Spermathecae | Prostate glands | Seminal vesicles |
|-----------------------------|--------------|----------------|------------------|
|                             | Left | Right | Left | Right | Left | Right |
| Coll. no. 1999-2-Shen       |      |       | Vestigial | Vestigial | Vestigial | Vestigial |
| 1 (holotype)                | 0    | 0     | Vestigial | Vestigial | Vestigial | Vestigial |
| Coll. no. 2000-75-Shen      |      |       | Absent     | Absent      | Vestigial | Vestigial |
| 2 (paratype)                | 0    | 0     | Vestigial | Vestigial | Vestigial | Vestigial |
| Coll. no. 2000-72-Shen      | 0    | 0     | Absent     | Absent      | Vestigial | Vestigial |
| Coll. no. 2000-77-Shen      | 0    | 0     | Vestigial | Vestigial | Vestigial | Vestigial |
| 5                            | 3    | (VI–VIII) | 3 (VI–VIII) | Nodule | Nodule | Large | Large |
| 6                            | 3    | (VI–VIII) | 3 (VI–VIII) | Normal | Normal | Large | Large |
| 7                            | 3    | (VI–VIII) | 3 (VI–VIII) | Nodule | Nodule | Large | Large |
| 8                            | 3    | (VI–VIII) | 1 (VII) | Nodule | Nodule | Large | Large |
| 9                            | 3    | (VI–VIII) | 3 (VI–VIII) | Vestigial | Vestigial | Large | Large |
| Coll. no. 2000-19-Shen      | 0    | 0     | Normal     | Normal      | Medium | Large |
| 10                           | 0    | 0     | Nodule | Nodule | Large | Large |
| 11                           | 0    | 0     | Nodule | Nodule | Large | Large |
| 12                           | 0    | 0     | Nodule | Nodule | Large | Large |
| Coll. no. 2000-20-Shen      | 0    | 0     | Nodule | Nodule | Large | Large |
| 13                           | 0    | 0     | Nodule | Nodule | Large | Large |
| 14                           | 0    | 0     | Nodule | Nodule | Large | Large |
| Coll. no. 2000-21-Shen      | 0    | 0     | Vestigial | Vestigial | Large | Large |
| 15                           | 2    | (VI–VII) | 2 (VII–VIII) | Nodule | Nodule | Large | Large |
| 16                           | 0    | 0     | Vestigial | Vestigial | Large | Large |
| Coll. no. 2000-22-Shen      | 0    | 0     | Nodule | Nodule | Medium | Medium |
| 17                           | 1    | (VII) | Nodule | Nodule | Vestigial | Vestigial |
| 18                           | 3    | (VI–VIII) | 1 (VI) | Absent | Absent | Medium | Medium |
| 19                           | 3    | (VI–VIII) | 1 (VI) | Nodule | Nodule | Medium | Medium |
| 20                           | 1    | (VI) | Nodule | Nodule | Vestigial | Vestigial |

ₐProstatic duct absent; ᵇspermathecae in VIII vestigial without diverticula; ᶜall spermatheca(c) vestigial without diverticulum(a); ᵈright seminal vesicle in XI vestigial; ᵉspermatheca in VIII with two ampullae and no diverticulum; ᶠdiverticulum vestigial.

Remarks

Amynthas shinanmontis sp. nov. is a parthenogenetic earthworm, consisting of individuals that have a continuous spectrum in degeneration of spermathecae and male reproductive organs (prostate glands, prostatic ducts, and seminal vesicles) (Table I). Most of the specimens examined have certain levels of degeneration of at least one of the organs. It is reasonable to consider that the specimens of A. shinanmontis studied are I₄ morph, an intermediate between Hp morph (with full reproductive organs but parthenogenetic) to ARZ morph (athecate, anarsenosomphic, and lacking all male reproductive organs) (Gates 1956, 1972). The rates of the degeneration vary among organs and also among individuals. Some of the individuals degenerated to or over A morph (athecate), R morph (aprostatic and no male terminalia), or AR morph (athecate and no male terminalia), but none reached ARZ morph. Generally, the rate of degeneration is faster for spermathecae (10 of 20 specimens, athecate) than that of prostate glands (three specimens, aprostatic). Seminal vesicles have the slowest rate of degeneration (all specimens with seminal vesicles). For spermathecae, the degeneration is faster for those in VIII than VII and VI, and those in VI are the final ones to be lost.
When all ancestral forms of spermathecae and male reproductive organs (Table I) are considered, it is reasonable to hypothesize that H morph (hermaphroditic bisexual form) is sexthecate earthworm with spermathecae in VI, VII, and VIII, belonging to the *gracilis* (=*hawaiyanus*) species-group of the genus *Amynthas* (Sims and Easton, 1972). However, which known species the H morph belongs to is unknown. *Amynthas shinanmontis* somewhat resembles *A. gracilis* (Kinberg, 1867), but they are easily distinguishable by genital papillae at the male pores: absent in *A. shinanmontis*, and one to several postsetal papillae arranged in one or two oblique rows medial to each of the male pores in *A. gracilis*. Also, the former is endemic while the latter is peregrine. According to Gates (1972), when the ancestral H morph is unknown, all parthenogenetic morphs that can be similarly linked (affiliated) together by intermediates (continuous changes) are considered as one species. For species delimitation of parthenogenetic morphs, see the discussion section.

*Amynthas chilanensis* Tsai and Tsai, sp. nov.  
(Figure 2)

**Type material**

Holotype: a clitellate specimen (168 mm, dissected) collected 17 October 2002 along the No. 100 Forest Road (elevation 1325 m), Chilan, Ilan County by C. F. Tsai, S. C. Tsai, H.

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Figure 2. *Amynthas chilanensis* sp. nov. (A) Ventral view of right male pore region (gp, genital papilla); (B) dorsal view of spermatheca in VI of holotype (amp, ampulla; dv, diverticulum); (C) dorso-lateral view of left testis sacs (ts) and seminal vesicles (sv) of a 133-mm specimen (coll. no. 2002-25-Shen) (dl, dorsal lobe; vd, vas deferens; ve, vas efferens); (D) dorsal view of right prostatic duct (pd) of a 133-mm specimen (coll. no. 2002-25-Shen).
Paratypes: a clitellate specimen (133 mm, dissected) and an aclitellate specimen (93 mm) (same collection data as holotype).

**Diagnosis**

Medium earthworm; length (clitellates) 133–168 mm, segments numbering 88–116. Setae 32–35 in VII, 47–50 in XX, and 11–12 between male pores. Spermathecal pores absent. No genital papillae in the preclitellar region. Male pores 0.26–0.32 body circumferences ventrally apart, each on a small oval porophore with a round or oval-shaped genital papilla with a depressed centre on setal line immediately medial to porophore, and then surrounded by three to four skin folds. Spermathecae usually absent (athecate). Seminal vesicles small. Prostate glands absent. Prostatic duct U-shaped with an enlarged distal end. No accessory glands. Parthenogenetic.

**External characters**

Total length 133–168 mm for clitellates and 93 mm for aclitellate. Clitellum constricted, 3.38–4.19 mm in length and 4.71–4.84 mm in width. Prostomium epilobous. Segments numbering 88–116. Setae minute, 32–35 in VII, 47–50 in XX, and 11–12 between male pores in XVIII. First dorsal pore in 11/12.

Spermathecal pores absent. No genital papillae in the preclitellar region. Female pore single, medio-ventral in XIV. Male pores paired in XVIII, ventro-lateral, 0.26–0.32 body circumferences apart. Each pore on a small, oval, disc-like porophore, with a small round or slightly oval-shaped genital papilla with a depressed centre, that is equal in size to or slightly smaller than that of the male porophore, on setal line immediately medial to porophore, and then surrounded by three to four oval skin folds (Figure 2A). Preserved specimens purplish brown on dorsum and light brown on ventrum. Clitellum dark chocolate in colour.

**Internal characters**

Septa 5/6–7/8 and 10/11–13/14 thickened, 8/9/10 missing. Nephridial tufts thick on anterior faces of 5/6/7 septa. Gizzard large in IX–X for clitellates but small in X for aclitellate. Oesophageal hearts enlarged in X–XIII. Intestine starting enlarged in XV. Intestinal caeca paired in XXVII, each simple with a wide base, extending anteriorly to XXIII or XXIV.

Spermathecae absent for 133-mm clitellate and 93-mm aclitellate, but a single vestigial spermatheca in right VI for 168-mm clitellate. The vestigial spermatheca small, with an oval ampulla and a long, straight stalk, and its diverticulum small, with a small oval seminal chamber and a short, straight stalk attached in the middle of the spermathecal stalk (Figure 2B). Ovaries in XIII, paired, large with follicular surface.

Holandry: testis sacs large, two pairs in X and XI. Vas efferens short, thick (swollen), joining in XII or XIII on each side to form a large, straight vas deferens, connecting to prostatic duct in XVIII. Seminal vesicles two pairs in XI and XII, small (degenerated), follicular surface, pink in colour, each with a large dorsal lobe either reddish brown or whitish in colour (Figure 2C). Prostate glands absent for all specimens, but prostatic ducts U-curved, distal end enlarged, silver coloured (Figure 2D). No accessory glands detected.
Etymology

The name *chilanensis* is given to this species with reference to its type locality at Chilan, Ilan County in northeastern Taiwan.

Remarks

According to the classification of parthenogenetic morphs of earthworms (Gates 1956, 1972), two specimens of *A. chilanensis* are I₅ morph, an intermediate between A morph (athecate) and AR morph (athecate and anarsenosomphic), and one specimen is late I₄ morph between H morph and AR morph. The former are thecate but the latter has a vestigial spermatheca in VI. Although all specimens are aprostatic, they have prostatic ducts, so that they are not considered as R morph.

*Amynthas chilanensis* is closely related to *A. sheni* from Hong Kong (Chen 1935). However, eight specimens of *A. sheni* are typical thecate A morph with well-developed male terminalia, prostate glands, precitellar genital papillae, and large accessory glands (Table II). According to the phylogenetic species concept (Cracraft 1989; Kullander 1999), species delimitation for parthenogenetic animals by the approach of Gates (1972) and views of Frost and Wright (1988) and Frost and Hillis (1990), *A. sheni* in Hong Kong and *A. chilanensis* in Taiwan are considered as two phylogenetic species. They are two clusters that have distinct diagnosable characters without intermediates, and each cluster has its own independent evolutionary lineage and direction (morphologically and biogeographically). See the species delimitation for parthenogenetic earthworms in discussion section.

Gates (1972, p 217) indicates that thecate individuals of *sheni* (Chen, 1935) are likely to be referable to *diffingens (=corticis)* or to *robustus* than to *hawayanus (=gracilis)* or *morrisi*. However, A, R, and AR morphs if seen were never recognized as belonging to *robustus*. This

| Characters               | chilanensis       | sheni               |
|--------------------------|-------------------|---------------------|
| Locality                 | Taiwan            | Hong Kong           |
| Body length (mm)         | 93–168            | 120–160             |
| Segment number           | 88–116            | 101–118             |
| Clitellum width/diameter (mm) | 4.71–4.84       | 5–7                 |
| First dorsal pore        | 11/12             | 11/12               |
| Prostomium               | Epilobous         | Epilobous           |
| Setal number             |                   |                     |
| VII                      | 32–35             | 36–42 (VIII)        |
| XX                       | 47–50             | –                   |
| XXV                      | –                 | 45–56               |
| Between male pores       | 11–12             | 11–15               |
| Genital papillae         |                   |                     |
| Precitellar              | Absent            | On VIII, occasionally also on IX |
| Postclitellar            | One medial to male pore | One medial to male pore |
| Spermathecae             | Absent, or vestigial in VI | Absent              |
| Intestinal caeca         | XXVII–XXIII or XXVII–XXIV | XXVII–XXII         |
| Testes                   | X, XI             | Compact, X, XI     |
| Seminal vesicles         | Small, XI, XII    | Small, XI, XII     |
| Prostate glands          | Absent            | Large, XVI–XXI     |
| Prostatic ducts          | Long, U-curved    | Long, U-curved     |
| Accessory glands         | Absent            | Present             |

Table II. A comparison of characters of *Amynthas chilanensis* from Taiwan and *A. sheni* (Chen, 1935) from Hong Kong.
“likely but not so” statement was interpreted by Blakemore (2003, p 16) to mean that Gates (1972) suggested *sheni* may be an athecate morph of either *robustus* or *corticis*, mostly likely the latter, so that he assigned *sheni* as a synonym with question mark to both *corticis* and *robustus*. Later Blakemore et al. (2006) further stated that this questionable synonym of *sheni* to *robustus* was proposed by Gates (1972).

For linking *sheni* to its possible H morph, when Chen (1935, p 41) erected the species he indicated that there is no intermediate to associate the athecate *sheni* with some typical species, and its general characters are very much like *Pheretima pingi* Stephenson, 1925 of Checking, China, but both are distinguishable specifically. The lack of intermediates might also be one of the reasons that Gates (1972, p 217) speculated but did not assign *sheni* as a synonym or a possible synonym of either *robustus* or *corticis*.

*Amynthas sheni* is distinguishable specifically from *robustus* simply by the character of genital papillae at male pores. *Amynthas sheni* has a single genital papilla (never paired) medial to each porophore, the consistent specific character (Chen 1935, p 39) like that of *chilanensis* (Figure 2A), whereas *robustus* usually has two genital papillae at each male pore, one presetal and one postsetal, others paired (apparently never median and unpaired) (Gates 1972, p 216). Also, in this study *A. chilanensis* of Taiwan, closely related to *A. sheni* of Hong Kong, has a rudimentary spermatheca in VI. This may imply that the athecate morph of *sheni*, like *chilanensis*, is derived from an ancestral H morph which had spermathecae in VI, unlike the quadrithecate *robustus* that has spermathecae only in VIII and IX. Apparently, *sheni* is not referable to *robustus*, as once suspected by Gates (1972) and nearly accepted by Blakemore (2003) and Blakemore et al. (2006).

Generally, *sheni* fairly resembles octothecate *corticis* as Gates (1972) indicated. The latter has spermathecae in VI. However, *sheni* is distinguishable from *corticis* in that the former has a consistent genital papilla immediately medial to each male porophore as mentioned previously. For the latter the genital papillae at the male pore region are highly variable in number and location: absent to one or more in number (Gates 1972, p 178), and one to two or three in number, in various arrangement for specimens from China (Figure 5F) (Chen 1933, p 235, Figure 16). In Taiwan *corticis* has often one or two genital papillae in different arrangement (Figure 5D, E) and specimens with three papillae are also observed; a single medial papilla is common (Tsai 1964), but it is often postsetal on the first skin fold separated from the male porophore (Figure 5D). Also, *sheni* is endemic to Hong Kong, and the closely related *chilanensis* is endemic to Taiwan, while *corticis* is peregrine with worldwide distribution. According to the differences in structure of male pore region, habitat, and migratory behaviour, *sheni* shows no specific affinity with *corticis*.

Actually, parthenogenetic morphs of *sheni* and *chilanensis* more resemble *Amynthas taipeiensis* (Tsai, 1964) of Taiwan and of China (= *Pheretima heterogens* Chen and Hsu, 1975) than *robustus* and *corticis*. The male pore structure with its genital papilla located immediately (contacted) medial to the male porophore of *sheni* and *chilanensis* (Figure 2A) is almost identical to that of *taipeiensis* (Tsai 1964, p 12, Figure 2) of Taiwan and China (Chen et al. 1975, p 90, Figure 2). However, the latter is sexthecate and has spermathecal pores in 6/7–8/9. Also, *taipeiensis* is distinguishable specifically from *sheni* in that the former has higher setal numbers (46–52 in VIII and 61–63 in XX) than those of the latter (36–42 in VIII and 45–56 in XXV), and also the former has a long and coiled prostatic duct, whereas the latter has a U-shaped duct.

Based on the differences in male pore region and its associated genital papillae and general somatic characters mentioned above, neither *robustus*, *corticis* nor *taipeiensis* is likely to be the H morph of *sheni* and *chilanensis*. Furthermore, there are no intermediates in
characters (numbers of spermathecae) that can link *sheni* (A morph) to either one of the latter three species to verify their specific affiliation as required (Gates 1972). Without intermediates to substantiate the specific affiliation, to consider *sheni* as a possible synonym (with question mark) of either *robustus* or *corticis* (Blakemore 2003; Blakemore et al. 2006), or even *taipeiensis* is simply a speculation. When the phylogenetic species concept (Cracraft 1989; Kullander 1999) is applied to species delimitation for both hermaphroditic amphimictic morphs and parthenogenetic morphs, speculation on the ancestral H morph of *sheni* and *chilanensis* becomes meaningless.

*Amynthas bilineatus* Tsai and Shen, sp. nov.  
(Figure 3)

*Type material*

Holotype: a clitellate (mature) specimen (dissected) collected 14 February 2000 from hill slope along Dongyan Creek (elevation 1000 m), Jen-ai, Nantou County by C. F. Tsai, S. C. Tsai, H. P. Shen, T. J. Lin, and H. P. Chen (coll. no. 2000-3-Shen). Paratypes: seven clitellates (three dissected) and three immature specimens (same collection data as holotype).

*Diagnosis*

Medium earthworm; length (clitellates) 96–153 mm, segments numbering 89–104. Setal number 44–52 in VII, 52–56 in XX, eight between male pores. Spermathecal pores absent. Male pores 0.23–0.26 circumferences ventrally apart, each on a round or oval porophore surrounded by three or four circular folds. Genital papillae two on each segment on mid-ventrum of VI–IX, arranged in two parallel longitudinal rows; each papilla round with a concave centre, presetal, adjacent to setal line. Also, genital papillae two to absent in XIX; if present, presetal, medial to male pore. Spermathecae absent. Seminal vesicles and prostate glands small, vestigial. Accessory glands sessile or stalked in the preclitellar region and stalked in the postclitellar region. Parthenogenetic.

*External characters*

Holotype 153 mm in length, 2.78 g in weight, clitellum width 5.3 mm, clitellum length 4.6 mm. Paratypes 96–118 mm in length, 0.82–1.23 g in weight, clitellum width 3.49–4.18 mm, clitellum length 2.60–3.15 mm. Prostomium epilobous. Segments numbering 89–104. First dorsal pore 11/12. Number of incomplete annulets (secondary segmentation) two or three per segment in VI–XIII, XVII, and XVIII. Setal number 44–52 in VII, 52–56 in XX, eight between male pores in XVIII. Clitellum XIV–XVI, smooth, setae absent, dorsal pores absent, dark brown in colour with lighter anterior and posterior edges. Spermathecal pores absent. Genital papillae presetal, closely paired in two parallel and longitudinal rows on mid-ventrum of VI–IX (Figure 3A) with numbers variable among specimens and segments. For eight mature type specimens examined, in VI one on right for two specimens, one on left for two specimens, paired for four specimens; in VII one on right for one specimen, paired for seven specimens; in VIII one on left for one specimen, paired for seven specimens; in IX paired for eight specimens; in X paired for one specimen.
Each papilla round, centre concave, 0.25–0.5 mm in diameter, adjacent to setal line. Female pore single, medio-ventral in XIV.

Male pores paired in XVIII, latero-ventral, distance between the pores 0.23–0.26 circumferences apart, and each pore minute, superficial, on a round or transversely oval porophore surrounded by three or four circular folds (Figure 3B, C). Genital papillae in XIX, presetal, each slightly medial to male pore (Figure 3C): for eight specimens examined, one pair for two specimens, one on left for two specimens, one on right for two specimens,
absent for two specimens. The structure of the papillae similar to those in the preclitellar region.

Preserved specimens tinted pink in colour in the preclitellar region, light brown in the postclitellar region, and dark brown around clitellum.

**Internal characters**

Septa 8/9/10 absent, 5/6–7/8 and 10/11–13/14 thickened. Gizzard round in IX and X. Intestine enlarged from XVI. Intestinal caeca paired in XXVII, each simple, short, surface slightly wrinkled, extending anteriorly to full XXV or to two-thirds of XXIV (Figure 3H). Oesophageal hearts XI–XIII, the second and third hearts enlarged.

Spermathecae absent. Accessory glands corresponding to external genital papillae in the preclitellar region; each round, nearly sessile or with stalk to 0.26 mm in length (Figure 3D).

Holandry: sperm sacs paired in X and XI, each small and round. Seminal vesicles paired in XI and XII, small, follicular, surface slightly wrinkled, yellow in colour, each with a small oval dorsal lobe (Figure 3E). Prostate glands paired in XVIII, wrinkled, extending to XVII and XIX. Prostatic duct U-shaped, occupying two segments XVII and XVIII, distal end enlarged (Figure 3F, G). Accessory glands in XIX corresponding to external genital papillae, each slightly divided into two or three round lobes with stalks 0.24–0.31 mm in length (Figure 3G).

**Etymology**

The name *bilineatus* (*bi*=two, *lineatus*=lines) is given to this species with reference to its unique arrangement of two longitudinal lines (rows) of genital papillae on mid-ventrum of the spermathecal region.

**Remarks**

*Amynthas bilineatus* sp. nov. is athecate (A morph) and closely related to athecate *Amynthas hohuanmontis* (Tsai et al., 2002) of central Taiwan and *A. sheni* of Hong Kong (Chen 1935) and to nearly athecate *A. chilanensis* of northeastern Taiwan. *Amynthas bilineatus* has paired, longitudinal series of ventral genital papillae in VI–IX (Figure 3A) that are easily distinguishable from a single pair in VIII for *sheni*, and absent for *chilanensis* and *hohuanmontis*. Also, *bilineatus* has a pair of ventral genital papillae in XIX and absent in XVIII, differing from *sheni, chilanensis*, and *hohuanmontis* that have no genital papilla in XIX but in XVIII. The above four athecate species are closely related and belong to the *sheni* species-subgroup (Tsai et al. 2002) of the *illotus* species-group (Easton 1981) within the genus *Amynthas* Kinberg (Sims and Easton, 1972). They apparently evolved from a common ancestor as a result of allopatric speciation.

*Amynthas cruxus* Tsai and Shen, sp. nov.
(Figure 4)

**Type material**

Holotype: a clitellate (dissected) collected 24 October 2000 from Tengchih (elevation 1500 m), Taoyuan, Kaohsiung County by H. P. Yang, S. T. Chang, C. Y. Chang, and H.
P. Shen (coll. no. 2000-71-Shen). Paratype: an amputated clitellate (same collection data as holotype).

Other material

Three clitellates and three aclitellates collected 25 October 2000 along Shihshan Forest Road in natural forest near the Middle Altitude Experimental Station, Taiwan Endemic Species Research Institute (elevation 1700 m), Kaohsiung County (coll. no. 2000-75-Shen); one clitellate and one aclitellate collected 26 October 2000 along a forest road in the Chuyunshan Nature Reserve (elevation 1200 m) in Kaohsiung County near the border with Taitung County (coll. no. 2000-80-Shen); six clitellates (one dissected) collected 26 October 2000 along a forest road in the Chuyunshan Nature Reserve (elevation 900 m) in Kaohsiung County near the border with Taitung County (coll. no. 2000-81-Shen). All collections were made by the same collectors of the holotype.
Diagnosis

Medium earthworm; length (clitellates) 100–170 mm, segments numbering 91–120. Setae 27–37 in VII, 39–52 in XX, 11–13 between male pores. Spermathecal pores four pairs in 5/6–8/9, about 0.31 body circumferences ventrally apart. No genital papillae in the preclitellar region. Male pores 0.24–0.26 body circumferences ventrally apart, each on a teat-like porophore on a flat, diamond-shaped male disc, on which four genital papillae are arranged in the form of a cross around the porophore, each papilla about 0.2 mm in diameter with a slightly depressed centre. The male disc is surrounded by three to four diamond-shaped skin folds. Spermathecae large, four pairs in VI–IX. Seminal vesicles and prostate glands large. Prostatic duct large, U-shaped, occupying three segments in XVI–XVIII. Amphimictic.

External characters

Total length (clitellates) 100–170 mm. Segments numbering 91–120. Prostomium epilobous. Number of incomplete secondary annulets two to three per segment in VII–XIII. Setal number 27–37 in VII, 39–52 in XX, 11–13 between male pores. First dorsal pore in 11/12. Clitellum XIV–XVI, setae and dorsal pores absent, 2.1–3.42 mm long, 3.32–4.76 mm wide. Spermathecal pores four pairs in intersegmental furrows of 5/6–8/9, each lip-like (Figure 4B), distance between paired pores about 0.31 body circumferences ventrally apart. No genital papillae in the preclitellar region. Female pore single, medio-ventral in XIV.

Male pores paired in XVIII, 0.24–0.26 body circumferences ventrally apart, each on a teat-like porophore on a flat, diamond-shaped disc (male disc), on which four genital papillae are arranged in the form of a cross around the porophore: one anterior, one posterior, one lateral, and one medial (Figure 4A). This male disc is surrounded by three to four diamond-shaped skin folds. Each of the genital papillae about 0.2 mm in diameter, white in colour, with a slightly depressed centre. No other genital papillae in the postclitellar region.

Preserved specimens light greyish brown on dorsum, light grey on ventrum and brown around clitellum.

Internal characters

Septa 5/6–7/8 and 10/11–13/14 thick, 8/9/10 absent. Gizzard in IX–X, large, bell-shaped. Intestine starting enlarged in XV or XVI. Intestinal caeca paired in XXVII, each simple, stocky, extending anteriorly to XXIV or XXV. Oesophageal hearts in XI–XIII.

Spermathecae large in VI–IX (Figure 4C), ampulla oval- to pear-shaped, 1.9–2.57 mm long, 1.4–1.83 mm wide, with a slender to stout spermathecal stalk of 0.6–0.95 mm in length. Diverticulum with a round or oval, iridescent seminal chamber, 0.45–0.8 mm in length, and a slender stalk of 0.92–1.15 mm in length. Diverticulum stalk slightly longer than spermathecal stalk. No accessory glands in the preclitellar region.

Holandry: testis sacs paired in X and XI, round, shiny. Seminal vesicles paired in XI and XII, large, finely folliculated, each with a round or cone-shaped dorsal lobe (Figure 4E). Prostate glands paired in XVIII, lobed, wrinkled, occupying three to four segments in XVII–XX. Prostatic duct unusually large, U-shaped, occupying three segments in XVI–XVIII, proximal half slender and distal half enlarged (Figure 4D). No accessory glands in the postclitellar region.
Etymology

The name *cruxus* (=cross) is given to the new species with reference to the cross formation of the genital papillae around the male pore.

Remarks

*Amynthas cruxus* sp. nov. from Taiwan belongs to the *diffringens (=corticis)* species-group of the genus *Amynthas* (Sims and Easton, 1972). It is closely related to *Amynthas pingi* (Stephenson, 1925) of China (Chen 1933) and *Amynthas hatomajimensis* (Ohfuchi, 1957) of the Ryukyus. These three species share a unique character in having a slightly elevated, flat, and smooth or granular male disc, on which there is a teat-like male porophore associated with genital papillae in a well-arranged pattern, and then surrounded by a groove or by one to few circular skin folds (rings) (Figures 4A, 5A). This male disc in the three species is easily distinguishable from the male pore region of *A. corticis* (Kinberg, 1867), that has a teat- or small disc-like elevated porophore, on which the male aperture is present, but its associated genital papillae if present (one or two) are located in an irregular pattern (not consistent arrangement) on first and second skin folds surrounding the porophore (not directly on the disc-like porophore) (Figure 5D–F). This flat male disc was noted for *hatomajimensis* by Ohfuchi (1957, p 246, Text-figure 20), and also for *pingi* by Chen (1933, p 230, Figure 15B). Gates (1938) compared characters between *diffringens* and *pingi*, and considered them as closely related species, but did not note this character for specific distinction.

*Amynthas cruxus* is easily distinguishable from *A. pingi* and *A. hatomajimensis* by the character of the genital papillae, length of spermathecal stalks, and shape and structure of the prostatic duct (Table III). *Amynthas cruxus* has four genital papillae on the male disc in

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Figure 5. Comparison of male pore regions, ventral views. (A) *A. hatomajimensis* (Ohfuchi 1957, p 246, Figure 20-1, Ryukyus, Japan); (B) *A. torii* (Ohfuchi 1941, p 246, Figure 2-1, Kyusyu, Japan); (C) *A. tajiroensis* (Ohfuchi 1938, p 48, Figure 12-2, Honshu, Japan); (D, E) *A. corticis (=P. diffringens, Taiwan); (F) *P. heterochaeta (=A. corticis)* (Chen 1933, p 235, Figure 16B, C, China).
### Table III. A comparison of characters among *Amynthas cruxus* sp. nov., *A. hatomajimensis*, and *A. pingi*.

| Characters | *A. cruxus* sp. nov. | *A. hatomajimensis* (Ohfuchi, 1957) | *A. pingi* (Chen, 1933) |
|-----------|----------------------|-------------------------------------|-------------------------|
| Locality  | Taiwan               | Ryukyus                             | China                   |
| Body length (mm) | 100–170             | 73–94                               | 160–340                 |
| Segment number | 91–120              | 75–93                               | 110–179                 |
| Clitellum width/diameter (mm) | 3.32–4.76          | 3–4.5                               | 6–10                    |
| First dorsal pore | 11/12               | 12/13                               | 12/13                   |
| Setal number |                                   |                                      |                         |
| VI        | –                    | 36–39                               | 30–36                   |
| VII       | 27–37                | 41–46                               | –                       |
| VIII      | –                    | 45–49                               | 34–57                   |
| XX        | 39–52                | 60–65                               | –                       |
| XXV       | –                    | –                                   | 47–72                   |
| Between male pores | 11–13               | 11–15                               | 12–20                   |
| Spermathecal pores | 5/6–8/9             | 5/6–8/9                             | 5/6–8/9                 |
| Preclitellar genital papillae |            |                                      |                         |
| 1. Spermathecal pore (each) | Absent            | Absent                              | One anterior            |
| 2. Presetal, paired | Absent            | Absent                              | VIII, IX, occasionally in X |
| 3. Postsetal, paired | Absent            | Absent                              | Absent or on VII        |
| Accessory glands | Absent            | Present                             | Round, duct short       |
| Male pores | In centre of a large, flat, diamond-shaped male disc | On lateral side of a large, round, elevated porophore (=male disc) | On lateral side of a large, round, smooth or glandular porophore (=male disc) |
| Male pore (MP) genital papillae |            |                                      |                         |
| Total number | 4                  | 3                                    | 2                       |
| 1. Anterior to MP | 1                  | 1 (antro-medial)                     | 1 (antro-medial)        |
| 2. Posterior to MP | 1                  | 1 (postro-medial)                    | 1 (postro-medial)       |
| 3. Lateral to MP | 1 (on setal line)  | Absent                              | Absent                  |
| 4. Medial to MP | 1 (on setal line)  | 1 (on setal line)                   | Absent                  |
| Accessory glands | Absent            | Present                             | Round, granular, duct short |
| Other postclitellar genital papillae | Absent            | Postsetal, paired, XVIII             | Presetal, paired, XIX   |
| Spermathecae | VI–IX               | VI–IX                               | VI–IX                   |
| Ampulla    | Large, oval- to pear-shaped | Large, elongate pear-shaped         | Heart- to elongate pear-shaped |
| Spermathecal duct | Slender to stout, 0.6–0.95 mm long | 1.3–2 mm long                        | Stout, long              |
| Diverticulum | Seminal chamber round or oval, stalk slender | Seminal chamber ovoid or elongate spherical, stalk slender | Seminal chamber ovoid or elongate spherical, stalk slender |
| Seminal vesicles | Large, folliculated, XI, XII | Well-developed, XI, XII             | Large, tubercular, XI, XII |
| Prostate glands | XVII–XX             | XVII–XX                             | XVI–XX or XVI–XXI       |
| Prostatic ducts | Large, U-shaped, distal end enlarged | U-shaped, distal end slender        | Short, stout, U-shaped, distal end thicker |
the form of a cross (one anterior, one posterior, one lateral, and one medial, the latter two on setal line), whereas *hatomajimensis* has three papillae (one anterior, one posterior, and one medial on setal line), and *pingi* has two (antro-medial and postro-medial). Also, *cruxus* has an unusually large, thick, muscular, U-shaped prostatic duct, covering three segments from XVI to XVIII (Figure 4D), differing significantly from *hatomajimensis* and *pingi* that have a short duct covering from the posterior half of XVII to anterior half of XVIII (Chen 1933; Ohfuchi 1957). *Amynthas cruxus* and *A. hatomajimensis* have a spermathecal stalk of which the length is about a third of the ampullar length, whereas for *pingi* the stalk is as long as the ampullar length. In addition, accessory glands associated with the genital papillae are absent in *cruxus*, present near spermathecae in *hatomajimensis*, and often present in VIII, IX (occasionally in X), XVIII, and XIX in *pingi*. Also, *hatomajimensis* is smaller in length and has lower segment number than *cruxus* and *pingi*. The three species have fully developed reproductive organs, suggesting that they are the bi-parental breeding populations.

*Amynthas cruxus* is also similar to *Amynthas nanrenensis* James et al., 2005 in having four pairs of spermathecae in VI–IX and small genital papillae around each male pore. However, *nanrenensis* has much higher setal number than *cruxus* with 60–64 in VII and 62–72 in XX for the former, and 27–37 in VII and 39–52 in XX for the latter.

*Amynthas hatomajimensis* from Hatomajima Island of Iriomote at the southern tip of the Ryukyu Archipelago (Ohfuchi 1957) is given as a synonym with question mark of *Amynthas corticis* in the checklists of Japanese earthworms (Easton 1981; Blakemore 2003), while *Pheretima toriii* Ohfuchi, 1941 from the cave of Shonyudo Shindo, Oita, Japan and *Pheretima tajiroensis* Ohfuchi, 1938 from Tajiro Island, Ojika, Japan are given as synonyms without question marks. There is no explanation on what the difference is between synonyms with question marks and those without question marks.

*Amynthas hatomajimensis* is easily distinguishable from *corticis*; the former has a flat male disc on which genital papillae are arranged in a consistent pattern around the male aperture (Figure 5A) (Ohfuchi 1957), whereas the latter has a small disc-like porophore, and genital papillae if present are one or two in irregular arrangement usually on the first skin fold or the second skin fold surrounding the porophore (Figure 5D–F). As mentioned above, *hatomajimensis* is neither synonymous with nor closely related to *corticis*, but is closely related to *cruxus* of Taiwan and *pingi* of China. The above three closely related species in China, Taiwan, and Iriomote Island at the southern tip of the Ryukyu Archipelago provide additional evidence for the zoogeographical association of the three areas (Hikida and Ota 1997; Tsai et al. 2002).

*Pheretima toriii* is a small cave earthworm, 37–43 mm in length, and has setal number of 43–45 in VIII, 56–58 in XX, teat-like porophore surrounded by six or eight skin folds (rings) without setae and genital papillae (Figure 5B), and prostatic duct slender and straight (Ohfuchi 1941), whereas *corticis* is larger, 45–170 mm in length, and has setal number of 26–46 in VIII, 39–54 in XX, a small disc-like porophore surrounded by a few skin folds often with one or two genital papillae, and U- or C-shaped muscular prostatic duct (Gates 1972). Ohfuchi (1941, p 246) already recognized a slender, straight prostatic duct as a unique character of *toriii* that is not seen in other species of the genus. Also, both species are different in ecological niches and migratory behaviour: *toriii* is cave dwelling and endemic, and *corticis* is terrestrial and peregrine. Unquestionably, *toriii* is a valid species distinguishable specifically from *corticis*.

*Pheretima tajiroensis* has a large (about 0.6 mm in diameter) and circular male porophore, deeply sunk down and surrounded by an elevated skin fold (Figure 5C) (Ohfuchi 1938, p 48, Text-figure 12), which differs greatly from the small disc-like porophore of *corticis*.
Based simply on the male porophore structure, *tajiroensis* is a valid species distinguishable specifically from *corticis*.

The above three species, *hatomajimensis*, *toriii*, and *tajiroensis*, have unique, specifically distinctive characters. It is difficult to imagine or to speculate that they are synonymous among each other, and also synonymous to *corticis* as suggested by Easton (1981) and Blakemore (2003). The former two species have fully developed reproductive organs, so they are bi-parental H morphs. If *hatomajimensis* and *toriii* were synonymous to *corticis*, then they would be the ancestral H morph of parthenogenetic, aprostatic *corticis* and also the ancestral H morph of *sheni* speculated by Gates (1972) and Blakemore (2003). This would be too much speculation.

The original description of *Perichaeta corticis* Kinberg, 1867 is very simple as “*P. corticis* n. Setae ubique c. 40: nae, minutaæ aliaque crescentes majores; segment. 114; longitudo 68 mm. Oahu, sub cortice arborum” (Kinberg 1867, p 102). Easton (1982, p 726) gave a diagnosis of *A. corticis* also very simply as “*Amynthas* with paired spermathecal pores c.1/3 of the body circumference apart in furrows 5/6/7/8/9; genital markings as Fig. 4a.” Later Blakemore (2003, p 16) redefined the diagnosis but still very loosely (not specific) as “*Amynthas* with four pairs of spermathecal pores ca. 0.3 body circumference apart in furrows 5/6/7/8/9. Genital markings small paired or variable near spermathecal and male pores. Intestinal caeca simple with smooth or incised margins, originating near segment 27. Parthenogenetic morphs common (e.g., prostates and/or spermathecal diverticula aborted). Size range given as 45–270 mm (Sims & Gerard 1985: 128, 1999: 128); cf. 45–170 mm (Gates 1972: 178), (cf. *Amynthas fuscatus* given as 100–450 mm).”

In addition to use of uncertain, speculative synonyms (with question marks), the over-simplified original description (Kinberg 1867), over-simple diagnosis (Easton 1982), and loosely defined diagnosis (Blakemore 2003), may be one of the reasons for so many synonyms for *corticis* in the checklists of Japanese earthworms (Easton 1981, p 49; Blakemore 2003, p 14–16). If there were more detailed verification with more definitive, specific diagnostic characters with clear species concept, many of the synonyms (with and without question marks) of *corticis* and other species in the Japanese earthworm checklists (Easton 1981; Blakemore 2003) might have been found to be valid nominal species, and their nominal status should not have been rejected at all from the Japanese earthworm fauna (biodiversity).

**Discussion**

*Species delimitation for parthenogenetic morphs*

Earthworms have been generally considered as hermaphroditic animals of obligatory amphilimixis, but species with obligatory parthenogenesis, through male sterility or inability to transfer or to receive sperm, are common (Gates 1971). In 29 species of British Lumbricidae, six species are parthenogenetic and almost certainly polyploid (triploid to decaploid) (Muldal 1952). Apparently, polyploidy upsets the sex chromosome mechanism for sex determination, since it automatically abolishes pairing of dissimilar chromosomes (Muldal 1952). For about 140 species of North American megadriles, 35 species are hermaphroditic amphimictic, 33 are parthenogenetic, and four are amphimictic with some parthenogenetic morphs (Reynolds 1974). For *Bimastos* all species in England (Muldal 1952) and North America (Reynolds 1974) are parthenogenetic.

Polyploid parthenogenesis occurs not only in hermaphroditic earthworms, but also in hermaphroditic snails (Muldal 1952), flatworms, insects, fish, and salamanders (Freeman...
and Herron 2005). For oriental pheretimoid earthworms, parthenogenetic earthworms are fairly common, particularly in Japan and Taiwan. Although their karyotypes have not been investigated, it is reasonably suspected that like those of Lumbricidae (Muldal 1952), polyploidy is the main attributable cause for parthenogenesis in Megascolecidae in Asia, but it still remains to be investigated.

Parthenogenetic species commonly occur in ephemeral or unstable habitats, whereas amphimictic species tend to inhabit more stable environmental situations. Successful clones of parthenogenetic species may be expected to possess general purpose genotypes (Jaenike and Selander 1979). Parthenogenetic lumbricids in Britain are all peregrine, successful and widespread species (Muldal 1952). For oriental megadriles, some parthenogenetic species, such as *A. corticis* and *A. hupeiensis*, are also peregrine and widely distributed species, while some species are endemic in unstable environments in mountain areas, such as *A. hohuanmontis*, *A. bilineatus*, and *A. shinamontis*, or endemic but also comparatively widely distributed (Tsai et al. 2002), such as *A. asacceus* in Hainan Island (Chen 1938) and in the Ryukyus (*Pheretima pusilla* Ohfuchi, 1956), and *A. oyuensis* in northeastern Honshu Island, Japan (Ohfuchi 1937), and *A. illotus* in southern China (Gates 1932, 1972) and in the Ryukyus (Ohfuchi 1956). Based on biogeography these parthenogenetic species might have evolved in the early Pleistocene or in the Pliocene (Tsai et al. 2002).

Apparently, parthenogenetic earthworms are highly adapted to various environments, and each species has its own independent evolutionary lineage. All species in the genus *Bimastos* are parthenogenetic (Muldal 1952; Reynolds 1974), and their ancestral hermaphroditic amphimictic morphs have never been known. Based on the above it is evident that speciation occurs in the evolution of parthenogenetic earthworms as in the hermaphroditic amphimictic earthworms. Parthenogenetic earthworms are not reproductively degenerated morphs of biparental species (Blakemore 2003) but earthworms of uniparental reproduction (Reynolds 1974).

Mayr and Ashlock (1991) indicate that when the parthenogenetic generation fails to return to sexuality, has morphological entity, occupies its own ecological niche, and plays its own evolutionary role, this parthenogenetic taxon should deserve species status. Frost and Wright (1988) and Frost and Hillis (1990) mention that though most recent authors agree that uniparentals do not form entities of the same kind as biparentals, but their descent with modification does occur in tokogenetic lines, to ignore the existence of tokogenetic arrays is to ignore the products of evolution. The objective of taxonomy is to store information on the history of evolution; if we exclude these uniparental tokogenetic lines we exclude some of the historical entities produced by evolution. Ehchelle (1990) and Frost and Hillis (1990) also suggest that, if a given historical group of parthenogenetic morphs is persistent and does not affect the evolutionary trajectory of the amphimictic ancestor, as indicated by biogeography, habitat preferences, and genetic divergence, it should be considered a species. We tend to accept the views of Mayr and Ashlock (1991), Frost and Wright (1988), and Frost and Hillis (1990) that parthenogenetic modification occurs in tokogenetic lines that are the products of evolution, and have their entities and evolutionary lineages, and thus, they should be treated equally to biparentals in systematics.

There are three common species concepts available at present. The biological species concept (BSC), the traditional species concept, defines species as a group of interbreeding natural populations that is reproductively isolated from other such groups (Mayr and Ashlock 1991). The evolutionary species concept (ESC) defines a species as an entity composed of organisms that maintain its identity from other such entities through time and
over space, and that has its own independent evolutionary fate and historical tendencies (Mayden 2002). The phylogenetic species concept (PSC) defines species as an irreducible (basal) cluster of organisms, diagnosably distinct from other such clusters, and within which there is a parental pattern of ancestry and descent (Cracraft 1989; Kullander 1999). For the above three species concepts, BSC is generally discarded by many taxonomists, because of its overemphasis on interbreeding that is difficult to prove for allopatric populations. For oligochate taxonomy BSC is difficult to apply to disjunctive allopatric amphimictic earthworms, as well as parthenogenetic earthworms, because reproductive isolation is difficult to prove for the former, and no interbreeding is found for the latter. ESC is conceptually applicable to both amphimictic and parthenogenetic earthworms, but it is not operational when applied, because it lacks its own methodology, and must use methods in other concepts as surrogates (Mayden 2002). PSC is applicable and operational to both amphimictic and parthenogenetic earthworms. When difference in a character between clusters is discrete (discontinuous), diagnosable, and not referable to ecologically induced variation, then there are distinct diagnosable populations that form allopatric species. We recommend PSC for the systematics and taxonomy of earthworms that have amphimictic and parthenogenetic reproduction.

Gates (1972) stated earlier that certain parthenogenetic morphs could be linked through intermediates to a population that can be regarded with some degree of confidence as amphimictic. In such a case, the species is understood to include not only the interbreeding population but also all recently evolved uniparental strains, clones, or morphs that clearly are affiliated with it. If an interbreeding population is not yet known, all parthenogenetic strains or morphs that can be similarly linked (affiliated) together by intermediates are considered as one species. The above Gates' (1972) statements obviously indicate that the presence of intermediates is a key requirement for species affiliation to link morphs as a species. In other words, parthenogenetic morphs from different localities have character(s) diagnosably distinct (discrete) without intermediates to link their affiliation, then they form allopatric species. Gates' (1972) concept of species delimitation for parthenogenetic morphs is similar to PSC (Cracraft 1989; Kullander 1999).

According to species delimitation by PSC (Cracraft 1989; Kullander 1999), the approach of Gates (1972), and the views of Frost and Wright (1988) and Frost and Hillis (1990), sheni in Hong Kong and chilanensis in Taiwan are considered to be two phylogenetic species. Also, A. asacceus in Hainan Island (Chen 1938) and in the Ryukyus (=P. pusilla Ohfuchi, 1956), and A. oyuensis in northeastern Honshu Island of Japan (Ohfuchi 1937) are properly regarded as different phylogenetic species.

**Synonyms with question marks**

Easton (1981) revised Japanese earthworms and listed 74 accepted nominal species in the checklist, together with 47 nominal species as synonyms without question marks and 23 nominal species as synonyms with question marks. There was no explanation on what the synonyms with question marks are. Both kinds of synonyms with and without question marks are placed together, and the nominal species status of the synonyms with question marks are rejected as those without question marks. Blakemore (2003) again revised Japanese earthworms and mentioned that some of the synonyms against which Easton (1981) placed question marks are supported pending further investigation. However, these synonyms with question marks, like those of Easton (1981), are placed together with those without question marks, and their nominal species status are rejected from the revised
checklist. Blakemore et al. (2006) further state that such synonyms with question marks add advantages of revealing possible species-complexes and of discouraging routine naming by certain authors of each parthenogenetically degraded morph they encounter.

Synonyms with question marks create uncertainty and confusion in the use and reliability of synonyms in oligochaete taxonomy. What are the author’s intentions of using synonyms with question marks (Blakemore 2003; Blakemore et al. 2006)? It is improper and unjustifiable to reject their nominal species status as those of accepted (validated) synonyms without question marks. Apparently, synonyms with question marks are not the synonym defined by the International Commission on Zoological Nomenclature (1999, p 117): “each of two or more names of the same rank used to denote the same taxonomic taxon.”

To erect a synonym to reject its nominal species status is a matter of taxonomy. As species is a basic taxonomic category, we argued that to erect a synonym to reject (invalidate) the species status of a nominal species, it should be an absolute synonym. It should be clearly proven that the synonym is within the boundaries of species delimitation of the other species. Using speculative synonyms with question marks (without reasoning) to deny the specific status of nominal species (Easton 1981; Blakemore 2003; Blakemore et al. 2006), and arbitrarily consider parthenogenetic nominal species as reproductively degenerated morphs (Blakemore 2003) to reject their specific status undoubtedly underestimates the biodiversity of the earthworm fauna of Japan, and creates confusion in oligochaete taxonomy.

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