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Research article

Re-description and iconography of *Tabanus striatus* (Diptera: Tabanidae) a common livestock pest and mechanical vector of *Trypanosoma evansi* in Asia

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Abstract

Female tabanids are regarded as mechanical vectors of several pathogens and are an important livestock pest. Approximately 4,400 species of tabanids are distributed in all kinds of landscape. Control-limiting methods, including environmental and zootechnical management, require species identification of the flies in a given area. Studies carried out in Thailand have shown a limited species diversity in livestock farms; nevertheless, identification is always difficult when a non-specialist uses dichotomic keys. New user-friendly guidelines recently published, facilitate the description and identification of biting flies. Following these guidelines the most common species, *Tabanus striatus*, was re-described with emphasis on the key points allowing distinction from the morphologically close *T. megalops*. In addition, a rich original iconography was provided with 30 pictures of this common biting fly, whose distribution spreads from Pakistan and India to China, and from Lao to Thailand and Vietnam.

Introduction

Females of the family Tabanidae (Diptera) are blood sucking insects which have a great impact on livestock farming systems (Foil, 1989). Important characteristics that make them a serious pest of livestock are: 1) their large size and highly vulnerant telmophagous type mouth-parts that can cause a large amount of blood spoliation and painful bites, including stress, defense movements and opportunities to move from one host to another which is favorable to mechanical transmission of pathogens; 2) their very high prolificacy, as one female may lay 100–800 eggs per batch per gonotrophic cycle, and there may be 5–8 cycles per lifetime, thus producing 500–4,000 eggs; and 3) their annoying behavior due to their multiple blood feedings from a single or several different hosts until fully satisfied by complete engorgement. Indeed, tabanids are mechanical vectors of bacteria such as *Bacillus anthracis* and *Anaplasma marginale*, viruses such as bovine leucosis virus and equine infectious anaemia virus (EIA) and parasites such as *Besnoitia besnoiti* and *Trypanosoma evansi*, the agent of surra (Desquesnes et al., 2013; Baldacchino et al., 2014). In Asia, successful experimental transmissions have been reported

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in at least 29 *Tabanus* spp., including *Tabanus rubidus, T. partitus, T. tenens* and *T. striatus* (Gill, 1977).

Tabanids are present elsewhere from the very northern areas of Alaska where they are highly seasonal with a very short peak of activity to the warmest climates where the longest periods of activity are favored by long rainy seasons. Spread amongst these varied landscapes, tabanids present a very rich natural diversity of around 4,400 species, for which species identification is always difficult when starting to work on local dichotomic identification keys. This identification generally requires high skills and very deep knowledge on the anatomy of the insects (Baldacchino et al., 2014).

Control methods for hematophagous biting insects like tabanids are limited and include environmental and zootechnical management for which a prerequisite is the proper identification of the biting fly species that annoy livestock in a given area. Although the total number of Tabanid species is very high, studies carried out in various countries have shown a limited species diversity of these flies on livestock farms, especially bovine and equid farms which tends to show that some tabanid species are particularly adapted to livestock (Baldacchino et al., 2014). As an example in Thailand, the most common species of tabanids on dairy farms in Saraburi province are *T. rubidus*, *T. striatus* and *T. systenus* together with two common *Hematopota* spp. (Phasuk et al., 2011). In addition to tabanids, 3–4 *Stomoxys* species have been regularly found with *Hematobia* spp. and *Musca crassirostris,* the hematophagous fly (Phasuk et al., 2013). Thus, around 11 species have been identified at the scale of livestock farms. Other species such as *Chrysops dispar*, *T. megalops* and *T. rhinargus* are found in other areas of Thailand. However, the total diversity generally ranges from 10 to12 species in livestock areas which produces a limited challenge for identification.

New user-friendly guidelines were recently published to improve the description and identification of biting flies to benefit from the progress and usefulness of macroscopic digital photography improved by the use of tri-dimensional software. When identifying tabanids from livestock farms in Thailand, medium-sized insects exhibiting dorsal abdominal stripes and looking alike may belong to a group known as the "striatus complex". Indeed, the morphological and anatomic characters are very close for three species of *Tabanus*: *T. striatus* Fabricius, *T. partitus* Walker (Krober, 1924; Schuurmans Stekhoven, 1926) (as *T. megalops*) (Austen, 1922; Stone, 1972; Burton, 1978) and *T. triceps* Thunberg (as *T. tenens*). Due to confusing previous studies and descriptions, identifying the complex or group of the three species of *Tabanus* is extremely difficult, especially between the two species *T. partitus* and *T. striatus* which both have a similar dorso-abdominal band.

A member within the species complex has been incriminated as a vector of surra, an important disease of horses and bovines, notably in Thailand, as reported by Phasuk et al. (2011). Surra is responsible for important economic losses from reduced weight gain, milk yield and reproduction performance; additional losses are due to the cost of treatment.

History of taxonomy and geographical distribution

By using the most common keys for tabanid identification in Southeast Asia (Burger and Thompson, 1981; Burton, 1978; Schuurmans Stekhoven, 1926), it was possible to make a synthesis of the *striatus* complex description (Table 1).

Burger and Thompson (1981) reported that *T. striatus* was described for the first time by Fabricius in 1787 but the description of this specie was interpreted too broadly. Burton (1978) discussed the confusion between *T. striatus* and a species commonly found in Southeast Asian countries (Thailand, Malaysia, Indonesia, the Philippines), known as *Tabanus partitus* Walker. Ricardo (1991) was not able to reach a conclusion on the limits of the geographical distribution of *T. striatus* and included *T. triceps* and *T. partitus* under *T. striatus*. Austen (1922), Philip (1959) and Burger and Thompson (1981) reported that *T. striatus* may or may not exhibit a weak continuous line on tergite 2; therefore, the *T. striatus* specimens that do have a middle stripe on their second tergite were not clearly distinguished from *T.triceps* (as *tenens*). In their discussion, Burger and Thompson (1981) reported that (Surcouf, 1923) correctly recognized *T. striatus* Fabricius as distinct from other species in India. He believed *T. tenens* Walker to be a synonym of *T. striatus* and Surcouf (1923) reported that to clearly separate *striatus* from related taxa with a median abdominal stripe beginning on the third tergite. Furthermore, they quoted Schuurmans Stekhoven, 1926) who compared northern specimens and a southern specimen of *striatus*, and reported that southern females "had wings with yellow-brown costal cells and the midstripe on the abdomen paler but not abruptly interrupted on the second segment". A similar report from Austen (1922) reported accepted differences that were used to separate *striatus* from the related *partitus*.

Burger and Thompson (1981) reported that Burton (1978) thoroughly discussed the confusion of *striatus* and related species and stated that females of *T. striatus* do not have a pale tomentose and pale-haired median stripe on the second tergum, which distinguishes them from *T. partitus* (as *megalops*). It must be mentioned that after Burger and Thompson (1981), more recent authors have preferably used the species name *megalops* in place of *partitus* (Phasuk et al., 2011; Changbunjong et al., 2017). These characters separate it from *T. partitus* females; furthermore, the body color of the dorsal abdomen is black in *T. striatus* females, and dark brown in *T. partitus*. Additionally, Burton (1978) reported that the yellow-tinted costal cell in the male of *T. partitus* separated it from *T. striatus* male which have a hyaline costal cell (as well as their females).

T. striatus is found in Pakistan, India, Sri Lanka, China, Myanmar, Laos, Cambodia, Vietnam and northern and eastern Thailand (Veer et al., 2002; Vasudeva et al., 2007; Grootaert, 2009; Chandra et al., 2015; Changbunjong et al., 2017).

T. triceps is differentiated from *T. striatus* by the middle dorsal stripe of the abdomen distinctly crossing the tergite 2 in both sexes, the unicolorous foretibia, the callosity not broadly contiguous with the eye margins, and the absence of a dark haired, middle ventral stripe on the abdomen (Burger and Thompson, 1981).

Table 1 Comparison of three species of *T. striatus* complex

Characteristic	*T. striatus* Fabricius		*T. megalops* Walker (as *partitus*)		*T. triceps* Thunberg	
	Female	Male	Female	Male	Female	Male
stripe on Tergite 2	absence on T2	absence on T3	present (continuous)	variably developed	broadly continuous	usually well developed
color of dorsal abdomen	blackish		brownish		yellow-brown steplike sublat. stripes	blackish
dark median stripe on ventral abdomen	ventral abdomen gray with a broad mediane dark stripe		no stripe, ventral abdomen uniformly yellowish		no stripe, ventral abdomen uniformly yellowish with gray tomentose and pale pillose	
female size (mm)	10–13		12.2–14.3		13.6–16	
basal callus contiguous/ distant from the eyes	contiguous for most or all of its length with large dorsal extension to median callus		contiguous for most or all of its length with large dorsal extension to median callus		narrowly distant at the basis and receding from eye margins above, with thin dorsal extension to median callus	
pilosity on the thorax	blackish		lighter in color		lighter in color	
color of the foretibia	pale color in 2/3 proximal and distal 1/4 blackish		pale color in 2/3 proximal and distal 1/4 blackish		forefemur and tibia uniformly orange to orange brown	
costal cell of the wing	hyalin (never tinted)		yellow tinted		tinted	yellow tinted
palps slightly	short and stout		medium		long and slender basally	
stem of the halter	pale brown		yellowish-white (Thai) brown-black (the Philippines)			
synonyms	dorsilinea, hilaris, tenens		partitus, manilensis, rufocallosus, tenens, striatus		tenens, strophiatus, partitus, striatus	
geographical distribution	Pakistan, India, Sri Lanka, Myanmar, China, Laos, Vietnam, Cambodia, Northern, eastern and central Thailand		Myanmar, Laos, Vietnam, Cambodia, Thailand, Malaysia, Indonesia, the Philippines, Micronesia		Pakistan, India, Sri Lanka	
regional variations	palp shorter, more stout and less yellowish than Philippin megalops		the Philippines females: palp more stout and yellowish than Thai; the Philippines frons narrow FI 1:6.0–7.5 Thailand: Frons larger FI 1:4.3–5.6 and scutellum yellowish			

Finally, *T. striatus* Fabricius, 1787 is an accepted name for which the synonyms are *Tabanus chinensis* Thunberg, 1827, *Tabanus dorsilinea* Wiedemann, 1824 and *Tabanus hilaris* Walker, 1850.

Tabanus megalops Walker, 1854 is an accepted name for which the synonyms are *Tabanus manilensis* Schiner, 1868, *Tabanus tenens* Walker, 1850, *Tabanus partitus* Walker, 1857 and *Tabanus rufocallosus* Bigot, 1892.

Tabanus triceps Thunberg, 1827 is an accepted name for which the synonyms are *Tabanus tenens* Walker, 1850 and *Tabanus strophiatus* Surcouf, 1923.

To facilitate the identification process, *Tabanus striatus* was re-described and an original iconography was provided involving 30 pictures of detailed anatomy with regard to the most commonly used identification keys of tabanids in Southeast Asia, developed by several authors (Burger and Thompson, 1981; Burton, 1978; Schuurmans Stekhoven, 1926).

Material and Methods

Fly collection and identification

Adult tabanid fly collection was made on a local dairy farm in Wang Nam Khiao district, Nakhon-Ratchasima province (14°21’04.2”N, 101°56’13.2”E) and Khao Khiao Open Zoo, Chonburi province (13°12’54.0174”N, 101°3’23.6118”E), from September 2013 to August 2014. The area is close to the Thap Lan National Park. Tabanids were captured using N-zi traps (Mihok et al., 2006; Tunnakundacha et al., 2017). Other trappings were carried out on the Kasetsart University campus, Kamphaeng Saen, Nakhorn Pathom province from May 2016 to July 2017 and in Nong Pho district, Ratchaburi province from May to December 2017. Traps were set up around the farms before 0600 hours. Insects were collected every 2 hr from 0600 hours to 1800 hours and cooled at 4°C for the rest of the day. Subsequently, the insects were transferred to the laboratory and frozen at -20°C, in individual tubes.

Tabanid flies were identified based on external morphology using a binocular and the conventional keys for tabanid identification in Southeast Asia (Burton, 1978; Schuurmans Stekhoven, 1926).

Building a picture bank

Specimens from the freezer were maintained for 5 min at room temperature and placed under binoculars to take pictures. Optic fiber lights were used to adjust the microscope light system. The photos in full of the insects were taken using a Sony Cyber-shot DSC-RX100 Carl Zeiss Objective camera. Pictures of anatomy details were

taken using a camera CMEX-5 CMOS 5 Mpixels USB-2 DC.5000c (S/N: KCL5001604100). Captured picture files were downloaded to a computer and processed using the Euromex; ImageFocus 4.0 software. For tri dimensional pictures (3D), 10–20 shots were taken under a gradient of focusing levels and processed using the Helicon focus 6 program (Product code: 32621 Focus) to merge them into one 3D picture.

Results

Trapping results

In Nakhorn Ratchasima and Chon Buri provinces, 488 tabanids belonging to three genera and nine species were collected and identified during a 1 yr study period from September 2013 to August 2014. The most abundant genus was *Tabanus* with six species followed by *Chrysops* with two species, and one species of *Haematopota*. *Tabanus striatus* was the most abundant (33.19%) followed by *Tabanus megalops* (9.63%), other *Tabanus* spp. (50%), *Chysops* spp. (6.55%) and *Heamatopota* spp. (0.61%). In the longitudinal study carried out in Nakhorn Pathom province, 1,024 tabanids were trapped with two species identified—*T. striatus* (17.77%) and *T. megalops* (8%). In Nong Pho district, Ratchaburi province, 42 tabanids were trapped—*T. megalops* (97.61%) and *T. striatus* (2.38%). This observation was in concordance with the known geographical distribution of *T. striatus*, in Northern and Eastern Thailand, since Ratchaburi province is at the southern limit of its geographical distribution. Indeed, in the southern province of Surat Thani, *T. striatus* has never been caught in transversal studies (unpublished data).

Identification of female T. striatus

The morphological characteristics of the female *T. striatus* as described by Burton (1978) were:

1. Subcallus covered with tomentum;
2. Wing with 1st posterior cell opens to hind margin (no infuscation);
3. Coastal cell clear;
4. Abdominal venter not predominantly black;
5. Abdomen brown with median stripe and bands;
6. Abdomen with a pale tomentose median stripe which crosses parts of at least tergites 3–5;
7. Sublateral area of abdomen has at least one tergite marked with a pale stripe;
8. Sublateral area of abdomen striped on more than one tergite; wing hyaline;
9. Callosity (basal callus) touches eye margin; relatively small species (up to 15.5 mm) with wing entirely hyaline including costal cell;
10. Scutum only indistinctly striped, with the scutellum not clearly carrying on the median pattern of the scutum;
11. Midline of tergite 2 not crossed by a stripe of pale tomentum and hairs; dark abdominal stripes generally quite black *

* For *T. megalops*: Midline of tergite 2 crossed by a stripe of pale tomentum and hairs; dark abdominal stripes generally a lighter shade of black to brown.

Female description, from the literature and the current study observations

Body length is between 12.5–15.5 mm and is dark brownish. Eye color appears metallic, shiny (green, red). Subcallus appears yellowish. Beard is whitish to gray. Dorsal of thorax is light blackish to gray, with 1 median until middle of thorax and 2 sublateral longitudinal lines are weak light brown stripes. Rim of scutellum appears yellowish. Thorax ventral part is mostly grayish. Femur is grayish, tibia is yellowish to orange and tarsi black. Wings are clear with light dark. Dorsal of abdominal part is mainly blackish with one yellow spot at tergite 1 linked to subleteral band. Subleteral band abdomen appears on tergite 1 to middle of abdomen. One median starts at the middle 2–3 tergites. Ventral part of abdomen appears brown and little black, rim of sternite appears yellowish except the last sternite is blackish.

Head

Frons appear yellowish to brown with black hairs and some yellowish hairs on vertex. Hairs are mostly black with some white hairs at vertex and also some at sides of median callus. Basal callus and median callus are approximately 38% and 62%, respectively, of the total length of calli (basal callus short/median callus long). Calli are reddish-brown to dark-brown, bare and shiny. Basal and median calli are generally linked. Upper basal callus is brown with some shiny and filling entire width of frons at base. Dorsal extension forms separate median callus (Fig. 2E) which is spindle shaped, connected to the lower basal callus. Subcallus and upper cheeks appear yellowish to white; face is white to grayish white with white hairs including beard (Fig. 3E). Cheeks are white to very light gray. Eye color is dark brown to black. The antenna is brownish to orange. The scape and pedicel are mostly yellow-brown to orange with black hairs on dorsal and some whitish to pale hairs on lateral sides (Fig. 3D). Pedicel is ornamented by a crown of black hairs (Fig. 3E). The basis of the plate (third segment, flagellum) is brownish and darkening with gray to black brown, with mainly whitish hairs on the plate and black hairs on the annuli. Palps are yellowish (Fig. 3A). The basal part is commonly entirely bare but the median and distal parts are covered with white and black hairs.

Thorax

Thorax appears light blackish to gray. Dorsal part is mostly dark gray with black hairs. Some part of them are light colors with yellowish and pale hairs. The stripes on the scutum have 3 stripes whereas 2 stripes are strong light color with yellowish to golden hairs on submedian and 1 stripe is weak whitish with pale and black hairs in the middle. The median stripe is interrupted from the middle of

thorax until the suture. Scutellum is of the same dark gray, with black hairs and the edges of thorax have long whitish to grayish hairs (Fig. 4A). Mesopleuron are light gray with yellowish and some black hairs. Ventral part is gray with white to light gray hairs. Forelegs coxa is basically gray with some white hairs. Lateral side of trochanter and femur are light gray with white hairs (Fig. 5A) and medial side is gray with white hairs and dark brown with black hairs respectively (Fig. 5B). Tibia is light brown to orange brown with whitish hairs and black hairs; tarsi are gray to black with black hairs (Fig. 5C and 5E). Midlegs show 2 spurs at the distal extremity of the tibia one short (at the back) and one long (at the front) in a V-shape (Fig. 6D). Wings are clear, but not fully hyaline, they appear a little dark in color (Fig. 6A), yellowish to light brown band presented at radial cell (under R_1 vein). Halter stems are yellow (Fig. 4F), and the knobs are generally yellowish white.

Abdomen

Abdomen mainly brownish to black, processing black hairs with 3 light stripes, The median stripe begins with whitish hairs spot on basal of tergite 1, representing again at the tergite 3 to 6 (Fig. 4D), and the sublateral stripes are light colored with whitish hairs from tergite 1 to 4 and weakly cross line between tergite 1 and 2. A series of stigma are visible on lateral sides of tergites and sternites. Lateral sides of the abdomen are light-colored, with whitish hairs (Fig. 4F). Ventral part is yellowish orange to brown, with whitish hairs on basal of sternites. The median of sternites are black hairs. Lateral parts of tergites and edges of sternites are yellowish pale hairs (Fig. 4E) and last sternite has only black hairs.

Iconography

According to the guidelines previously published, pictures taken of a fresh specimen of female *Tabanus striatus* are presented in this section including a complete dorsal view (Fig. 1A), complete ventral view (Fig. 1B), complete profile view (Fig. 1C), head complete facial (Fig. 2A), head dorsal view including antenna (Fig. 2B), head ventral including antenna (Fig. 2C), head frons detail (from apex to subcallus) (Fig. 2D), head top detail ocelli, ocellar tubercule (Fig. 2E), head eye detail (Fig. 2F), head lower palps and proboscis (Fig. 3A), head profile including antenna (Fig. 3B), head, antenna dorsal (Fig. 3C), head, antenna lateral (Fig. 3D), head, antenna medial (Fig. 3E), thorax dorsal (Fig. 4A), thorax ventral (Fig. 4B), thorax profile including legs (Fig. 4C), abdomen dorsal (wings apart) (Fig. 4D), abdomen ventral (Fig. 4E), abdomen profile (Fig. 4F), female abdomen terminalia (Fig. 6C), wing dorsal (left wing) (Fig. 6A), wing ventral (left wing) (Fig. 6B), leg 1 lateral (Fig. 5A), leg 1 medial (Fig. 5B), 2eg 2 posterior (Fig. 5C), leg 2 anterior (Fig. 5D), leg 3 medial (Fig. 5E), leg 3 lateral (Fig. 5F), leg 2, 2 distal tibia spurs (Fig. 6D), complete dorsal view of *T. striatus* and *T. megalops* specimens (Fig. 7A) and abdomen dorsal of *T. striatus* and *T. megalops* (Fig. 7B).

Figures have been tagged using the following codes: Legend: T: Tabanus; s: striatus; species; f: female; (n) natural eye color in fresh specimen

Although, *T. striatus* is closely related to *T. megalops* (as *partitus*), and both are described as mechanical vectors of *Trypanosoma evansi* (surra) in Asia (Gill, 1977), the characters described here allow a clear distinction of the two species. Indeed, following the keys for identification by Burton (1978) as summarized under point 3.1., the complete description of the specimens given in part 3.2 is fully supported by 30 pictures provided in part 3.3. The authors are hopeful that this complete re-description of the species would be useful for the correct identification of tabanid species. It can be confidently expected in the near future that more tabanid species will be described following the same guidelines (Desquesnes et al., 2018).

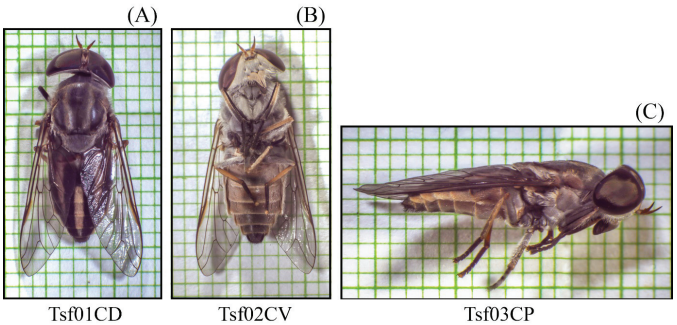

Fig. 1 Complete body of *T. striatus*: (A) complete dorsal view (Tsf01CD); (B) complete ventral view (Tsf02CV); (C) complete profile view (Tsf03CP); T = *Tabanus*; s = *striatus*; f = female.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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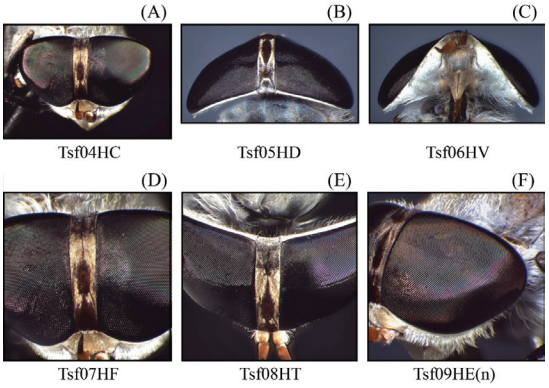

Fig. 2 Head of *T. striatus*: (A) head complete facial (Tsf04HC); (B) head dorsal view including antenna (Tsf05HD); (C) head ventral including antenna (Tsf06HV); (D) head frons detail (from apex to subcallus) (Tsf07HF); (E) head top detail (Tsf08HT); (F) head eye detail (Tsf09HE(n)); T = *Tabanus*; s = *striatus*; f = female; (n) = natural eye color in fresh specimen

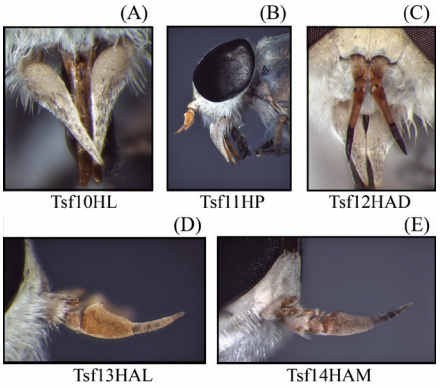

Fig. 3 Mouthpart and antenna of *T. striatus*: (A) head lower palps and proboscis (Tsf10HL); (B) head profile including antenna (Tsf11HP); (C) head, antenna dorsal (Tsf12HAD); (D) head, antenna lateral (Tsf13HAL); (E) head, antenna medial (Tsf14HAM); T = *Tabanus*; s = *striatus*; f = female.

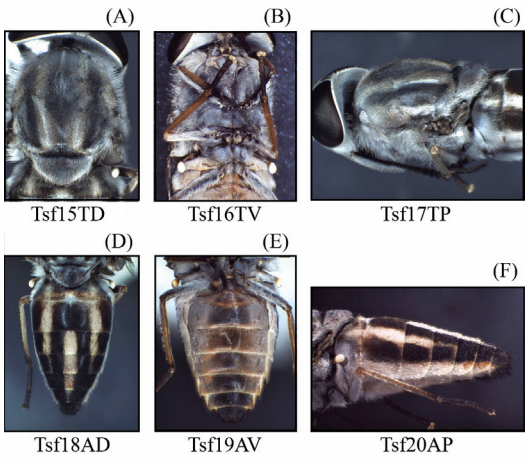

Fig. 4 Thorax and abdomen of *T. striatus*: (A) thorax dorsal (Tsf15TD); (B) thorax ventral (Tsf16TV); (C) thorax profile including legs (Tsf17TP); (D) abdomen dorsal (wings apart) (Tsf18AD); (E) abdomen ventral (Tsf19AV); (F) abdomen profile (Tsf20AP); T = *Tabanus*; s = *striatus*; f = female.

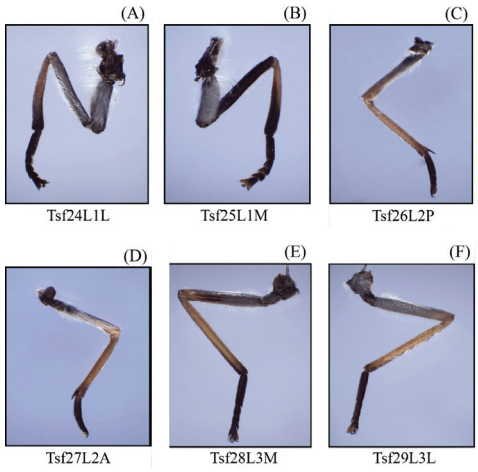

Fig. 5 Leg of *T. striatus*: (A) leg 1 lateral (Tsf24L1L); (B) leg 1 medial (Tsf25L1M); (C) leg 2 posterior (Tsf26L2P); (D) leg 2 anterior (Tsf27L2A); (E) leg 3 medial (Tsf28L3M); (F) leg 3 lateral (Tsf29L3L); T = *Tabanus*; s = *striatus*; f = female.

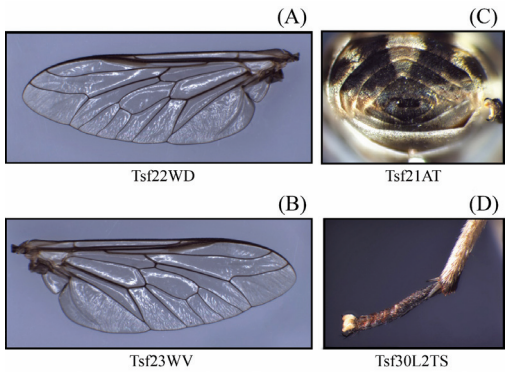

Fig. 6 Wing, spur and teminalia: (A) wing dorsal (left wing) (Tsf22WD); (B) wing ventral (left wing) (Tsf23WV); (C) female abdomen terminalia (Tsf21AT); (D) leg 2, 2 distal tibia spurs (Tsf30L2TS); T = *Tabanus*; s = *striatus*; f = female.

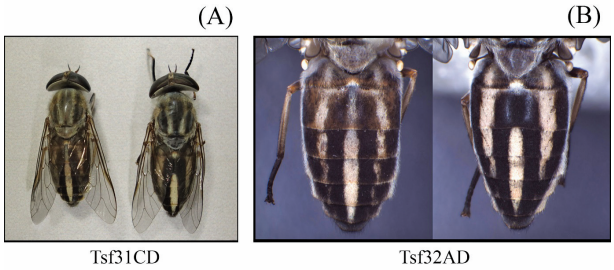

Fig. 7 Comparison of *T. megalops* and *T. striatus*: (A) complete dorsal view of *T. megalops* and *T. striatus* specimens (Tsf31CD); (B) abdomen dorsal of *T. megalops* and *T. striatus* (Tsf32AD); T = *Tabanus*; s = *striatus*; f = female.

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