

# Seven new species of land planarian from Japan and China (Platyhelminthes, Tricladida, Bipaliidae), with a morphological review of all Japanese bipaliids and a biogeographic overview of Far Eastern species

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**ABSTRACT.** An account is given of seven new species of land planarian of the family Bipaliidae von Graff, 1896 collected from various localities in Japan and China : three new species of the genus *Bipalium* Stimpson, 1857 and two new species of the genus *Novibipalium* Kawakatsu, Ogren & Froehlich, 1998 from Japan, and two new species of *Bipalium* from China. The bipaliid fauna of Japan and neighbouring countries (South Korea, Taiwan, NE China, and Primorskiy in Russia) is reviewed. The study concludes with a detailed distribution map of this group of animals in the Far East.

**KEY WORDS :** Platyhelminthes, Bipaliidae, *Bipalium*, *Novibipalium*, *Diversibipalium*, Japan, Korea, Taiwan, China, Primorskiy, taxonomy, morphology, biogeography.

## INTRODUCTION

William Stimpson, an American naturalist who visited Japan in 1853 and 1854, was the first scholar who reported on Japanese land planarians, describing four bipaliid species and one geoplanid species (STIMPSON, 1857). His contribution was followed by VON GRAFF's (1899) Monograph, describing two bipaliid species from Japan (one species concerning a misidentification), and a paper by KABURAKI (1922a) reporting ten bipaliids, two rhyngchodemids, and a single geoplanid species, including STIMPSON's uncertain species. Although the last-mentioned publication contains errors in species identification, it became the fundamental literature on the terrestrial planarians in Japan until recently (cf. KAWAKATSU, 1991a; see also the web article by KAWAKATSU & SASAKI, 2001).

More modern revisions of a few Japanese bipaliid species were made by several workers (MACK-FIRA & KAWAKATSU, 1972; KAWAKATSU, 1991b; KAWAKATSU & KAWAKATSU, 1991) and two new Japanese bipaliid species were reported by KAWAKATSU et al. (1982) and MAKINO & SHIRASAWA (1983).

More recently, the Land Planarian Indices Series has promoted the taxonomic study of Japanese land planarians (see under URL's in References). In addition to the bibliographic clarification offered in these indices of all known Japanese terricolans, they also provided a taxonomic revision of the entire genus *Bipalium* s.l. Stimpson, 1857 and erected the new Oriental genus *Novibipalium* Kawakatsu, Ogren & Froehlich, 1998 (see also

KAWAKATSU & OGREN, 1998a, b). In recent issues of the Land Planarian Indices Series the new collective (genus) group *Diversibipalium* Kawakatsu, Ogren, Froehlich & Sasaki, 2002 was created to contain uncertain bipaliid species that cannot be classified in the genera *Bipalium*, *Novibipalium*, and *Humbertium* Ogren & Sluys, 2001 (KAWAKATSU et al., 2002). A distribution map for the Bipaliidae was published by OGREN et al. (1992).

In the present paper we contribute further to the knowledge on the diversity of Japanese and Chinese terricolans by describing five new species of the genus *Bipalium*, two new species of the genus *Novibipalium*, and by providing a morphological, anatomical, and biogeographic review of all bipaliid species from Japan, as well as several species from SE Asia, thus facilitating identification of future samples of these animals.

## MATERIAL AND METHODS

Prior to embedding in Paraplast, preserved specimens were first soaked in a mixture with equivalent parts of glycerin and 70% ethanol for about three months (cf. KAWAKATSU et al., 1981). Subsequently, each specimen was divided transversally into 2-4 pieces according to the size of the animals : head-and-prepharyngeal piece (HP, or PRE), pharynx-and-copulatory/genital apparatus piece (labelled as PC, PG, or PHG), and tail piece (T). Relatively short animals were cut into two pieces, viz. HP and PC (also labelled as GT or CT), the latter including the tail. In rather long specimens the PC part was divided into

two sections, one containing the pharynx (P), the other the copulatory/genital apparatus + tail (CT, or GT).

Embedded pieces were serially sectioned at intervals of 7–8 µm. Generally, each of the pieces was sectioned sagittally. A short part taken from the posterior end of the HP piece (i.e. just anterior to the root of the pharynx) was sectioned transversally for examination of the body musculature; this is the prepharyngeal transverse piece (PRE). The serial sections were stained with Delafield's hematoxylin and erythrosin.

The material is deposited in the Zoological Museum of the University of Amsterdam (ZMA) and the National Science Museum in Tokyo (NSMT).

Abbreviations used for expressing the dimensions of the preserved specimens are as follows : TL, total length; HML, distance from the anterior tip to the mouth; HGL, distance from the anterior tip to the genital pore; WM, width over the mouth; TB, thickness of the body at the level just anterior to the pharyngeal region.

#### *Abbreviations used in the figures*

au, auricle; bc, bulbar cavity; ca, common genital atrium; cs, creeping sole; csd, common sperm duct; dos, dorsal surface; dst, dorsal stripes; e, eye(s); ed, ejaculatory duct; eg, erythrophilic glands; fa, female genital antrum; fgd, female genital duct; fgp, female genital pore; gl, glands; gp, gonopore; h, head plate; i, intestine; ma, male genital antrum; mgp, male genital pore; od, ovovitelline duct; p, parasite; pb, penis bulb; pg, penis glands; pp, penis papilla; ps, penis sheath; sd, sperm duct; sv, seminal vesicle; te, testis; vs, ventral surface.

#### *A note on anatomical terminology*

In previous papers of the senior author, the female copulatory apparatus was described with the terms glandular chamber or glandular duct, following VON GRAFF'S (1899) usage of the German term Drüsengang. In this paper we refer to this particular part of the copulatory apparatus as the female genital duct. VON GRAFF used the term Drüsengang, or glandular duct, for any duct receiving the openings of shell glands. Thus, a Drüsengang could refer to separate oviducts receiving shell glands, a common oviduct receiving the shell glands, or another duct penetrated by gland openings. However, a common oviduct, for example, should not be called a glandular duct simply because it receives the shell glands. Homologous structures should be described with similar terminology. The word Drüsengang or glandular duct refers to several, non-homologous structures.

We presume that in bipaliids the part of the female copulatory apparatus receiving the openings of the oviducts is homologous with the bursal canal of other terricolans. However, in view of the absence of a copulatory bursa, we refrain from using the term bursal canal and instead prefer to use female genital duct. A female genital duct is characterized by a histology and musculature that is dif-

ferent from that of oviducts, common oviduct, and female or common antrum. The term female genital duct has been used in the description of marine triclads that lack a bursal canal (cf. SLUYS, 1989) and was already applied to terricolans by BALL & SLUYS (1990).

### SYSTEMATIC ACCOUNT

Suborder TRICLADIDA Lang, 1884

Infraorder TERRICOLA Hallez, 1892

Family BIPALIIDAE von Graff, 1896

Genus *Bipalium* Stimpson, 1857

*Bipalium tatsuyai* sp. nov

*Material* : Holotype, ZMA V.Pl. 984.1, Mt. Moiwa (alt. approx. 500 m), the western part of Sapporo City, Hokkaidô, 8 August 1966, sagittal sections on 100 slides (HP : 51 slides; PC : 50 slides).

#### Diagnosis

*Bipalium tatsuyai* sp. nov. can externally be distinguished from its congeners by its moderate size (60 mm long), lunate head with a blackish margin, uniformly brown dorsal surface with rather narrow blackish mid-dorsal stripe running from the level of the "neck" to the pharynx, and by the absence of stripes on the ventral surface. With respect to anatomical features the new species differs from other species of *Bipalium* in the presence of a large penis bulb, a moderately large conical penis papilla, wide penial lumen with many plicae, spacious and rather muscular male antrum, and a glandular organ that is moderate in size, muscular and houses a moderately glandular female genital duct which is provided with many plicae.

#### Ecology and distribution

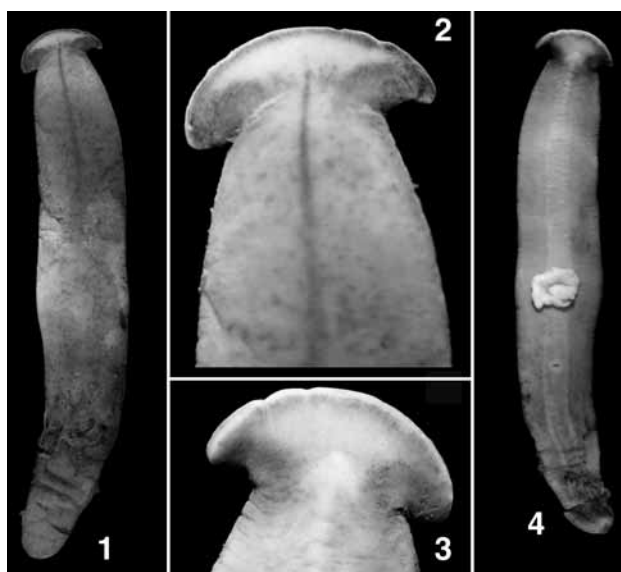
Known only from the type locality.

#### Etymology

The specific epithet is based on the name of Kawakatsu's son, who was one of the collectors of this new species.

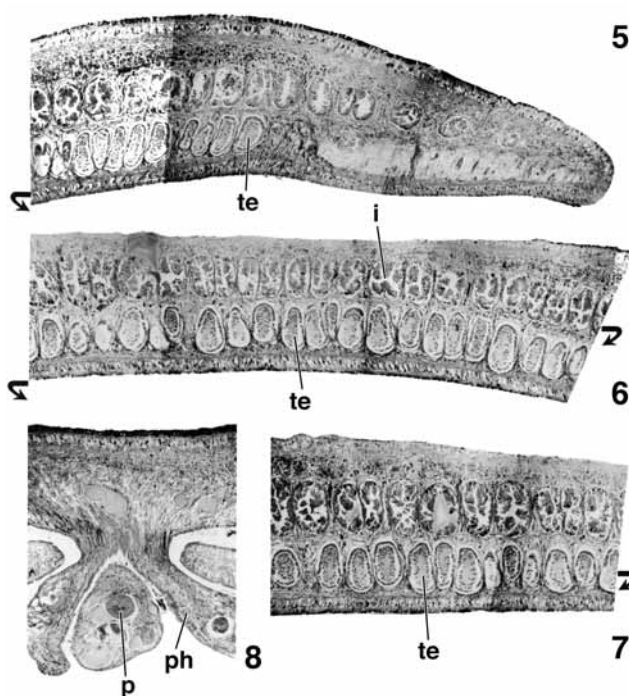
#### Description

The living, sexually mature specimen in elongated state measured over 60 mm in length. The dimensions of the preserved holotype specimen were as follows : TL : 33 mm, HML : 18 mm, HGL : 23 mm, WM : 2.5 mm. The semi-lunar head has a pair of protruding, moderately recurved auricles (Figs 1-4). Behind the head the body narrows slightly and then gradually widens towards the pharynx and the copulatory apparatus; tail bluntly pointed.



Figs 1-4. – *Bipalium tetsuyai*. ZMA V.Pl. 984.1. 1, dorsal view of preserved specimen; 2, dorsal view of the anterior end; 3, ventral view of the head; 4, ventral view.

The ground colour of the dorsal surface is a uniform brown, except for the whitish head. Auricles and peripheral region of the head are black (Fig. 1). A blackish longitudinal mid-dorsal stripe extends from the middle of the head to the prepharyngeal region. The ventral surface is pale brown, except for the creeping sole and regions over the pharynx and the copulatory apparatus. The margin of the head and basal part of the auricles (i.e. the neck) are greyish black.



Figs 5-8. – *Bipalium tetsuyai*. ZMA V.Pl. 984.1. Sagittal section through front end (5), prepharyngeal region (6, 7), and pharynx (8).

Numerous small eyes are set along the anterior margin of the head in 2-3 or more rows, this “band” of eyes being widest at the regions of the auricles and the “neck”.

The ventral testes are rather small and oblong, occupying about one-third of the dorso-ventral diameter in the prepharyngeal part of the body (Figs 5-8). The testes are arranged in one or two longitudinal rows, extending from behind the ovaries to the level of the pharynx or somewhat beyond. Ovaries are located ventrally, near the posterior level of the brain (Fig. 5). Yolk glands are well developed.

The penis bulb is moderately muscular at its ventral side and houses a wide bulbar cavity (or seminal vesicle) with several conspicuous plicae. This bulbar cavity tapers gradually to form an irregularly shaped ejaculatory duct that opens at the tip of the penial papilla. The bulbar cavity and ejaculatory duct are lined with a flat, nucleated and glandular epithelium that is underlain with a thin layer of circular muscle fibres. Posterior and middle sections of the penis lumen receive the numerous openings of erythrophilic glands. The two sperm ducts form well developed spermiducal vesicles, opening separately into the antero-ventral part of the bulbar cavity.

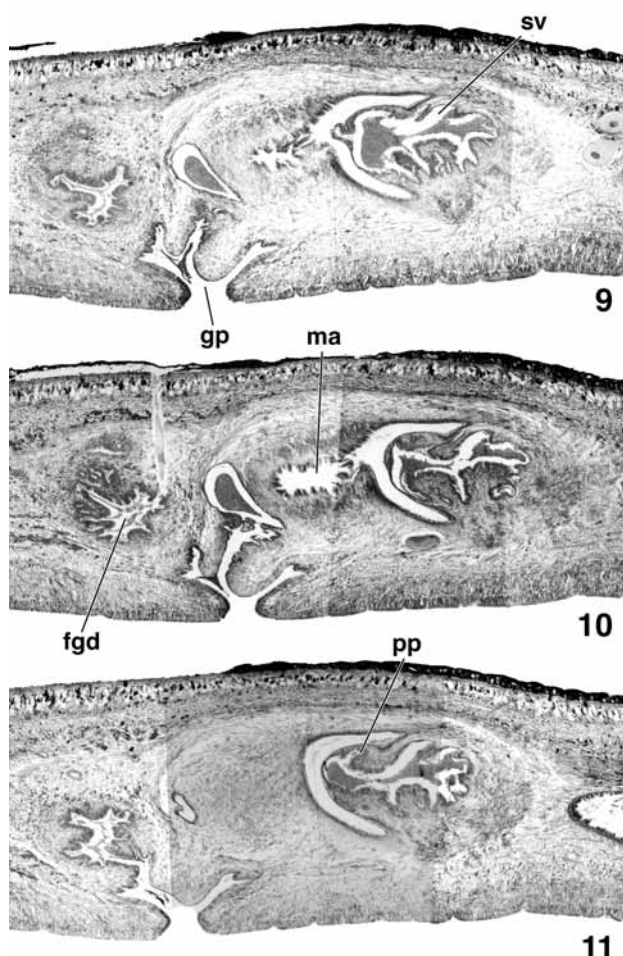


Fig. 9-11. – *Bipalium tetsuyai*. ZMA V.Pl. 948.1 Sagittal sections of the copulatory apparatus; anterior to the right.

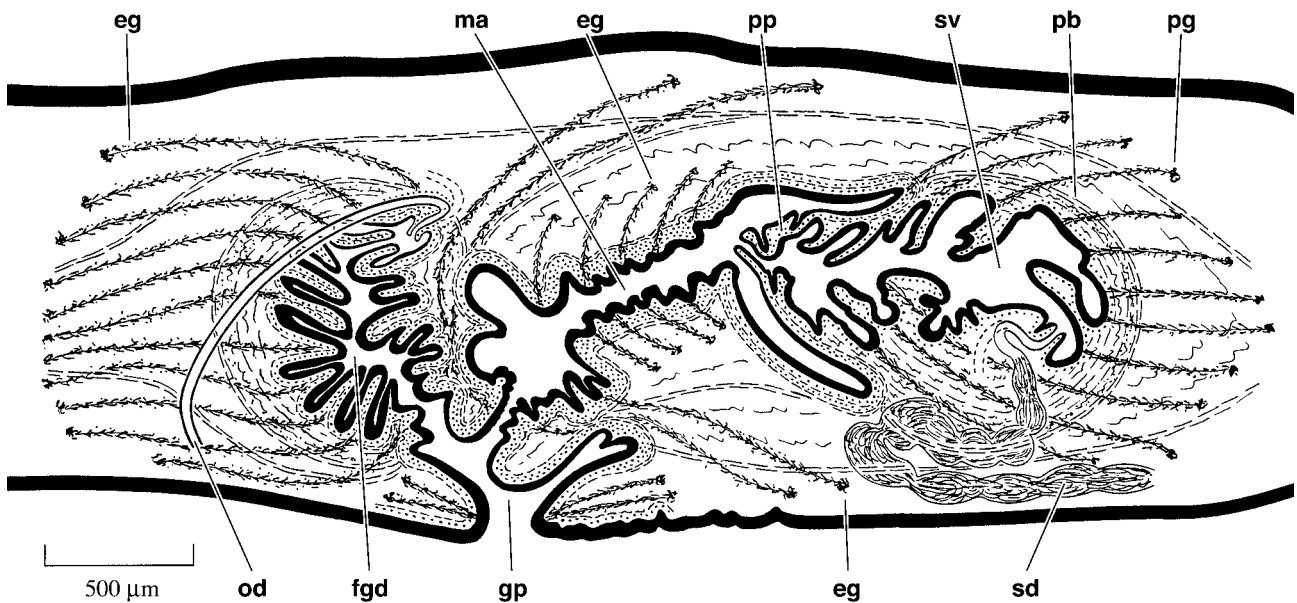


Fig. 12. – *Bipalium tetsuyai*. Holotype. ZMA V.Pl. 984.1. Sagittal reconstruction of the copulatory apparatus; anterior to the right.

The moderately large, conical penis papilla projects into the basal part of the male genital antrum. Judging from the uneven outline of the papilla, it was rather contracted when the animal was fixed (Figs 9–11). The outer wall of the penis papilla is covered with a thin, nucleated epithelium. Near its tip the papilla is provided with a thin, subepithelial layer of circular muscle. In the middle and more basal part of the penis papilla the circular muscle layer is considerably thicker and bounded by a layer of longitudinal muscles.

The irregularly shaped male genital antrum consists of an anterior, proximal cup-shaped cavity, a middle, tubular part provided with plicae, and a posterior, distal section with large folds, communicating with the common genital antrum through a narrow, tubular portion (Fig. 12). The male antrum is lined with a glandular, nucleated epithelium, underlain with a subepithelial circular muscle layer, followed by a thin longitudinal one. On the middle and posterior portions of the antrum the layer of subepithelial circular muscle is thicker than around the anterior part of the antrum; accompanying eosinophilous gland ducts are conspicuous in these areas (Fig. 12).

The rather wide female genital duct is provided with many large plicae and receives the separate openings of the ovovitelline ducts at its anterodorsal section. It is lined with a flat, nucleated and glandular epithelium that is underlain with a thin, subepithelial layer of circular muscle, followed by an equally thin layer of longitudinal muscle fibres. Both layers are thicker at the terminal part of the duct. The female genital duct receives the openings of numerous erythrophilic glands.

The common genital antrum is a shallow, cup-shaped cavity, lined with a flat, glandular epithelium and sur-

rounded by a layer of circular muscle and a layer of longitudinal muscle.

Additionally, the holotype specimen turned out to be infested with a gregarine species of which encysted specimens occur in the parenchyma and the muscular tissue of the pharynx (Fig. 8).

### Discussion

Among the 12 known *Bipalium* species from Japan, of which three are new species reported in the present paper, *Bipalium tetsuyai* stands apart from the other species in both external features and anatomy of the genital apparatus (see Diagnosis and Table 1). A lunate head with moderate auricles and a blackish margin (as observed in the living, holotype specimen) represent unique features of this species.

A single, longitudinal blackish mid-dorsal stripe is found also in *B. fuscolineatum*, *B. hilgendorfi*, *B. kisoense*, *B. monolineatum*, *B. ochroleucum*, and *B. tetsuyai*; all these species are devoid of stripes on the ventral surface. However, in *B. tetsuyai* this mid-dorsal stripe runs only between the “neck” and the pharynx, in contrast to the other species, in which this stripe reaches the posterior end of the body.

The anatomy of both female and male genital apparatus of *B. tetsuyai* is similar to that of *B. hilgendorfi* (cf. KABURAKI, 1922a; KAWAKATSU & KAWAKATSU, 1991, Fig. 4A, B; see also Table 1). However, the penis lumen of *B. tetsuyai* is wide and provided with many large plicae, in contrast to the more regularly shaped lumen in *B. hilgendorfi*. With respect to external features it should be noted that in *B. hilgendorfi* the head is rotundate and provided with short auricles, contrasting with the semilunate head of *B. tetsuyai*.

*B. tetsuyai* can be distinguished from the Korean species *B. koreense* and the Chinese species *B. kaburakii* and *B. katoi* by the fact that these species have a single mid-dorsal stripe, as well as two lateral and two marginal longitudinal stripes (see Table 4).

***Bipalium glandiantrum* sp. nov.**

**Material :** Holotype, ZMA V.Pl. 985.1, Sanjō City, Nigata Pref., Chūbu Region, Honshū, 3-6 June 1987, sagittal sections on 28 slides (PRE), and sagittal sections on 31 slides (GT).

Paratypes : ZMA V.Pl. 985.2, *ibid.*, sagittal sections on 14 slides (PRE); V. Pl. 985.2, *ibid.*, transverse sections on 17 slides (PT); V.Pl. 985.2, sagittal sections on 35 slides (G).

NSMT 5417, *ibid.*, sagittal sections on 25 slides (PRE); NSMT 5417, *ibid.*, sagittal sections on 30 slides (CT).

Other material examined : ZMA V.Pl. 986.1, Sanjō City, Nigata Pref., Chūbu Region, Honshū, 21 July 1987, sagittal sections on 19 slides (PRE); V.Pl. 986.1, *ibid.*, sagittal sections on 18 slides (CT); V.Pl. 986.2, *ibid.*, whole mount on 1 slide.

**Diagnosis**

*Bipalium glandiantrum* sp. nov. can be distinguished from its congeners by its small size (30 – 50 mm long), semilunate head with recurved auricles, uniform ochre or yellowish brown dorsal body surface with relatively broad, blackish middorsal stripe and a pair of lateral stripes, dark colouration on submarginal ventral part of the head and on both sides of the neck. The species can be distinguished by a moderately sized penis bulb, elongated conical penial papilla, long and tubular penis lumen, and moderately sized male antrum, spherical female organ with a spacious female genital duct provided with several plicae, common genital antrum anteriorly provided with an adenodactyl-like structure. Furthermore, *B. glandiantrum* sp. nov. has a diploid complement with  $2n = 10$  chromosomes.

**Ecology and distribution**

Known only from the type locality, where it was collected from the garden of Mr. Kozakai's residence.

**Etymology**

The specific epithet is derived from the Latin prefix *glandi*, meaning “glandular” and the noun *antrum*, “cave”. It alludes to the glandular nature of the anterior part of the common genital antrum.

**Description**

A rather small species. According to Mr. Murayama, one of the collectors, the largest sexual specimen in elongated state was approximately 50 mm in length with a width of about 5mm. The body dimensions of four pre-

served specimens are as follows : TL : 29-38 mm, HML : 14-18 mm, HGL : 17-23 mm, WM : 3.5-4 mm.

In the living animal the semi-lunar head shows a pair of protruding and recurved auricles. In preserved condition the depressed head is rotundate with short and rounded auricles. The body narrows slightly at the region of the “neck”, and subsequently broadens again towards the pharynx and the copulatory apparatus; the tail is bluntly pointed. In preserved specimens the body has a serrate outline (Figs 13, 14).

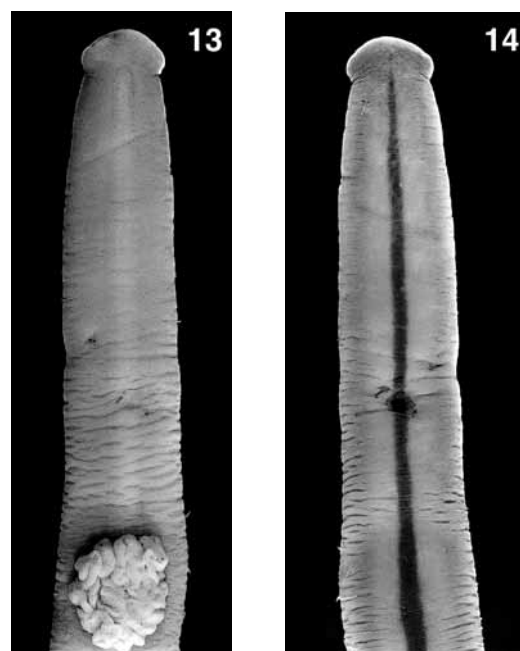


Fig. 13-14. – *Bipalium glandiantrum*. ZMA V.Pl. 985. Ventral (13) and dorsal (14) views of preserved specimen.

The dorsal surface has a uniform ochre or yellowish brown ground colour; the head is darkish, except for its margin. The dorsal surface is provided with three longitudinal stripes. There is a black and relatively broad mid-dorsal stripe, extending over the entire body, except for the anterior part of the head plate; the stripe becomes slightly broader over the regions of the pharynx and the copulatory apparatus. There are two dark coloured, relatively broad lateral stripes, one on either side of the body, beginning at the “neck” and extending to almost the posterior end of the body.

The ventral body surface has a uniformly pale colouration, except for the creeping sole, the submarginal parts of the head and both sides of the “neck” that show a dark colouration; furthermore, a pair of brownish, relatively wide lateral longitudinal stripes is conspicuous in living specimens.

A few rows of numerous small eyes are irregularly distributed along the margin of the head.

The testis follicles are situated ventrally in the prepharyngeal part of the body, but are only well developed (albeit not fully mature) in specimen V.Pl.986.1 (Fig. 15).

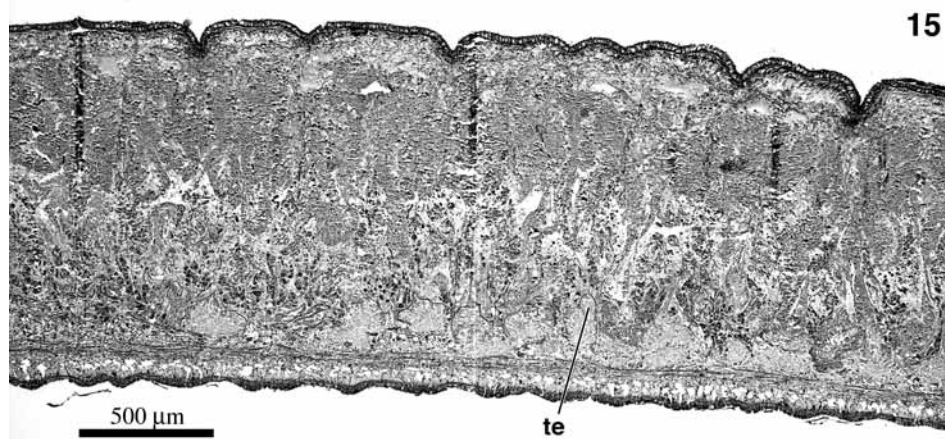


Fig. 15. – *Bipalium glandiantrum*. ZMA V.Pl. 986.1. Sagittal section of the prepharyngeal part; anterior to the right; notice testes.

The penis consists of a moderately large spherical bulb and an elongated, conical papilla. The bulb is moderately muscular and houses a narrow, tubular cavity. The latter receives the separate openings of the sperm ducts at its anterior part, while the posterior section of the cavity communicates with the club-shaped ejaculatory duct, which opens at the tip of the penis papilla (Figs 16, 17). The bulbar cavity and the ejaculatory duct are lined with a nucleated, glandular epithelium that is underlain with a subepithelial layer of circular muscle, followed by a layer of longitudinal muscle fibres. Erythrophilic penis glands open into the bulbar cavity and into the basal portion of the ejaculatory duct. The penis papilla is covered with a thin, nucleated epithelium, underlain with a thin, subepithelial layer of circular muscle, being rather thick at the base of the papilla, followed by an equally thin layer of longitudinal muscles.

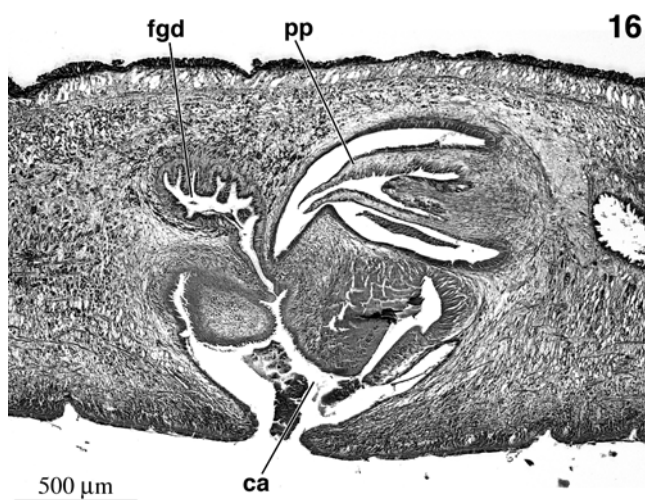


Fig. 16. – *Bipalium glandiantrum*. NSMT 5417. Sagittal section of the copulatory apparatus; anterior to the right.

The male genital antrum, with the shape of a champagne glass, communicates with the dorsal section of the posterior part of the common atrium (Fig. 17). The male antrum is lined with a thin, nucleated epithelium, underlain with a thin, subepithelial layer of circular muscle, followed by a thin layer of longitudinal muscles.

The female genital duct consists of two parts: a wide posterior part provided with several well-developed pliae, and an anterior section that ventrally opens into the posterodorsal part of the common antrum (Fig. 17). Two ovovitelline ducts open separately into the posterior part of the female genital duct. The small ovaries are situated immediately above and slightly embedded in the thickened sections of the ventral nerve cords that form the brain. Yolk glands are well developed and lie dispersed in the parenchyma.

The female genital duct is lined with a rather flat, nucleated epithelium and is surrounded by a subepithelial layer of circular muscle and a layer of longitudinal muscle fibres. Over its entire length the duct receives the numerous openings of erythrophilic glands.

The common genital atrium is formed by a shallow cup-shaped cavity that opens into the gonopore.

Ventrally to the male antrum, a hump-shaped adenodactyl-like organ is differentiated, consisting of loosely arranged muscles and a rather wide lumen. This lumen is lined with a flat, infranucleated epithelium and is surrounded by a relatively thick subepithelial layer of circular muscle, followed by a thin layer of longitudinal fibres. The lumen receives the numerous openings of erythrophilic and cyanophilic glands; it opens into the anterior part of the common antrum.

The posterior section of the common antrum adjacent to the adenodactyl-like organ is provided with a thick layer of circular muscle fibres, followed by a thinner layer of longitudinal fibres. The entire common antrum is lined with a nucleated epithelium.

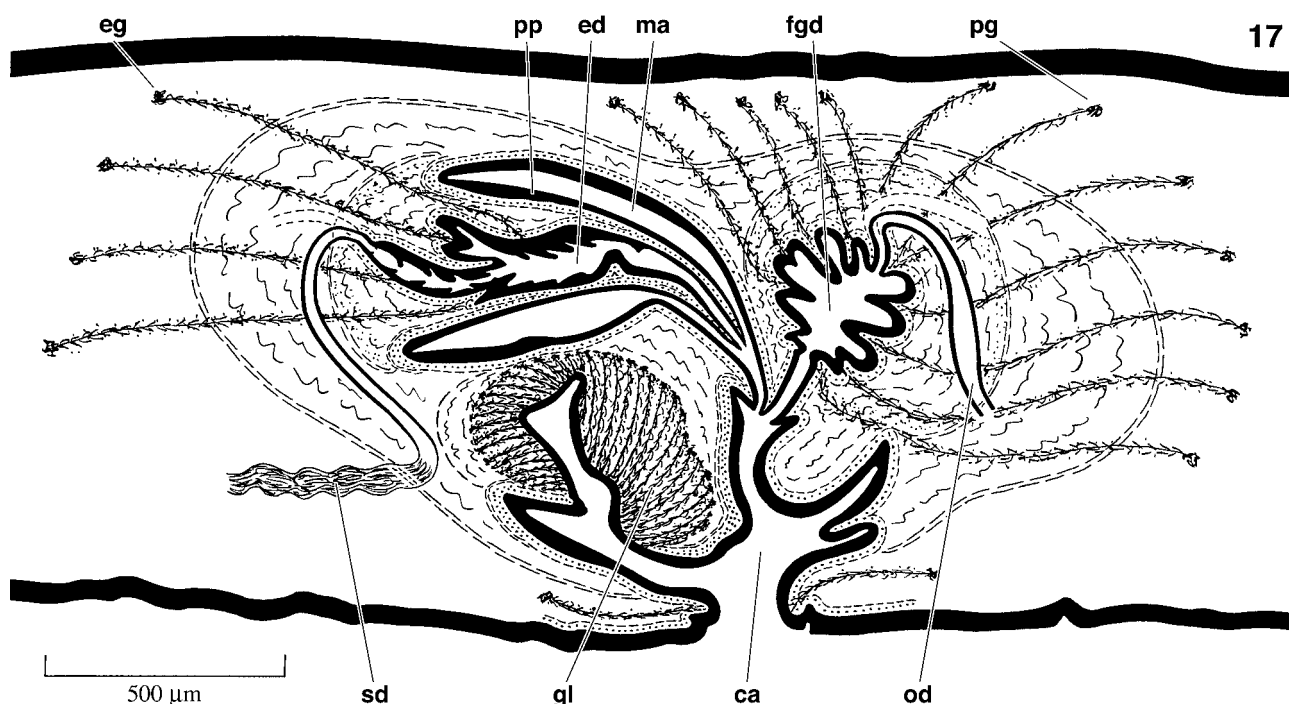


Fig. 17. – *Bipalium glandiantrum*. Holotype. ZMA V.Pl. 985.1. Sagittal reconstruction of the copulatory apparatus; anterior to the left.

## Discussion

This species can be distinguished from the other eleven Japanese species of *Bipalium* by its rather small body size, semilunate head with moderately recurved auricles, yellowish brown dorsal surface with three longitudinal stripes, and a pair of brownish longitudinal lateral stripes on the ventral surface (Table 1); these external features are unique for *B. glandiantrum*.

With respect to its external features, *B. glandiantrum* resembles somewhat *Novibipalium trifuscostratum* (Kaburaki, 1922) (cf. KAWAKATSU, 1991b, figs 1A-C). However, the latter is a dark brown species with three very conspicuous, blackish longitudinal stripes on the dorsal surface, while the ventral surface is without stripes (see Tables 1 and 2). On the basis of their genital anatomy, these two species belong to different genera.

Characteristic for *B. glandiantrum* is its common genital antrum provided with an adenodactyl-like structure not found in any other Japanese species of *Bipalium* (cf. Table 1). In *B. nobile* and *B. kewense* there is a small glandular structure situated in the roof of the common genital antrum but morphologically and histologically these glandular organs are unlike the adenodactyl-like structure in *B. glandiantrum* (cf. KAWAKATSU, 1985, Fig. 4; KAWAKATSU et al., 1982, figs 6A, C).

### *Bipalium muninense* sp. nov.

**Material:** Holotype, ZMA V.Pl. 987.1, October–November 1987, Ômura, Chichi-jima Island, the Ogasawara Islands, Japan, sagittal sections on 16 slides (PRE); V.Pl. 987.1, ibid., sagittal sections on 43 slides (PHG).

**Paratypes:** ZMA V.Pl. 987.2, ibid., sagittal sections on 26 slides (PG); V.Pl. 987.2, ibid., transverse sections on

17 slides (PRE); NSMT 5418, ibid., sagittal sections on 22 slides (PG); ZMA V.Pl. 987.3, ibid., sagittal sections on 18 slides (PG); V.Pl. 987.4, whole mount on 1 slide.

## Diagnosis

With respect to external features, *Bipalium muninense* sp. nov. can be distinguished from its congeners by its small size (less than 50 mm in length), lunate head with non-recurved auricles, slightly reddish dark brown dorsal surface, yellowish brown head plate, and five dark brown stripes arranged as follows: slender mid-dorsal stripe that extends on the head as an oblongate spot; a broad lateral stripe on each side of the median one and beginning at the “neck”; a pair of broad submarginal stripes. Ventral surface devoid of stripes. Anatomically the species is characterized by ellipsoidal, moderately sized penis bulb, short conical penis papilla, spacious penial lumen, well muscularized male antrum at its posterior section, and an oblongate female organ provided with a spacious female genital duct.

## Ecology and distribution

Known only from the type locality, a subtropical forest at Ômura on Chichi-jima Island (cf. KAWAKATSU et al., 1999, fig. 1).

## Etymology

The specific epithet is derived from Munin-jima Island(s), the oldest name for the Ogasawara Islands. “Munin” (or “Mujin”) in the Japanese language meaning “without residents”, the English name “Bonin Islands” being derived from the Japanese name for these islands.



## Description

A rather small species. According to the information provided by the collectors, the largest living, sexually mature specimen reached a length of 50 mm in elongated state. The dimensions taken from three preserved specimens are as follows : TL : 24-33 mm; HML : 11-13 mm; HGL : 16-22 mm; WM : 3-4 mm.

In the living animal the lunate head has a pair of moderately developed, non-recurved auricles (Fig. 18). In preserved condition the head has a more reniform shape (Figs 19, 20). The body narrows abruptly at the level of the "neck", and subsequently widens gradually towards the region of the pharynx and the copulatory apparatus; the tail is bluntly pointed.

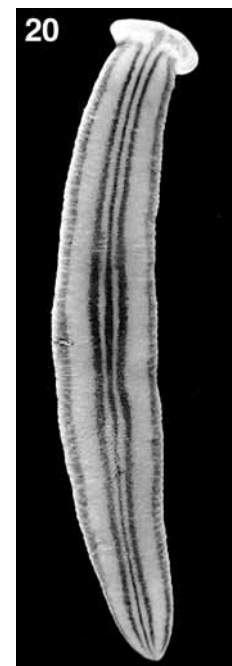
The ground colour of the dorsal surface is rather dark brown, with reddish tint, except for the head plate which shows a yellowish brown colouration; the central and posterior parts of the head plate have a brownish tint. Five dark brown conspicuous dorsal stripes extend to almost the posterior end of the body. A mid-dorsal stripe starts as an oblongate spot on the head and extends as a narrow line to the posterior end of the body. This median stripe is flanked by lateral stripes that begin at the level of the "neck" and stop short of the hind end of the body. Along the body margins runs a rather broad submarginal stripe from the "neck" up to the posterior end. The ventral side shows a much paler ground colour, with only the creeping sole being bordered by an indistinct dark pigmentation and the lateral body margins being provided with an equally indistinct pigment pattern.

Three or more rows with numerous eyes situated along the periphery of the head, particularly concentrated in the "neck" region (also on the ventral side). The eyes extend posteriorly along the sides of the body but there they are fewer in number, more aligned in a single row, and spaced further apart.

Numerous, rounded testes are situated ventrally, extending from behind the ovaries to the level of the pharynx (Fig. 21).

The penis is provided with a moderately large, ellipsoidal bulb and a conical papilla. The bulb is moderately muscular and houses a very large, irregularly-shaped, obpyriform cavity that anteroventrally receives the separate openings of the two sperm ducts. The bulbar cavity extends into the penis papilla, gradually tapering to give rise to a wide, tubular ejaculatory duct that opens at the tip of the papilla. The entire penis lumen is lined with a tall, nucleated epithelium that is underlain with a subepithelial layer of circular muscle fibres followed by a layer of longitudinal muscle (partly intermingled circular and longitudinal muscle fibres at the basal part of the bulbar cavity).

The penis papilla is covered with a thin, nucleated epithelium and is provided with a thin, subepithelial layer of circular muscle, followed by an equally thin layer of longitudinal muscle fibres.



Figs 18-20. – *Bipalium muninense*. 18, live specimen. Ventral (19) and dorsal (20) views of preserved specimen.

The male genital antrum consists of an anterior, cup-shaped cavity housing the penis papilla and a posterior, lenticular part that opens into the male genital pore (Fig. 22). The anterior part of the male antrum is lined with a thin, glandular and nucleated epithelium, underlain with a thin, subepithelial layer of circular muscle and an equally thin layer of longitudinal muscle fibres. Both the glandu-



lar epithelium and the muscular coat become thicker on the posterior section of the male antrum. The musculature around this posterior part consists of a thick, subepithelial layer of circular muscle, a thick layer of intermingled muscle, followed by an outer layer of longitudinal muscle fibres. Erythrophilic gland ducts open into the bulbar cavity, into the posterior part of the male antrum, and into the anterior part of the male antrum.

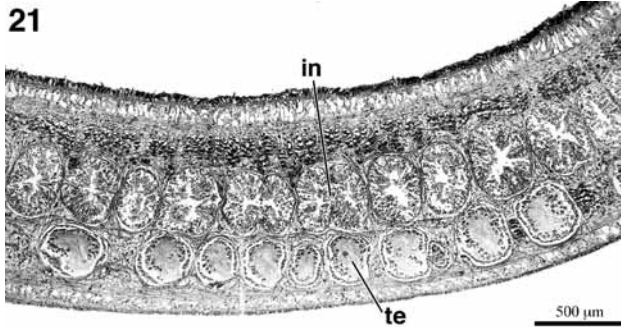


Fig. 21. – *Bipalium muninense*. ZMA V.Pl. 987.1. Sagittal section of the prepharyngeal region; anterior to the left; notice testes.

The small ovaries are situated immediately above and slightly embedded in the thickened sections of the ventral nerve cords that form the posterior part of the brain. Yolk glands are well developed and lie dispersed in the parenchyma.

The female genital duct consists of two parts, viz. a narrow posterior cavity with several plicae and an anterior part that opens into the posteroventral section of the female genital pore. The posterior part of the female genital duct receives the separate openings of the ovovitelline

ducts, the latter approaching the duct from posterolateral direction. Many erythrophilic and a few cyanophilic gland ducts penetrate the wall of the female genital duct, excepting its terminal, ventral part. The entire female duct is lined with a relatively tall, glandular and nucleated epithelium; it is surrounded by a thin subepithelial layer of circular muscle, followed by an equally thin layer of longitudinal muscle fibres.

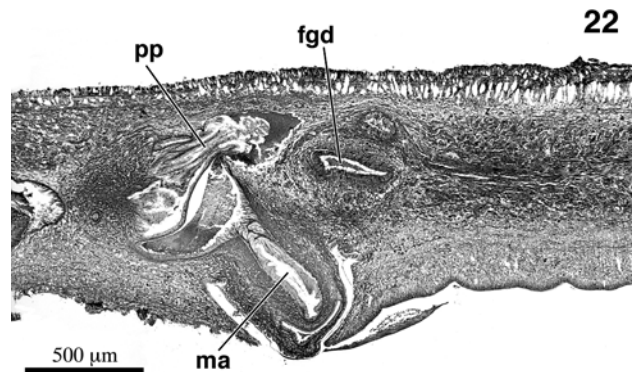


Fig. 22. – *Bipalium muninense*. ZMA V.Pl. 987.3. Sagittal section of the copulatory apparatus; anterior to the left.

In the holotype specimen (Fig. 23), a common genital antrum is hardly developed, except for its anterior portion, due to the elongation of the posterior part of the male antrum and the tubular portion of the female genital duct. The common antrum is lined with a nucleate epithelium that is underlain with a subepithelial layer of circular muscle and a layer of longitudinal muscles.

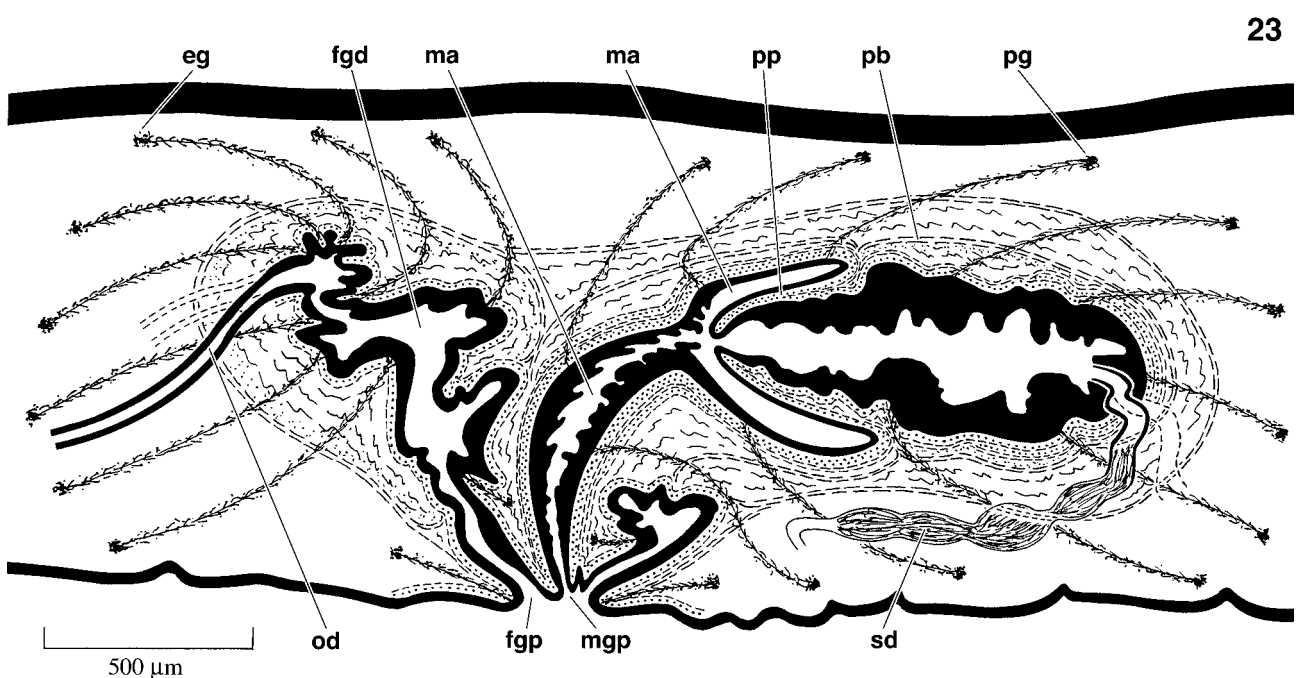


Fig. 23. – *Bipalium muninense*. Holotype. ZMA V.Pl. 987.1. Sagittal reconstruction of the copulatory apparatus; anterior to the right.

## Karyology

Chromosome complement :  $2x = 10$ , with a karyotype of  $2m + 2sm + 2sm + 2sm + 2m$  (cf. KAWAKATSU et al., 1990, figs 15D, 16 : *Bipalium* sp. 3; OKI et al., 1991, figs 2C, 3 : *Bipalium* sp. 3).

## Discussion

This species can easily be distinguished from other Japanese species of *Bipalium* by its rather small size, lunate head with non-recurved auricles, slightly reddish brown dorsal surface with five longitudinal dark brown stripes, and the absence of stripes on the ventral body surface (Fig. 20; see also Table 1).

Although *B. kewense* also shows five longitudinal dorsal stripes, their pattern is completely different from that in *B. muninense* (cf. KAWAKATSU et al., 1982, figs 3A-C, E, H-I). Furthermore, *B. kewense* possesses ventrally a pair of lateral stripes (cf. KAWAKATSU et al., 1982, figs 3D, F, J). Both the dorsal and ventral patterns of longitudinal stripes in *B. nobile* are quite different from the situation in *B. muninense* (cf. KAWAKATSU et al., 1982, figs 1A-F, 2; see also web articles by SASAKI et al., 2001; YAMAMOTO et al., 2003). Additionally, *B. kewense* and *B. nobile* are very long or giant species, respectively.

The dorsal pattern of *Diversibipalium multilineatum* (Makino & Shirasawa, 1983) resembles that of *B. muninense*, especially in the thickened anterior section of the mid-dorsal stripe on the head plate. However, *D. multilineatum* has three longitudinal stripes on the ventral surface, contrasting with the non-striped condition in *B. muninense*. Furthermore, *D. multilineatum* is a long species.

The Chinese species *B. katoi* also has five dorsal stripes but their pattern is quite different from that in *B. muninense* (cf. KATÔ, 1950, Fig. 4; see also Fig. 26 and Table 4).

The anatomy of the reproductive apparatus of *B. muninense* differs from that in other species, notably in the presence of the well-muscularized anterior section of the male genital antrum.

### *Bipalium kaburakii* sp. nov.

## Diagnosis

The dorsal surface is dark brown, with five black stripes, one median and two lateral, which extend almost throughout the whole length of the body. The copulatory apparatus shows the following characteristics : an ovoid penis bulb and a conical papilla; a tubular penis lumen with many plicae; a moderately large female genital duct, the posterior part of the latter receiving the openings of the ovovitelline ducts; ovovitelline ducts approaching the female duct from ventro-lateral direction; common genital antrum shallow and cup-shaped.

## Etymology

The new name refers to the late Dr. Tokio Kaburaki, who first reported on these Chinese specimens from Soochow.

## Description and comparative discussion

KABURAKI (1922b) reported “*Bipalium cantori* Wright, 1860” from Soochow (=Suzhou;  $31^{\circ}21'N$   $120^{\circ}40'E$ ), near Shanghai, Chiangsu Province, SE China. In point of fact, this locality is approximately 50 km NW of WRIGHT’S (1860) locality of “*Dunlopea Cantoria*”(i.e. Ningpo,  $29^{\circ}54'N$   $121^{\circ}33'E$ ), which is now classified as *Diversibipalium cantori* Wright, 1860 (see below).

KABURAKI (1922b) described his worms as follows : “In shape the worm conforms to the typical *Bipalium*-outline, with the head, which is semi-lunar, rather less than the breadth of the trunk, and marked off from it by a constriction. One of the two specimens measures about 165 mm long by 5 mm broad. The ground colour of the dorsal surface is dark brown, with five black stripes, one median and two lateral, which extend almost throughout the whole length of the body. The median stripe is very fine and anteriorly merges into the ground colour of the head in association with the fine inner pair. The outer pair at the margin of the body anteriorly terminates at the base of the cephalic lappets and is very faint in the preserved specimens. The ventral surface is of a much lighter colour than the dorsal.”

KABURAKI (1922b) did not provide any illustrations of the external features of his Chinese specimens. However, in his description of the habitus of the animal he did not mention the most characteristic features of *D. cantori*, viz. the presence of a dark brown margin on the head plate and the two dark lateral stripes that expand on the head to form beak-shaped spots (see above). In the experience of the senior author, external morphological features correlate with anatomical differences and generally occur only in restricted geographic ranges. As a consequence, stripes and pigmentation patterns on the dorsal surface represent valuable taxonomic characters for species identification.

In conclusion, KABURAKI’S (1922b) “*Bipalium cantori* from Soochow” is here considered to be a misidentification of a new local species. Its copulatory apparatus is characterized by the following features : a moderately large, ovoid penis bulb and a moderately sized conical papilla; a tubular penis lumen with many plicae; a moderately large female genital duct, the posterior part of the latter receiving the openings of the ovovitelline ducts; ovovitelline ducts approaching the female duct from ventro-lateral direction; common genital antrum shallow and cup-shaped (Fig. 24).

The samples of this Chinese animal studied by KABURAKI (1922b) were lost (cf. KAWAKATSU & SASAKI, 2004).

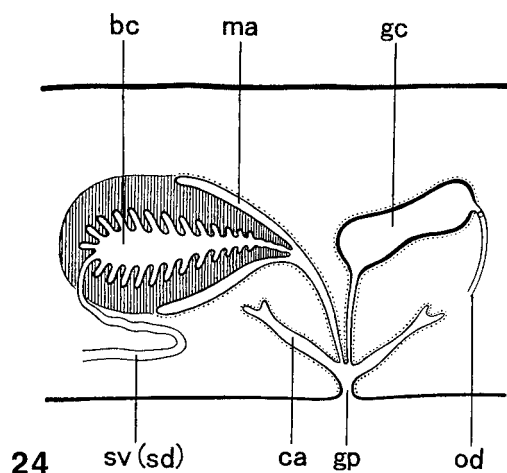


Fig. 24. – *Bipalium kaburakii*. Sagittal view of the copulatory apparatus (after KABURAKI, 1922b); anterior to the right.

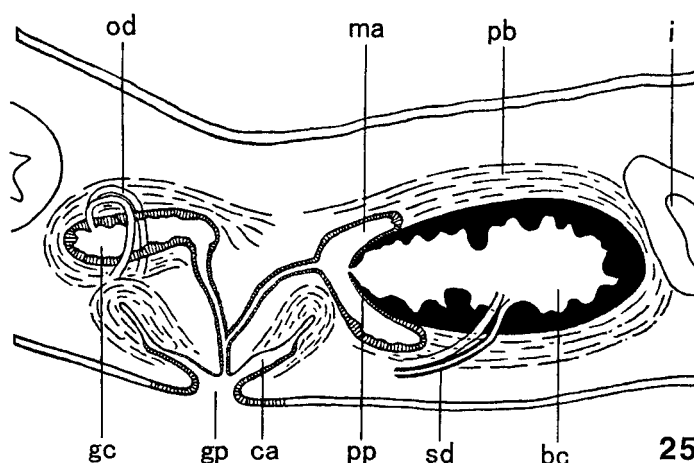


Fig. 25. – *Bipalium katoii*. Sagittal view of the copulatory apparatus (after KATÔ, 1950); anterior to the left.

#### *Bipalium katoii* sp. nov.

#### Diagnosis

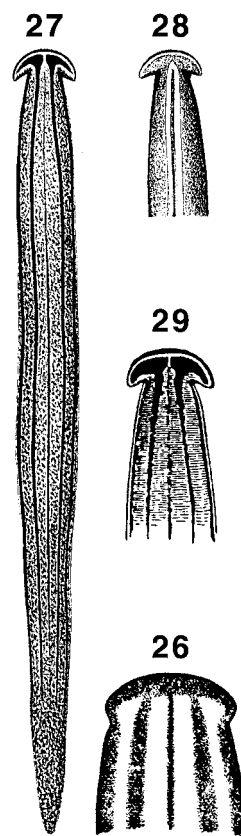
The dorsal surface shows five black, longitudinal stripes: a rather thin middorsal stripe, two broad lateral ones, and two broad marginal stripes; all stripes merge with a wide black band running along the entire margin of the head. The copulatory apparatus is characterized by the following features: short, conical penial papilla; very spacious penis lumen receiving the sperm ducts in its middle section; ovovitelline ducts opening dorso-laterally into the posterior portion of the female genital duct; female genital duct and the posterior, tubular part of the male antrum fuse to form a short common duct that opens at the midventral section of a muscular genital pad.

#### Etymology

The new name refers to the late Dr. Kojirô Katô, who was the first to describe the animals from Shanxi Province.

#### Description and comparative discussion

KATÔ (1950) reported a single, sexually mature specimen of “*Bipalium cantori* (Wright, 1860)” from a locality between Huang-shuighen and Huang-lingkuan, Shanxi Province (i.e. between 34°30' – 40°30'N, 109°30' – 113°30'E). Unfortunately, the material is no longer available for study since Dr. Kato's histological slides were lost during the Second World War (cf. KAWAKATSU & SASAKI, 2004). In preserved condition the animal was 70 mm long and 4 mm wide, with a rounded head. The colour of the body was a blackish brown, but after the animal had been exposed to a clearing agent, five black, longitudinal stripes were observed: a rather thin middorsal stripe, two broad lateral ones, and two broad marginal stripes. All stripes merge with a wide black band running along the entire margin of the head (Fig. 26).



Figs 26-29. – *Bipalium katoii* and *Diversibipalium cantori*. *B. katoii*. 26: dorsal view of the head (after Katô, 1950); *D. cantori*. 27: dorsal view; 28: ventral view of the head and anterior part of the body (after VON GRAFF, 1899); 29: dorsal view of the head and the anterior part (after WRIGHT, 1860).

The male copulatory apparatus consists of a spheroidal penis bulb and a short, conical papilla. Both papilla and bulb are provided with a very spacious, plicate lumen. Sperm ducts approach the lumen from ventro-posterior direction and open into the middle section of the penis lumen.

The female genital duct receives the separate openings of the ovovitelline ducts at its dorsolateral section. Female genital duct and male antrum fuse to form a short common duct that opens at the midventral section of a muscular genital pad, the latter projecting into the common antrum. This common antrum is provided with a thick coat of muscle (Fig. 25).

KATÔ (1950) noted that there are several morphological and anatomical differences between his animal from Shanxi Province and KABURAKI'S (1922b) specimens from Chiangsu Province, but he attributed these differences to geographical variation within a single species (the two sampling localities are approximately 1000 km apart).

However, the external morphology of the head and the anterior part of the body in KATÔ'S specimen is quite different from that of *Diversibipalium cantori* and *Bipalium kaburakii* sp. nov. Although the anatomy of the copulatory apparatus of Katô's animal resembles that of *B. kaburakii* sp. nov., the former differs by exhibiting the following features: short, conical penial papilla; very spacious penis lumen receiving the sperm ducts in its middle section; sperm ducts approaching the penis lumen from ventro-lateral direction; ovovitelline ducts opening dorso-laterally into the posterior portion of the female genital duct; female genital duct and the posterior, tubular part of the male antrum fuse to form a short common duct that opens at the midventral section of a muscular genital pad, the latter projecting into the common antrum.

In view of the considerations presented above we conclude that Katô's "*Bipalium cantori*" from Shanxi Province actually represents a new species, for which we here coin the name *Bipalium katoi* sp. nov.

#### Genus *Novibipalium*

Kawakatsu, Ogren & Froehlich, 1998

#### *Novibipalium miyukiae* sp. nov.

**Material:** Holotype, ZMA V.Pl. 988.1, 28 October 1983, Hakodate City, Hokkaidô, sagittal sections on 18 slides (H); V.Pl. 988.1, ibid., sagittal sections on 16 slides (PC).

#### Diagnosis

On external features, *Novibipalium miyukiae* sp. nov. can be distinguished from other species of *Novibipalium* by its small size (preserved, 26 mm), rotundate head, and uniformly dark to blackish brown dorsal surface being devoid of stripes. Anatomically, the species is characterized by the following features: large, spheroidal penis bulb; penis papilla with turbinate base and long, pointed tip; penis lumen consisting of a T-shaped seminal vesicle, a middle section constituting a spacious bulbar cavity with many plicae, and a proximal section forming a tubular ejaculatory duct. The middle and posterior sections of

the male antrum form a well-developed penis sheath provided with a long, wide and bellows-shaped copulatory canal that is surrounded by a thick muscle coat. Relatively large, ellipsoidal female organ housing a spacious, irregular female genital duct that opens through a narrow, tubular part into the common antrum.

#### Ecology and distribution

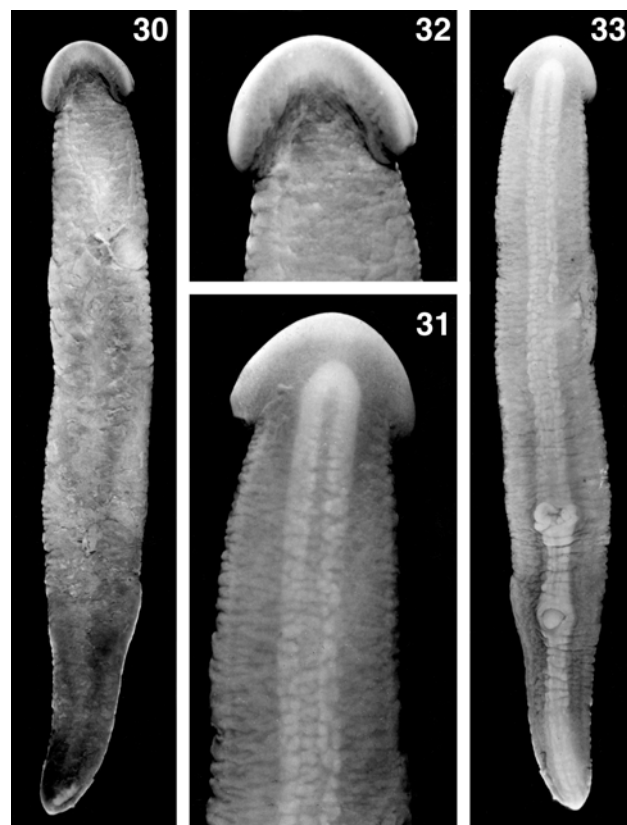
Known only from the type locality, where it was collected from the garden of Dr. Munakata's residence, Kaji-chô, Hakodate.

#### Etymology

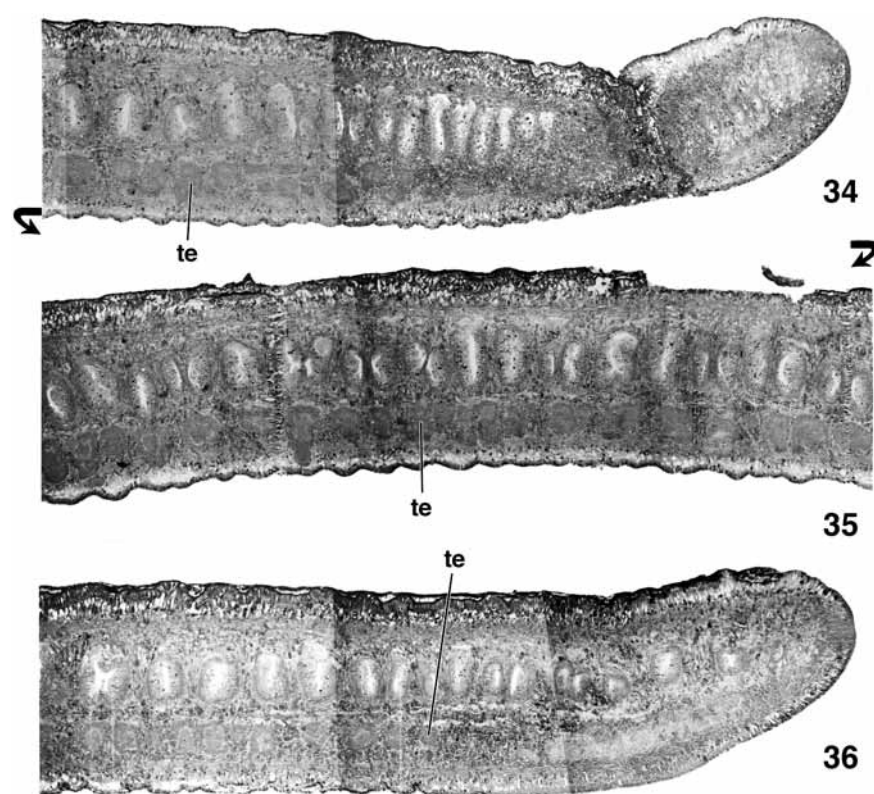
The specific epithet is based on the name of Kawakatsu's daughter, whose technical assistance throughout the years has been invaluable for the turbellarian studies of the senior author.

#### Description

A small and rather slender species. The dimensions of the preserved holotype specimen were as follows: TL: 26 mm; HML: 16 mm; HGL: 20 mm; WM: 3 mm. The contracted head was acorn-shaped with short, bluntly pointed auricles. Behind the head the body narrows slightly to form a "neck", after which it gradually widens again towards the regions of the pharynx and the copulatory apparatus; tail bluntly pointed. Denticulate lateral margins are conspicuous in the preserved specimen (Figs 30-33).



Figs 30-33. – *Novibipalium miyukiae*. ZMA V.Pl. 988.1, 30, dorsal view of preserved specimen; 31, ventral view of the anterior end; 32, dorsal view of the head; 33, ventral view.



Figs 34-36. *Novibipalium miyukiae*. ZMA V.Pl. 988.1. Sagittal sections of the prepharyngeal part of the animal.

The head plate is dark reddish brown and the dorsal body surface is uniform dark to blackish brown, without stripes. The ventral surface is uniformly greyish brown, except for the wide creeping sole. Numerous small eyes are present along the margin of the head plate, arranged in several rows.

The musculature in the dorsal part of the body is made up of a subepithelial muscle system consisting of a thin layer of circular muscle directly underneath the basement membrane, followed by a thin layer of longitudinal muscle fibres. A submuscular nerve net and a relatively thick layer of longitudinal muscle fibres are located below the subepithelial muscle layers. The body musculature on the ventral surface consists of a thin subepithelial layer of circular muscle, an equally thin layer of longitudinal fibres, a submuscular nerve net, and a thick layer of intermingled circular and longitudinal muscle fibres.

The ventral, prepharyngeal testes are small and rounded (Figs 34-36), the follicles being arranged in two longitudinal rows. Yolk glands lie dispersed in the parenchyma. The ovaries are small and rounded. Judging from the histological condition of ovaries and testes, the holotype specimen is probably not fully mature.

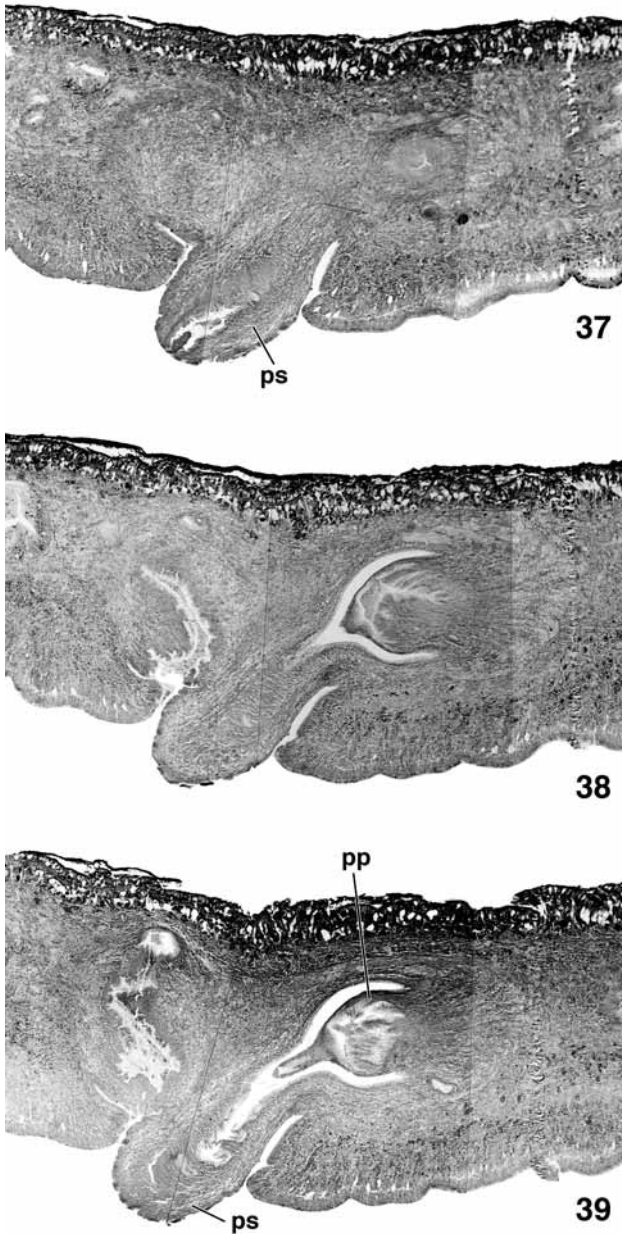
The penis is provided with a spheroidal bulb and a penial papilla consisting of a turbinate basal part and a long, pointed tip (Figs. 39, 40). The muscular bulb houses the narrow, "T-shaped", anterior part of the seminal vesicle, receiving the separate openings of the sperm ducts at its anteroventral portion, while its posterodorsal part communicates with the irregularly shaped cavity in the base of the penial papilla. This plicate cavity in the turbinate

part of the penis receives the numerous openings of penis glands and narrows abruptly to give rise to the narrow ejaculatory duct. The penis lumen is lined with a nucleated epithelium, underlain with a layer of circular muscle fibres.

The penis papilla is lined with a flat, nucleated epithelium and projects into the tubular canal of the penis sheath, or pseudophallus, the latter arising from the anterior section of the male genital antrum (Fig. 40). The canal of the penis sheath is lined with a nucleated epithelium and is surrounded by a thick, subepithelial layer of circular muscle, followed by a thin layer of longitudinal muscle. The penis sheath is covered with a relatively thick, nucleated epithelium that is underlain with a well developed, subepithelial layer of circular muscle and a layer of longitudinal muscle fibres. Furthermore, loosely arranged muscles fibres traverse the parenchyma of the free portion of the pseudophallus. In addition, a conspicuous annular zone of circular muscle extends from the base of the penis sheath well into the parenchyma of the body. Abundant erythrophilic penis glands open into the middle part of the male antrum.

The female copulatory apparatus is a large, spheroidal, moderately muscular organ provided with a female genital duct, receiving the openings of numerous erythrophilic glands. Many erythrophilic glands open into the beginning and especially into the posterior wall of the female genital duct. This female genital duct has many plicae and receives the separate openings of the ovovitelline ducts at its anterodorsal portion. The female genital duct is lined with a thick, nucleated epithelium and is surrounded by a

thick coat of muscle : a thin, subepithelial layer of longitudinal muscle, a relatively thick layer of intermingled circular and longitudinal fibres, and a third thin layer of longitudinal muscle fibres.



Figs 37-39. – *Novibipalium miyukiae*. ZMA V.Pl. 988.1. Sagittal sections of the copulatory apparatus; anterior to the right.

## Discussion

In addition to the two new species of *Novibipalium* described in this paper three other species have been reported from Japan, viz. *N. falsifuscatum* Kawakatsu, Ogren & Froehlich, 1998, *N. trifuscostriatum* (Kaburaki, 1922), and *N. venosum* (Kaburaki, 1922) (cf. KAWAKATSU, 1991b; KAWAKATSU et al., 1998; KAWAKATSU & SASAKI, 2001; see also Table 2).

On the basis of its external appearance, with blackish brown colouration on the dorsal body surface and without stripes on both dorsal and ventral surface, *N. miyukiae*

can easily be distinguished from *N. falsifuscatum* and *N. trifuscostriatum*.

*N. venosum* is a moderately sized species (2 specimens examined by the original author were 90 x 5 mm and 50 x 2.5 mm) with a lunate head with well-developed auricles, dark brown dorsal body surface, and without stripes on dorsal or ventral body surface. Both externally and anatomically, *N. miyukiae* and *N. venosum* are rather similar. As already pointed out by KAWAKATSU et al. (1991b), reidentification of KABURAKI'S (1922a) species presents serious difficulties. This is due to KABURAKI'S classical descriptions and his rather simplified drawings of the copulatory apparatus. Muscle layers of the copulatory apparatus and details of glandular ducts are usually not detailed in his figures. Unfortunately, all of his original specimens were lost (cf. KAWAKATSU & SASAKI, 2004).

*N. miyukiae* is much smaller than *N. venosum*. Furthermore, the genital anatomy of the former differs from the latter in the following features : presence of a large, spherical penis bulb; penis papilla with turbinate base and long, pointed tip; penis lumen consisting of a T-shaped seminal vesicle, a middle section constituting a spacious bulbar cavity with many plicae, and a proximal section forming a tubular ejaculatory duct; the middle and posterior sections of the male antrum form a well-developed penis sheath provided with a long, wide and bellows-shaped copulatory canal that is surrounded by a thick muscle coat. Furthermore, in *N. miyukiae* abundant erythrophilic glands open into the posterior section of the penis lumen, while the female genital duct and the copulatory canal are very conspicuous.

The distance between the type localities of *N. miyukiae* and *N. venosum* is about 1000 km and crosses the Tsugaru Straits. The latter are also known as Blakiston's Line, representing one of the biogeographical boundaries of both plants and animals in Japan; the Strait opened some time during the Late Pleistocene, about 1 My ago (see KAWAKATSU et al., 1990). There is no indication that the Hakodate population of *N. miyukiae* is the result of an artificial introduction from Honshû.

In view of the arguments presented above, we conclude that *N. miyukiae* from southern Hokkaidô in northern Japan, represents a new species.

## *Novibipalium murayamai* sp. nov.

**Material :** Holotype, ZMA V.Pl. 989.1, 3-6 June 1987, Sanjô City, Nîgata Prefecture, Chûbu Region, Honshû, sagittal sections on 46 slides (G).

Paratypes : ZMA V.Pl. 989.2, *ibid.*, sagittal sections on 54 slides (G); V.Pl. 989.2, *ibid.*, sagittal sections on 73 slides (PH); V.Pl. 989.2, *ibid.*, sagittal sections on 66 slides (H); V.Pl. 989.2, *ibid.*, transverse sections on 33 slides (PRE); NSMT 5419, *ibid.*, sagittal sections on 60 slides (G); ZMA V.Pl. 989.3, *ibid.*, whole mount of front end.

Other material examined : ZMA V.Pl. 990.1, 21 July 1987, Sanjô City, Nîgata Prefecture, Chûbu Region, Honshû, sagittal sections on 38 slides (PRE); V.Pl. 990.1, *ibid.*, transverse sections on 30 slides (PRE); V.Pl. 990.1, *ibid.*, sagittal sections on 42 slides (PG); V.Pl. 990.1, sagittal sections on 25 slides (T).

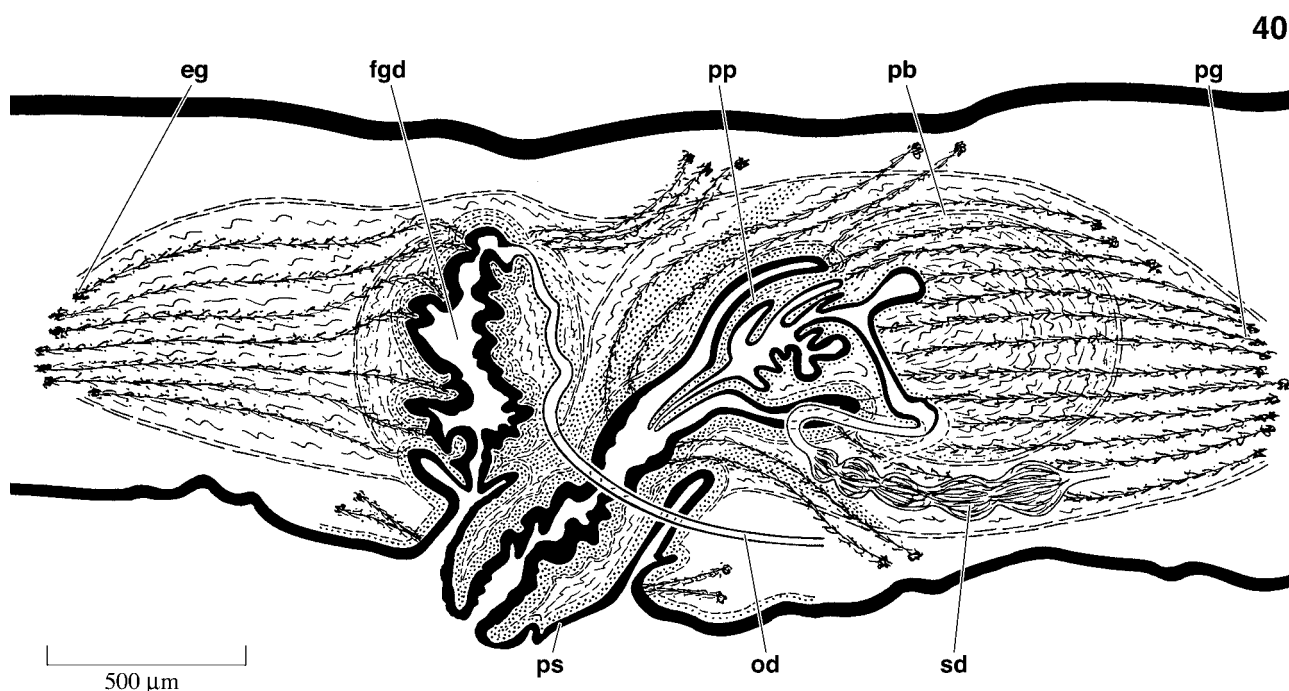


Fig. 40. – *Novibipalium miyukiae*. Holotype. ZMA V.Pl. 988.1. Sagittal reconstruction of the copulatory apparatus; anterior to the right.

### Diagnosis

On external features *Novibipalium murayamai* sp. nov. can be distinguished from its congeners by the following features: moderate size (50 – 60 mm long), semilunar head with protruding, recurved auricles; head plate and auricles with yellowish brown border and crescent-shaped spots; uniform yellowish brown to ochre-coloured on the dorsal body surface, with a pair of brownish lateral stripes. The ventral surface is devoid of stripes. Anatomically the species is characterized by the following features: large, spherical penis bulb; short, conical penis papilla; sperm ducts opening into the mid-ventral portion of the intrabulbar, plicate seminal vesicle; male atrium giving rise to a highly muscular penis sheath, or pseudophallus; female genital duct with an obovoid dorsal section, receiving the separate openings of the oovittelline ducts, and a bellows-shaped ventral part.

### Ecology and distribution

Known only from the type locality, where it was collected from the garden of Mr. Kozakai's residence.

### Etymology

The specific epithet is based on the family name of Mr. Hitoshi Murayama, whose cooperation for over 30 years has been invaluable for the turbellarian studies of the senior author.

### Description

According to observations made by the collectors, the largest living, sexually mature specimen in elongated condition measured approximately 100 mm in length, with a body width of about 6 mm. Dimensions taken from

three preserved specimens are as follows: TL: 56–60 mm; HML: 27–32 mm; HGL: 35–40 mm; WM: 6–7 mm.



Figs 41–42. – *Novibipalium murayamai*. ZMA V.Pl. 989. Ventral (41) and dorsal (42) view of preserved specimen.

The wide, semilunate head provided with protruding and recurved auricles (Figs 41–42). The body is rather flat and broad, with only a slightly narrower “neck” region and bluntly pointed tail.



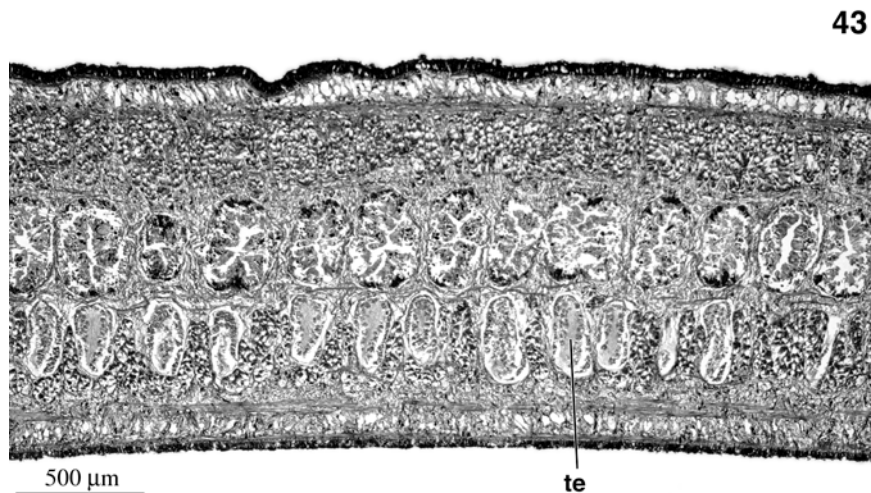


Fig. 43. – *Novibipalium murayamai*. ZMA V.Pl. 989.2. Sagittal section of the prepharyngeal region; anterior to the left; notice testes.

The dorsal surface is pale yellowish brown or ochre coloured, with the margins of the head plate and auricles being yellowish brown. The head pattern is very characteristic, consisting of several crescent-shaped spots arranged as follows : the outer, yellowish brown edge of the head plate, a crescent-shaped dark brown submarginal mark, a third, and crescent-shaped yellowish brown spot, followed lastly by a dark brown reniform spot on the “neck” or the basal part of the head plate. Two longitudinal brownish lateral stripes run from the “neck” region to the tail. The ventral surface is uniform greyish brown with relatively narrow creeping sole.

Numerous small eyes are located along the margin of the head and on the basal parts of the “neck”.

The testes are located ventrally, extending from behind the ovaries to just posterior of the pharyngeal pouch (Fig. 43).

The penis consists of a large, spherical bulb and a conical papilla. The bulb houses a plicate cavity, receiving the separate openings of the sperm ducts at its mid-ventral portion. This intrabulbar cavity continues in the penial papilla as an undulating ejaculatory duct, opening at the tip of the papilla. The papilla is covered with a flat, nucleated epithelium, underlain with a relatively thick, subepithelial layer of circular muscle, followed by a thin layer of longitudinal fibres. The entire penis lumen (i.e. cavity and duct) is lined with a flat, nucleated epithelium, underlain with a thin, subepithelial layer of circular muscle and an equally thin layer of longitudinal muscle fibres.

The male genital antrum shows three sections : (a) an anterior, bowl-shaped cavity housing the penial papilla, (b) a middle, fusiform cavity, and (c) a posterior, wine glass-shaped part, opening into the male genital pore. The middle and posterior parts of the antrum form the lumen

of a well-developed penis sheath, or pseudophallus. The lining epithelium of the anterior and middle sections of the antrum consists of relatively tall, nucleated, and highly glandular cells. The musculature around these parts consists of a thick, subepithelial layer of circular muscle and a much thinner layer of longitudinal muscle fibres; on the middle section the musculature becomes somewhat thicker than on the other sections. Middle and posterior section of the antrum are well separated by a conspicuous diaphragm; the posterior part is lined with a flat, nucleate and glandular epithelium that is underlain with thin layers of circular and longitudinal muscles (Fig. 44).

The penis lumen and the anterior and middle portions of the male antrum receive the abundant secretion of erythrophilic penis glands.

The free portion of the penis sheath is covered with a flat, nucleated and glandular epithelium, underlain with thin layers of circular and longitudinal muscle. Loosely arranged muscles lie dispersed in the parenchyma of the penis sheath (Fig. 45).

The female genital duct comprises two parts, viz. an obovoid dorsal section receiving the separate openings of the ovovitelline ducts, and a ventral, bellows-shaped section opening into the anteroventral part of the common genital antrum. The female genital duct is lined with a thick, nucleated epithelium that is pierced by the openings of numerous erythrophilic glands. The dorsal part of the duct is surrounded by a thick, subepithelial layer of circular muscle, followed by a thin layer of longitudinal fibres. The muscle coat around the ventral part of the female genital duct is much thinner.

The common genital antrum is lined with a flat, glandular and nucleated epithelium.

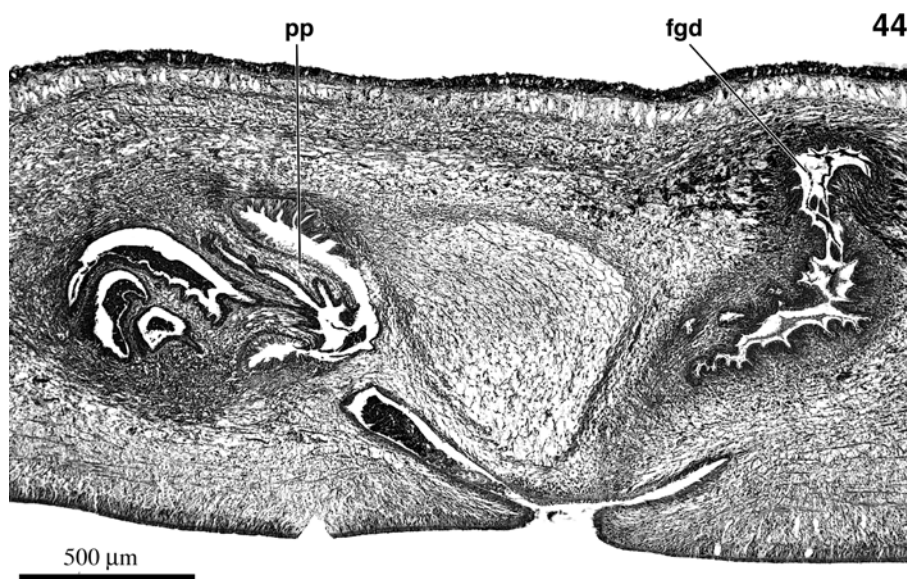


Fig. 44. – *Novibipalium murayamai*. NSMT 5419. Sagittal section of the copulatory apparatus; anterior to the left.

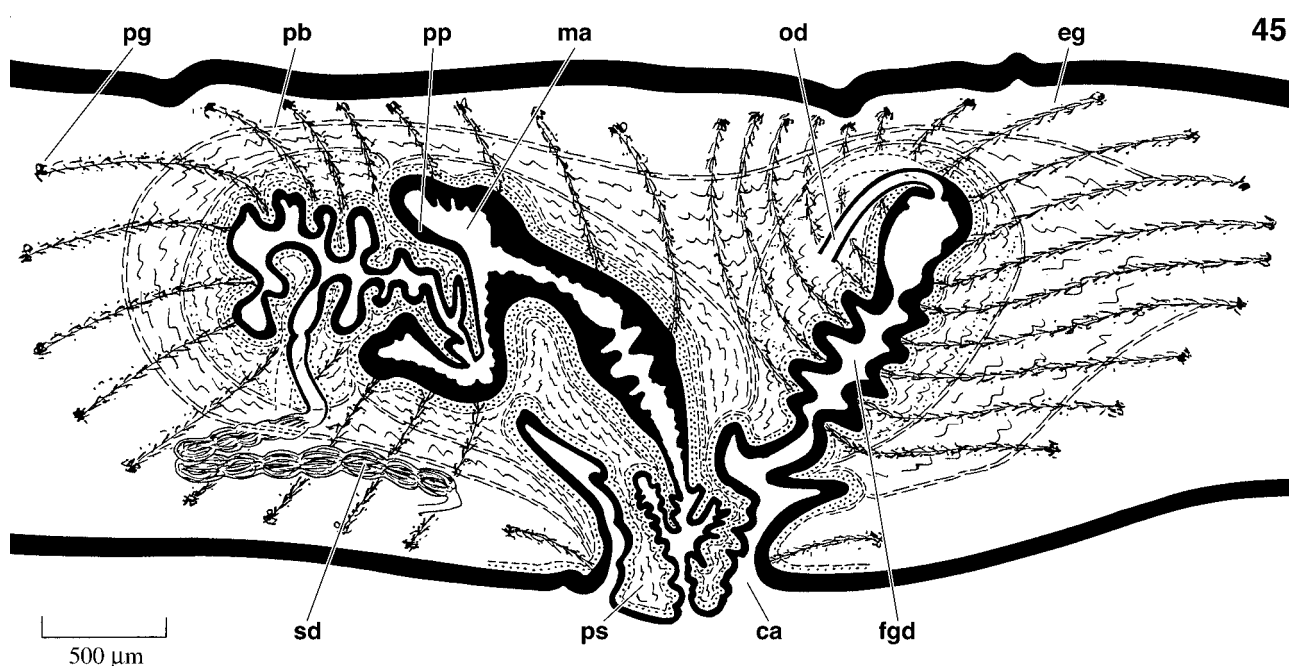


Fig. 45. – *Novibipalium murayamai*. Holotype. ZMA V.Pl. 989.1. Sagittal reconstruction of the copulatory apparatus; anterior to the left.

### Karyology

Chromosome complement :  $2x = 10$ , with a karyotype of  $2m + 2sm + 2sm + 2sm + 2m$  (cf. KAWAKATSU et al., 1990, figs 15C, 16 : *Bipalium* sp. 2; OKI et al., 1991, fig. 3 : *Bipalium* sp. 2).

### Discussion

*N. murayamai* can be distinguished from the other four Japanese species of *Novibipalium* by its characteristic

external features : lunate or semilunate head with moderately protruding, recurved auricles; head plate and auricles provided with a conspicuous crescent-shaped mark; a pair of brownish and rather broad longitudinal stripes on a yellowish brown dorsal surface; lack of stripes on the ventral body surface.

Among the known species of *Novibipalium*, the mid-ventral openings of the sperm ducts into the bulbar cavity are conspicuous only *N. murayamai*. Another unique character of *N. murayamai* is the presence of a well-

developed, highly muscular penis sheath, with its middle and posterior sections being separated by a conspicuous diaphragm. With respect to the female reproductive apparatus *N. murayamai* can be distinguished by its large

female genital duct consisting of a wide cavity, followed by a bellows-shaped section that communicates with the anteroventral part of the common genital antrum.

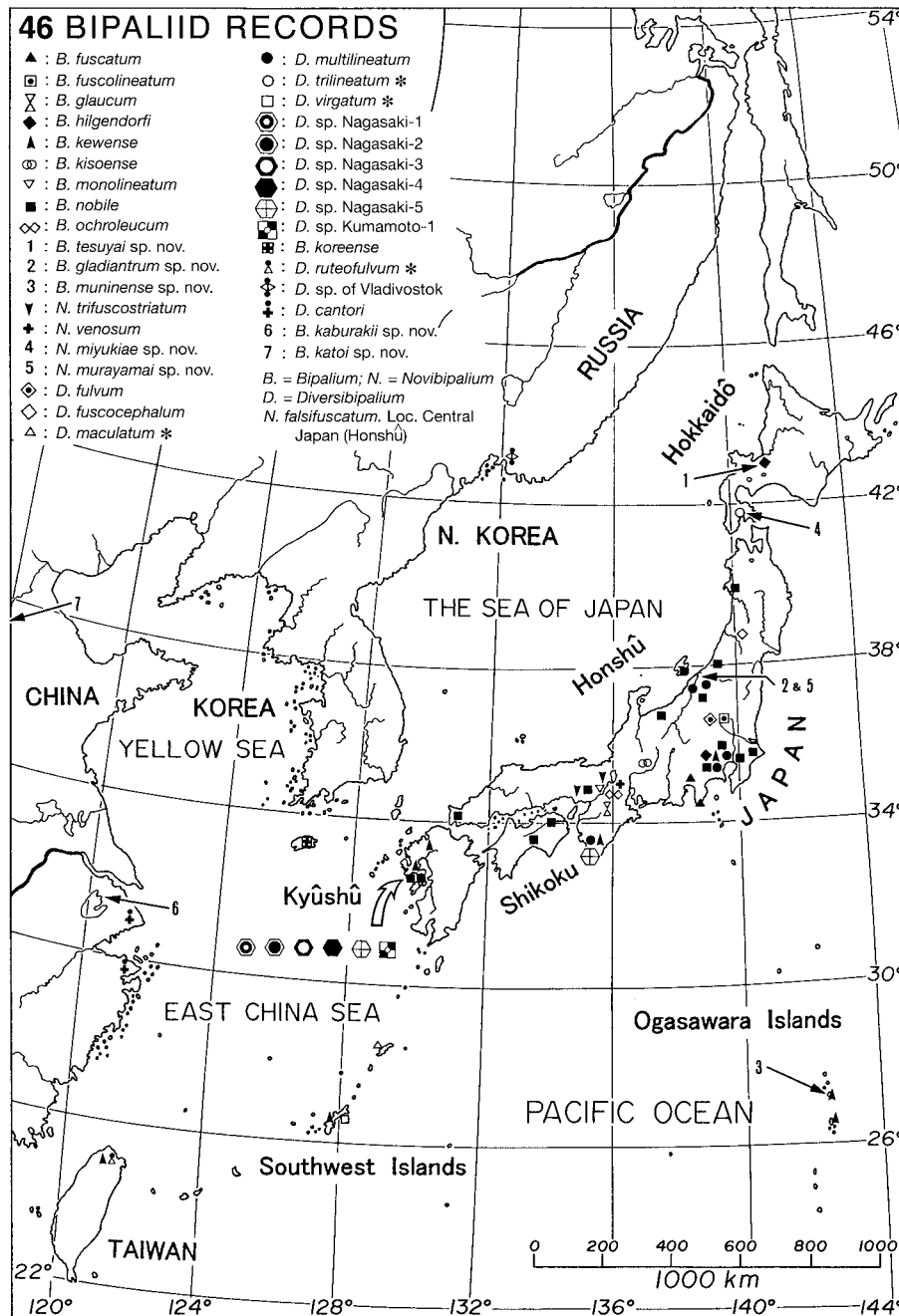


Fig. 46. – Distributional records of bipaliid species from the Far East. Each symbol on the map generally represents a separate record. Arrows with the numbers 1 – 5 point to the type localities of the five new Japanese species described in this paper; numbers 6 – 7 point to the localities of the two new Chinese species. N.B. The locality of *N. falsifuscum* is only known as Central Japan.

# **BIOGEOGRAPHIC OVERVIEW OF FAR EASTERN SPECIES, WITH TAXONOMIC NOTES**

## *Japan*

A total of 18 bipaliid species has been reported from Japan (Tables 1-3, Fig. 46) : nine *Bipalium* species, three *Novibipalium* species, and six species of the collective group *Diversibipalium*. Additionally, six unidentified species, tentatively considered *Diversibipalium* species, are known from the vicinity of Nagasaki City, Kyūshū, in South Japan (KAWAKATSU et al., 2000; YAMAMOTO et al., 2001, 2003). Furthermore, two *Diversibipalium* spp. have been recorded also from Central Japan. With respect to these species, the following unresolved taxonomic problems remain.

1. Of the nine species of *Bipalium*, four have not yet been redescribed from a modern taxonomic point of

view : *B. fuscolineatum* Kaburaki, 1922; *B. glaucum* (Kaburaki, 1922); *B. kisoense* Kaburaki, 1922; *B. ochroleucum* Kaburaki, 1922. There is a possibility that some of these four nominal species constitute synonyms.

2. A comparative taxonomic study, based on new material, of *Novibipalium falsifuscatum* Kawakatsu, Ogren & Froehlich, 1998 and *N. venosum* Kawakatsu, Ogren & Froehlich, 1998 is necessary since KABURAKI (1922a) gave a mixed description of the two species under the name of a single species, viz. “*Placocephalus fuscatus* Stimpson”. Later, this species was separated into two species, viz. *Bipalium fuscatum* Stimpson, 1857 and *Novibipalium falsifuscatum* Kawakatsu, Ogren & Froehlich, 1998, with the latter being classified only on the basis of KABURAKI’S (1922a) description with illustrations of the copulatory apparatus (cf. KAWAKATSU, OGREN & FROEHLICH, 1998).

TABLE 1

Comparative morphological and anatomical data for Japanese species of *Bipalium*. Dimensions of the animals shown as length x width. Abbreviations and conventions for stripes : md, mid-dorsal stripe; la, lateral stripes; mg, marginal stripes (occurring only on the prepharyngeal region of the body). Chromosome data : [1] 2x=18. KAWAKATSU et al. (1990, 2000); OKI et al. (1991, 1995); YAMAMOTO et al. (2001, 2003); [2] 2x=10. KAWAKATSU et al. (1990, 2000); OKI et al. (1991, 1995); YAMAMOTO et al. 2001, 2003); [3] 2x=10. KAWAKATSU et al. (1990 : *Bipalium* sp. 3); OKI et al. (1991 : *Bipalium* sp. 3).

SPECIES		<i>B. fuscatum</i>	<i>B. fuscolineatum</i>	<i>B. glaucum</i>	<i>B. hilgendorfi</i>	<i>B. kewense</i>	<i>B. kisoense</i>	<i>B. monolineatum</i>	<i>B. nobile</i>	<i>B. ochroleucum</i>	<i>B. tatsuyai</i>	<i>B. glandantrum</i>	<i>B. murinense</i>
BODY	Size (in mm)	80-120 x 7-8	50 x 3	120-200 x 3.5-4	60-80 x 5	120-200 x 5	30-35 x 2	35 x 5	300-1000 x 5-7	50 x 3.5	60 x 2.5	30-50 x 5	50 x 3-4
HEAD	Plate	lunate	lunate	rotundate	rotundate	rotundate	lunate	lunate	rotundate	rotundate	lunate	semilunate	lunate
	Auricle	large	large	short	short	short	moderate	well developed recurved	short	short	moderate	moderate	moderate
DORSAL SIDE	Ground colour	black	dark olive	greenish grey	reddish brown	yellowish brown	dark olive brown	dark brownish orange	yellowish brown	dark yellow	brown	yellowish brown	dark brown
	Stripes	—	1md	—	1md	1md + 2la + 2mg	1md	1md	1md + 2la + 2mg-pre	1md	1md	1md + 2la	1md + 2la + 2mg
	Patterns	—	—	—	—	wide patch (neck)	—	—	—	—	h.p. with dark edge	—	—
VENTRAL SIDE	Ground colour	dark grey	grey	pale	pale	pale	pale brown	pale	pale	pale	pale	pale brown	pale
	Stripes	—	—	—	—	2la	—	—	2la	—	—	2la	—
	Patterns	—	—	—	—	wide patch (neck)	—	—	—	—	narrow patch (neck)	dark colour (neck)	—
PENIS	Penis bulb	large	moderate	large	moderate	large	moderate	moderate	large	moderate	large	moderate	moderate
	Penis papilla	small	moderate	large, long	moderate	moderate	large, long	large, long	moderate	large, long	moderate	large, long	large
	Bulbar cavity	narrow	moderate	narrow	wide	wide	narrow	narrow	wide	moderate	wide	narrow, tubular	wide
	Ejaculatory duct	short, tubular	short, tubular	short, tubular	moderate, tubular	long, tubular	moderate, tubular	long, tubular	long, tubular	narrow, tubular	wide	long, tubular	wide
MALE ANTRUM	Antrum	moderate	moderate	moderate	moderate	wide	moderate	moderate	moderate	moderate	wide	moderate	wide, tubular
	Penis sheath	—	—	—	—	—	—	—	—	—	—	—	—
FEMALE COP. APP.	Organ	moderate, muscular	small	small	moderate	large	moderate	moderate	moderate	moderate	moderate	moderate	moderate
	Female genital canal	narrow, tubular	narrow	narrow, tubular	wide	wide, tubular	narrow, tubular	narrow, tubular	moderate, tubular	moderate, tubular	moderate	wide	wide
COMMON GENITAL ANTRUM		moderate	narrow	narrow	wide, glandular	wide, glandular	moderate	moderate	moderate	wide	moderate	moderate, glandular	moderate
CHROMOSOME NUMBER (2 x)		?	?	?	?	18 [1]	?	?	10 [2]	?	?	?	10 [3]

TABLE 2

Comparative morphological and anatomical data for Japanese species of *Novibipalium*. For further explanation, see Table 1. [4] 2x = 10. KAWAKATSU et al. (1987 : *Bipalium* sp. TFS type); OKI et al. (1988 : *Bipalium* sp. TFS type); [5] 2x = 10. KAWAKATSU et al. (1990 : *Bipalium* sp. 2); OKI et al. (1991 : *Bipalium* sp. 2).

SPECIES		<i>N. falsifuscatum</i>	<i>N. trifusco-striatum</i>	<i>N. venosum</i>	<i>N. miyukiae</i>	<i>N. murayamai</i>
BODY	Size (in mm)	120 x 4	55 x 6-8	50-90 x 2.5	20-26 x 3	50-60 x 6-7
HEAD	Plate	lunate	lunate	lunate	rotundate	lunate (crescent mark)
	Auricle	well developed	short	well developed	moderate	moderate
DORSAL SIDE	Ground colour	black	dark brown	dark brown	blackish brown	yellowish brown
	Stripes	—	1md + 2la	—	1md	2la
	Patterns	—	—	—	—	h.p. with brown edge
VENTRAL SIDE	Ground colour	dark grey	pale	pale	greyish brown	greyish brown
	Stripes	—	—	—	—	2la
	Patterns	—	—	—	—	—
PENIS	Penis bulb	large	large	small	large	large
	Penis papilla	short	short	moderate	moderate	large
	Bulbar cavity	narrow, tubular	wide	moderate	wide	wide
	Ejaculatory duct	short, wide	short, tubular	short, wide	long, tubular	long, tubular
MALE ANTRUM	Antrum	moderate	moderate	moderate	moderate	moderate
	Penis sheath	well developed	well developed	well developed	well developed	well developed
FEMALE COP. APP.	Organ	large	large	small	moderate	large
	Female genital canal	wide	wide	wide, tubular	wide	wide, tubular
COMMON GENITAL ANTRUM		shallow	shallow	wide	shallow	moderate
CHROMOSOME NUMBER (2 x)		?	10 [4]	?	?	10 [5]

3. Proper reidentification of STIMPSON's species *Diversibipalium maculatum* (Stimpson, 1857), *D. trilineatum* (Stimpson, 1857), and *D. virgatum* (Stimpson, 1857) is not possible, due to their very superficial original descriptions that lack any illustrations. Therefore, these three species can be classified only as "species inquirendae."

4. The descriptions of *Diversibipalium fulvum* (Kaburaki, 1922) and *D. fuscocephalum* (Kaburaki, 1922) are based on non-sexual specimens, albeit supplied with colour sketches of the external appearance of the animals. Therefore, these species can be identified properly only after new material of sexual specimens has become available. Thus, both species must be considered as a "species incertae sedis."

5. Although sexual specimens of *Diversibipalium multineatum* (Makino & Shirasawa, 1983) have not yet been obtained, the external features of the species seem to be sufficiently different from other Japanese bipaliids to consider it as a separate "species incertae sedis."

### Korea

Only a single species has been reported from Quelpart Island, viz. *Bipalium koreense* Friebe, 1923 (Table 4, Fig. 47). This moderately large species (77-81 mm in length, with a width of 9 mm, in preserved condition) has been described with yellowish brown to greyish yellow dorsal surface, devoid of stripes; ventral side pale and also devoid of stripes (cf. FRIEB, 1923, pl. 15, fig. 1). The species shows a large penis bulb with a narrow cavity, and a very long, pointed penis papilla (being coiled in Friebe's figure) with a tubular ejaculatory duct. The female genital

duct is small and tubular (cf. FRIEB, 1923, T. 15, figs 2-3; Fig. 47).

*B. koreense* shows some resemblance, both externally and anatomically, to *B. glaucum* (Kaburaki, 1922) from Japan (cf. KABURAKI, 1922a, figs 20-21, pl. 1, fig. 17). Both species are known only from their original descriptions.

According to notes made by RS in October 1989, the catalogue of the Natural History Museum, London, lists spirit specimens as types.

### Taiwan

Two species have been reported from Taipei and its surroundings (Table 4, Fig. 40) : *Bipalium kewense* Moseley, 1878 (synonym "*Placocephalus virgatus* (Stimpson)" sensu Kaburaki, 1922; cf. WINSOR, 1983; KAWAKATSU & SASAKI, 2001), and *Diversibipalium ruteofulvum* (Kaburaki, 1922). A colour sketch of the last-mentioned species was given by KABURAKI (1922a, Pl. I, fig. 10) and it is here considered to be a "species incertae sedis".

For the latest taxonomic and distribution data of land planarians from Taiwan, see KAWAKATSU et al. (2005) and WU et al. (2005).

### China

Taxonomic reviews of the bipaliids from eastern and south-eastern China can be found in KAWAKATSU & LUE (1984), LUE & KAWAKATSU (1986), OGREN & KAWAKATSU (1987, 1988), and KAWAKATSU (1991b). Discussions on the occurrence of *Bipalium nobile* Kawakatsu & Makino, 1982 and *Bipalium kewense*

TABLE 3

Comparative morphological and anatomical data for Japanese species of *Diversibipalium*. \*: species inquirenda. For further explanation, see Table 1. [6] 2x=10. KAWAKATSU et al. (2000); KUBOTA et al. (2001); YAMAMOTO et al. (2001, 2003); [7], [8], [9], [10] 2x=10. KAWAKATSU et al. (2000); YAMAMOTO et al. (2001, 2003); [11] 2x=12. KAWAKATSU et al. (2000); KUBOTA et al. (2001); YAMAMOTO et al. (2001, 2003); [12] 2x=10. YAMAMOTO et al. (2003).

SPECIES		<i>D. fulvum</i>	<i>D. fuscoccephalum</i>	<i>D. multilineatum</i>	<i>D. maculatum</i> *	<i>D. trilineatum</i> *	<i>D. virgatum</i> *	<i>D. sp. Nagasaki-1 (Isahaya)</i>	<i>D. sp. Nagasaki-2 (Shimabara)</i>	<i>D. sp. Nagasaki-3 (Shimabara)</i>	<i>D. sp. Nagasaki-4 (Nagasaki)</i>	<i>D. sp. Nagasaki-5 (Shimabara)</i>	<i>D. sp. Kumamoto-1 (Kumamoto)</i>	<i>D. sp. Chiba City-1</i>	<i>D. sp. Chiba City-2</i>
BODY	Size (in mm)	20 x 7.5	35 x 3	100-200 x 5	75 x 5	40 x 5.5	50 x 4	70 x 4	70 x 6	80 x 5-7	30x 2-4	200 x 10-15	30 x 3	96 x 5	160 x 5
HEAD	Plate	rotundate	lunate	rotundate	lunate	lunate	lunate	lunate	lunate	semilunate	lunate	lunate	lunate	lunate	lunate
	Auricle	inconspicuous	moderate, recurved	short	large	moderate	large, recurved	moderate	well developed	well developed	moderate	moderate	moderate	short	moderate
	DORSAL SIDE														
	Ground colour	pale reddish yellow	dark brown	yellowish brown	dark brown	pale yellowish brown	pale orange	dark brown	dark greyish brown	light yellowish brown	dark brown	blackish brown	dark blackish brown	dark yellowish brown	dark yellowish brown
	Stripes	—	1md	1md + 2la	—	3 lines	5 lines	1md + 2la	1md + 2mg	1md + 2mg	1md	—	—	1md + 2la	—
	Patterns	—	—	—	—?	—	—?	—	—	—	—	pigmented	—	—	—
VENTRAL SIDE	Ground colour	pale	pale	pale	?	?	?	pale	pale	pale	pale	pale	blackish brown	pale	pale
	Stripes	—?	—?	1md + 2la	?	?	?	2la	2la	2la	—	—	—	—	—
	Patterns	—?	—?	—	?	?	?	—	—	—	—	pigmented	—	—	—
PENIS	Penis bulb	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Penis papilla	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Bulbar cavity	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Ejaculatory duct	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	MALE ANTRUM														
	Antrum	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Penis sheath	?	?	?	?	?	?	?	?	?	?	?	?	?	?
FEMALE COP. APP.	Organ	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Female genital canal	?	?	?	?	?	?	?	?	?	?	?	?	?	?
COMMON GENITAL ANTRUM		?	?	?	?	?	?	?	?	?	?	?	?	?	?
CHROMOSOME NUMBER (2 x)		?	?	10 [6]	?	?	?	10 [7]	10 [8]	10 [9]	10 [10]	12 [11]	10 [12]	?	?

Moseley, 1878 can be found in KAWAKATSU et al. (2001); see also SASAKI et al. (2001). Following up on these studies, OGREN et al. (1997) listed three species for NE China: *Bipalium cantori* (Wright, 1860), *B. grayi* (Wright, 1860), *B. kewense*.

We have made a careful re-examination of the descriptions and published records for China and came to the conclusion that (1) two species should be placed in the collective group *Diversibipalium*, (2) presumed “*B. cantori*” from Shanxi Province (cf. KATÔ, 1950) represents a new species (see above), and (3) presumed “*B. cantori*” from Chiangsu Province (cf. KABURAKI, 1922b) also represents a new species (see above). Our arguments concerning *B. grayi* and *B. cantori* are detailed below.

*Diversibipalium grayi* (Wright, 1860) comb. nov. Species inquirenda

WRIGHT (1860) described this species under the name of *Dunlopea Grayia*. His figure of the animal is based on a “coloured drawing by Dr. Cantor (the collector of the animal) in the collection of the British Museum”. Judging by both textual description and figure (for a reproduction of Wright’s text and figure, see KAWAKATSU et al., 2001), the species is characterized by a triangular head with pointed, recurved auricles, brownish yellow ground colour, dark stripe along the margin of the head, and two broad, dark longitudinal stripes, perhaps flanked by a thin stripe on either side (Table 4). Since the genital anatomy of the species is not known, it is here classified under *Diversibipalium*.

*Diversibipalium cantori* (Wright, 1860) comb. nov. (Figs 27-29)

The species was described by WRIGHT (1860) and VON GRAFF (1899, T. XIII, figs 1-2), the last-mentioned worker basing his description on the original specimens, as a large species (140 - 200 mm in length with a width of 6 - 8 mm, in preserved condition) showing the following features : an “expanded hammer-head-like” with recurved auricles; a dark brown edge surrounding the head plate; a dirty yellow dorsal surface showing many small, dark spots; a thin, dark mid-dorsal stripe; two dark lateral stripes that expand on the head to form very clear beak-shaped spots; two dark marginal stripes; devoid of stripes in the tail region; ventral surface of the head provided with pale brown edge and body surface showing two dark marginal stripes (Table 4).

Since the genital anatomy of the species is not known, we do here tentatively place the species in the collective group *Diversibipalium*; it is considered to be a “species incertae sedis.” The animal was reported from Ningpo (29°45' N 121°33'E), Chekiang (=Zhèjiang) Province, SE China.

According to notes made by RS in October 1989, the catalogue of the Natural History Museum, London, lists the presence of the preserved type specimen.

#### Primorskiy (Russia)

A single, non-sexual specimen was described as *Bipalium* sp. from Vladivostok. Details on the external features of this specimen can be found in KAWAKATSU et al. (2000) and SASAKI et al. (2001). In this paper we classify this animal as *Diversibipalium* sp. of Vladivostok (Table 4); it is a “species incertae sedis.”

TABLE 4

Comparative morphological and anatomical data for *Novibipalium*, *Bipalium*, and *Diversibipalium* species from SE Asia. \* : species inquirenda. For further explanation, see Table 1.

COUNTRIES		INDO-NESIA	KOREA	TAIWAN		CHINA			RUSSIA	
SPECIES		<i>N. alterifuscatum</i>	<i>B. koreense</i>	<i>B. kewense</i>	<i>D. ruteofulvum</i>	<i>B. kaburakii</i>	<i>B. katoi</i>	<i>D. cantori</i>	<i>D. grayi</i> *	<i>D. sp. Vladivostok</i>
BODY	Size (in mm)	120 x 4	77-81 x 9	60 x 3	45 x 6	165 x 5	70 x 4	140-200 x 6-8	?	20 x 4.8
HEAD	Plate	lunate	lunate	rotundate	lunate	semilunate	rotundate	lunate	lunate	lunate
	Auricle	well developed, recurved	moderate	short	moderate	moderate?	short	moderate	recurved	short?
DORSAL SIDE	Ground colour	black	yellowish-greenish brown	pale yellow	dark reddish brown	dark brown	blackish brown	yellowish brown	yellowish brown	pale greyish
	Stripes	—	—	1md + 2la + 2mg	—	1md + 2la + 2mg	1md + 2la + 2mg	1md + 2la + 2mg	1md? + 2la	—
	Patterns	—	—	wide patch (neck)	—	—	head with arched dark edge	2 beak-shaped patterns	?	—
VENTRAL SIDE	Ground colour	dark grey	pale	pale?	pale	pale	pale?	pale	?	pale
	Stripes	—	—	2la?	—	—	—	—	?	—
	Patterns	—	—	wide patch (neck)?	—	—	—	—	?	—
PENIS	Penis bulb	moderate	globose, large	large?	?	moderate	ellipsoidal, large	?	?	?
	Penis papilla	small	very long (coiled)	moderate?	?	moderate	short	?	?	?
	Bulbar cavity	moderate	narrow	wide?	?	moderate	wide	?	?	?
	Ejaculatory duct	wide	long, tubular	long, tubular?	?	moderate, tubular	wide	?	?	?
MALE ANTRUM	Antrum	moderate	moderate	wide?	?	moderate	moderate	?	?	?
	Penis sheath	well developed	—	—	?	—	—	?	?	?
FEMALE COP. APP.	Organ	moderate	small	large?	?	small	small	?	?	?
	Female genital canal	wide	moderate, muscular	wide, tubular?	?	moderate	moderate	?	?	?
COMMON GENITAL ANTRUM		wide	moderate	wide, glandular?	?	narrow	narrow	?	?	?
CHROMOSOME NUMBER (2 x)		?	?	18?	?	?	?	?	?	?



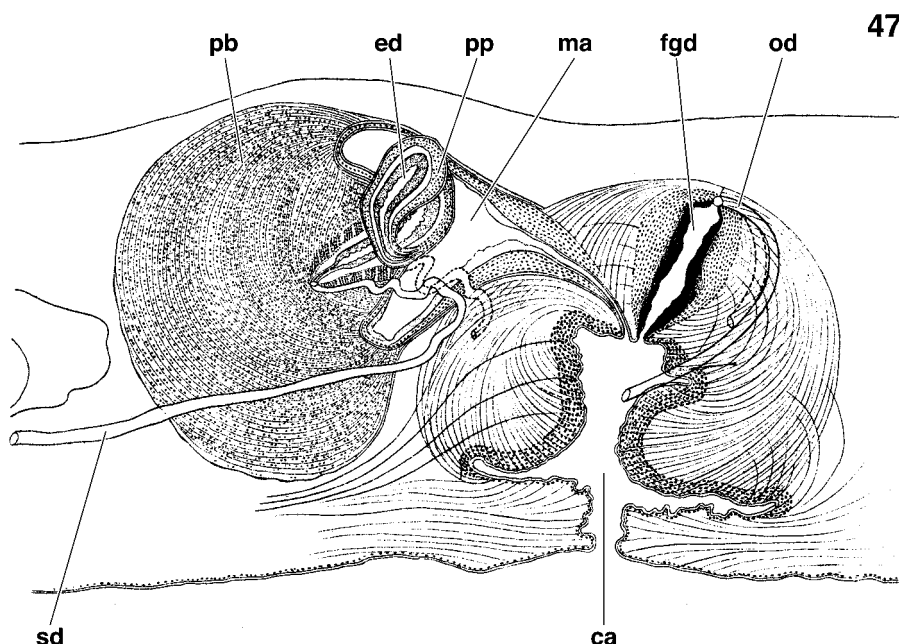


Fig. 47. – *Bipalium koreense*. Sagittal reconstruction of the copulatory apparatus (after Frieb, 1923; retouched and labels adapted according to current terminology); anterior to the left.

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