First record of Trichoceridae (Diptera) in the maritime Antarctic

Odile Volonterio[1], Rodrigo Ponce de León[1], Peter Convey[2]& Ewa Krzeminska[3]

[1]Sección Zoología de Invertebrados, Facultad de Ciencias, Universidad de la República, Iguá 4225, 11400 Montevideo, Uruguay, o.volonterio@outlook.com, eumeswill@yahoo.com; [2]British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom, pcon@bas.ac.uk; [3]Institute of Systematics and Evolution of Animals, Polish Academy of Sciences ul. Slawkowska 17, 31-016 Krakow, Poland, krzeminska@isez.pan.krakow.pl

Abstract During the austral summer of 2006-07, abundant Diptera were found in the sewage system of the Base Científica Antártica Artigas on King George Island. These are here identified as *Trichocera* (*Saltrichocera*) *maculipennis* (Diptera: Trichoceridae), a Holarctic species widely distributed in the Northern Hemisphere which has been introduced to some sub-Antarctic islands, but never been recorded in the maritime Antarctic. The distribution of the fly on King George Island indicates that it has been introduced by human agency. Although its origin is unclear, adult specimens have distinctive morphological features rarely represented in autochthonous populations in Europe. To date, larvae have been found only in the Artigas Base sewage system, but adults have been observed around the buildings and more widely in the vicinity. Given the species' natural northern range, habitats and feeding preferences, it is likely to have good pre-adaptation permitting survival in the natural terrestrial ecosystems of the maritime Antarctic. We recommend that urgent eradication efforts are made.

Keywords: *Trichocera*, non-indigenous species, anthropogenic introduction, King George Island

Introduction

Until recent decades, the extreme geographical isolation of the Antarctic continent protected its autochthonous fauna and flora from colonisation by non-indigenous species (Frenot et al. 2005; Barnes et al. 2006). Since the late Eighteenth Century, human activities such as the historical whaling and sealing industries and, more recently, fisheries, scientific research and tourism, have rendered the Antarctic biome more susceptible to human-mediated introduction of both animals and plants (Frenot et al. 2005; Hughes et al. 2005, 2006; Chown et al. 2012). The sub-Antarctic islands were subjected to these pressures earlier than areas at higher southern latitude, and currently host over 95% of the non-indigenous species known to be established in the wider Antarctic region (Frenot et al. 2005; Convey and Lebouvier 2009). Initial efforts to avoid the introduction of non-indigenous species into the Antarctic Treaty area were directed towards regulating intentional introductions, and only recently has more attention been paid to the unintentional import of species with cargo, equipment, clothing and footwear (Hughes et al. 2005, 2010; Lee and Chown 2009; Convey 2010; Chown et al. 2012; Tsujimoto and Imura 2012).

The majority of non-indigenous species arriving in Antarctica, by natural or human-assisted means, will be unable to survive in the region's extreme climatic conditions. Successful colonization of Antarctica, as elsewhere, is a complex process, depending on the existence of appropriate habitat and environmental conditions (Gressitt 1970; Ellis-Evans and Walton 1990; Hughes et al. 2006). However, as Hughes et al. (2005) noted, even species which cannot survive in the natural Antarctic environment may persist synanthropically for long periods, for instance establishing reproducing populations in heated buildings or storage facilities.

During a routine check in the austral summer of 2006-07, larvae and abundant adult Diptera were found in the sewage system of the Uruguayan Artigas Base on King George Island (South Shetland Islands). Adults were also observed flying outside the Base buildings during this period. In an attempt at eradication, a treatment with permethrin was immediately applied to the tank where the flies were located. In addition, as part of the sewage system management plan, sewage water and sludge were removed from the Base and from the Antarctic Treaty Area (Uruguayan Antarctic Institute 2008). Subsequently, systematic inspections of all sewage tanks carried out during the summer of 2007-08 gave negative results for the presence of adult or larval flies, and it was concluded that the measures taken had been effective and that the species had been eradicated (Uruguayan Antarctic Institute 2008). However, although no formal monitoring plan was put in place over subsequent years, a few specimens were seen flying outside the buildings of the Base by station staff and two of the the co-authors (OV, RPdL) during the period 2009-2011, suggesting that the initial eradication attempt had been unsuccessful.

The dipteran is here identified as *Trichocera* (*Saltrichocera*) *maculipennis* Meigen, 1818 (Diptera: Trichoceridae). This finding, representing the first record of both the species and family in the maritime Antarctic, is documented here and its implications discussed.

Materials and methods

About 100 adult male and female flies were collected between December 2006 and February 2007 by station staff and one of the co-authors (RPdL) from the sewage system of the Base Científica Antártica Artigas, Fildes Peninsula, King George Island, South Shetland Islands (62°11’18”S, 58°51’07”W; Fig 1A,B). Between 15 January and 15 February 2011, pitfall traps (n = 45) were placed randomly in a radius of 1,000 m around the Base, and were checked daily for flies (coll. RPdL). The use of pitfall traps was in part driven by the typically windy conditions of the South Shetland Islands meaning that conventional flying insect traps were not practicable to maintain in a non-attended state. Additionally, as observed for the native winged chironomid *Parochlus steinenii* (Gercke) (Convey and Block 1996), conditions are rarely suitable for insect flight, and adult insects are often restricted to activity on the ground. Pitfall traps therefore provide a suitable and pragmatic sampling protocol for the study of species at this location. Sampling sites closest to the Base are shown in Fig. 1C. All specimens were fixed in absolute ethanol and stored at -20°C.

Species identity was confirmed through examination of male and female genitalia, and wing venation characteristics (Dahl 1966). The material collected was compared with museum specimens from a range of northern European locations.

Abbreviations:

BMNH – British Museum - Natural History, London, UK

CIFC – Colección de Invertebrados de la Facultad de Ciencias, Montevideo, Uruguay

ISEA – Institute of Systematics and Evolution of Animals, Kraków, Poland

MNHN – Musée National d’Histoire Naturelle, Neuchâtel, Switzerland

Material examined

1. Base Científica Antártica Artigas, Fildes Peninsula, King George Island, South Shetland Islands: 19 males and 2 females deposited in the ISEA (MP-D-873) and 14 males and 6 females deposited in the CIFC (BP 11022).

2. Specimens with unicolorous abdomens: Switzerland, Grottes: Sieben Hengste Hofgang, 4. Galerie des Amours: 1675 m, 26.XII. 1986-29.XII. 1987 – 2 f (Fig. 2A); Salle de la fonction 1451 m, same date – 20 f, 1 m; further samples from these caves, altogether c. 200 specimens (A. Hof, MNHN). Poland: Ojców National Park, 6. IV. 1989 – 6 f (leg. E. Krzemińska; ISEA). Iceland: Reykjavik 1.VIII. 1921 – 9f, 1m (leg. B. Samundsson; BMNH). Bear Island (Norway) - Tunheim 26-29. VI. 1932 – 4f ; 1-10.VII. 1932 – 2m, 2f; South Coast 18.VII. 1932 – 1m; Fugleodden 8-13.VII. 1932 – 3m, 4f; Kap Holthoff 15. VII. 1932 – 1f; Moservantat 25.VI. 1932 – 1m, 2f; Spitrefoss 18.VII. 1933 – 1m, 3f (all leg. D. Lack; BMNH). Jan Mayen Isle (Norway) 8.VIII. 1947, living rooms – 2f; Camp V (in pony stable) – 1m (all leg. A. MacFayden; BMNH).

3. Specimens with ringed abdomens: Iceland: Unadsdalur, 27.VIII. 1947 – 1f (leg. I.L. Cloudsley; BMNH). Lithuania: Vilnius 19.IV. 1986 – 1f; 1.II. 1989 – 1f; 20.II. 1989 – 1m; 14.V. 1989 – 1m; Mažeikiai dist., Juodeikai vill. 5.V. 1988 – 2m, 1f; (all leg. S. Podenas; ISEA).

Results

All flies collected were identified as *Trichocera (Saltrichocera) maculipennis* Meigen (for a list of synonyms see Krzemińska et al. 2009). In 2011, abundant flies were present in three of the sewage tanks. Several adults were noted flying in the Base and its surroundings, and about 10 were collected in the pitfall traps at sampling locations 7 and 8 (Fig. 1C, 2B). Flies were not found in the traps placed further from the Base, nor noted away from its vicinity in opportunistic observations during the period 2006-2011 (OV, RPdL, pers. obs.). However, a single adult was collected by P. Fretwell (British

Antarctic Survey) on a moss surface near Frei Base (62°12’06” S, 58°57’47” W) on 19 November 2006, indicating a wider occurrence around Maxwell Bay in that season.

Morphological notes

The specimens from King George Island have a conspicuously ringed abdomen (Fig. 2C,D), with each segment being paler distally than proximally (Fig. 2E). This colouration pattern is different from that of *T.* (*S.*) *annulata*, the only other congeneric species with a ringed abdomen, in which the distal portions are darker than the proximal. Other morphological structures of the specimens examined, including antennae, palpi and genitalia of males and females, bear all the diagnostic characters of the species, as observed among the specimens from European localities. Particularly, the antennae, especially in females, have a characteristically large first flagellomere. The wing (Fig. 2F) has the typical pattern for the genus: a large dark patch on the origin of the vein Rs, two additional patches over the cross-veins r-m and r-r, and smudges along the veins forming the discal cell and Cu. Between the distal radial veins there are diffused, paler spots. Male genitalia (Fig. 2G) are characterized by the gonostylus having a distinct basal tubercle on the mesal face and a triangular gonocoxal bridge. The female ovipositor has a sharp tip and the setulose area is distinctly delimited (Fig. 2H), the fork of genital plate is very short, and the subgenital plate has two bristles set widely apart.

Discussion

Taxonomic insights

The abdomen of adult *T. maculipennis* is usually described as uniformly dark brown (Tokunaga 1938, Karandikar 1931; Seguy1940), or no mention of striping is given, as in the species' original description from the type locality in Austria (Meigen 1818), or in descriptions of material from other localities (Dahl 1966, 1967, 1968; Alexander 1965). The distinctive striped abdominal pattern observed in the specimens collected in this study is unusual. Of the museum samples examined here, the ringed abdomen was present only in specimens from Lithuania and Iceland. In the literature, ringed abdomen coloration has been reported only in populations from northern Great Britain (Edwards 1938) and in the subspecies *T. m. pictipennis* from Japan (Alexander 1930).

Biogeography

The genus is widely distributed in the Northern Hemisphere, especially in boreal and temperate regions (Dahl and Alexander 1976; Dahl and Krzemińska 1997). The natural distribution of *T. maculipennis* is northern boreal. In the Southern Hemisphere, the family Trichoceridae is represented by the native genera *Paracladura* and *Nothotrichocera*, whose distributions extend south to the New Zealand shelf islands (Alexander 1955; Krzemińska 2005), but not to higher southern latitudes. In addition, three of the c. 110 northern species of *Trichocera* have been reported, all from sub-Antarctic or southern cold temperate oceanic locations where they are thought to have been introduced by human agency: *T. annulata* in Australia (Alexander 1926) and New Zealand (Edwards 1928), *T. regelationis* in South Georgia and the Falkland Islands (Bréthes 1925; Edwards 1928; Dahl 1970a, and *T. maculipennis* from Îles Kerguelen (Seguy 1940; Dahl 1970b). The occurrence of *T. maculipennis* at King George Island is therefore the first record of the species and of the family Trichoceridae in the maritime Antarctic.

Life history characteristics of the genus *Trichocera*

All species of *Trichocera* are adapted to cold environments. Larvae are mostly saprophagous and sometimes coprophagous; in some areas they aestivate throughout the summer, sometimes buried deep in the soil (Dahl 1970c), thus protected against heat and desiccation. There are four larval instars and pupation usually lasts only a few hours. Winged adults typically appear in the cooler seasons (autumn to early spring). Recent studies in Norway (Hågvar & Krzemińska 2008) have demonstrated that adults of several species can continue mating and laying eggs at the height of winter, and that larvae can complete development to adult emergence under snow cover during the same winter. In the majority of species the adult stage shifts progressively into the summer months with increasing latitude or altitude (Dahl 1970a).

The three species of *Trichocera* established in the Southern Hemisphere are closely related and belong to the *regelationis* group of species (*sensu* Krzemińska 1999), implying they share some biological features allowing them to survive the transport required from the Northern to the Southern Hemisphere. They are known to share the ability to survive the relatively warm conditions experienced towards the southern limits of their distributions in Europe (Krzemińska 1995; Dahl et al. 2002), and the ability to use rich substrata (Perris 1847; Keilin 1912; Karandikar 1931; Krzemińska 2000; Dahl 1970c).

In addition to being able to survive transport, *T. maculipennis* is sometimes characterized as synanthropic (Lindroth 1931; Dahl 1967). It seems to require (or at least tolerate) more constant and somewhat higher temperatures for larval development than other related species (Dahl 1966). The larvae can utilize very rich substrata, such as composting vegetable matter and animal carcasses and droppings, and sometimes they are pests of stored vegetables (EK unpubl. data). In a scenario of anthropogenic introduction, such synanthropy could predispose the species to survive on initial transfer.

Occurrence on King George Island

The northern natural distribution of this species is consistent with the species' presence on King George Island being the result of an anthropogenic introduction. Indeed, the November 2006 observation and collection of a specimen close to the runway facility at Frei Base, which predates by several weeks the first observations at Artigas Base (at about 4 km from Frei), is suggestive of such an event. However, with the evidence available, it is not possible to suggest the original source of the population.

The current observations do not provide a categorical introduction date to King George Island, not least as no national research programme on the island has operated any form of terrestrial biodiversity monitoring programme, and relatively few collections of terrestrial invertebrates have been made. The species was clearly not present in the 1978/79 summer season during extensive surveys by the dipterist Wiesław Krzemiński (ISEA), who only reported the native chironomid *Parochlus steinenii*. (W. Krzemiński, pers. comm.).

Despite an intensive eradication attempt after its initial discovery, the fly continues to occur around Artigas Base. As noted by Hughes et al. (2005), established synanthropic species may prove extremely difficult to eradicate. If, as thought, the eradication was successful within the facilities of the Base, the species' subsequent re-appearance within them suggests that it may be established in the natural environment beyond the Base confines and that the sewage tanks were recolonized between 2008 and 2011.

Potential for establishment and dispersal

In the northern parts of its natural distribution, such as in Iceland, Greenland, Jan Mayen Island and Bjornøya (Dahl 1957, 1970a, 1973; Coulson & Resfeth 2004), *T. maculipennis* will experience similar low summer temperatures and, in some areas, winter temperatures considerably more extreme than those of the South Shetland Islands. Furthermore, throughout this archipelago, and indeed along much of the western Antarctic Peninsula, there are many sources of suitable decaying organic matter (bird and seal guano, carcasses, vegetation, microbial mats, etc.). Therefore, *T. maculipennis* is highly likely to have life history and physiological characteristics that would assist its survival during the transport, initial transfer and establishment in the conditions that are typical throughout the maritime Antarctic.

The close proximity of the records reported here to Antarctic Specially Protected Area 150 (Ardley Island) provides particular cause for concern, as there is no barrier to prevent the fly moving into and colonising this important area (cf. Hughes and Convey 2010). This risk has separately been illustrated recently by the colonisation of ASPA 128 (Western Shore of Admiralty Bay, a location also on King George Island) by alien plants (Olech and Chwedorzewska 2011; Cuba-Diaz et al. 2012).

Due to the proximity of many research stations on King George Island, and the observation of some individual adults beyond the buildings and boundary of Artigas Base, there is also a risk of *T. maculipennis* establishing populations at other stations in the immediate vicinity on the Fildes Peninsula. Furthermore, and enhanced by the magnitude of aircraft and vessel traffic utilising the logistic and tourist hubs on King George Island to access the entire Antarctic Peninsula, synergy with regional climatic change and the relatively close proximity of other ice-free ground in this region, there is also a high risk of the species spreading beyond the immediate vicinity of the Fildes Peninsula. Analogous risks of within-region expansion of the distribution of an already-established insect in the maritime Antarctic have recently been demonstrated in a study of the potential distribution of the alien midge *Eretmoptera murphyi*, an introduced species currently restricted to Signy Island (South Orkney Islands) (Hughes and Worland 2010; Hughes et al. 2012).

Alien species with potential to become invasive often do not to do so for a significant period after initial establishment (Frenot et al. 2005). To provide an objective assessment of the current risk of spread and establishment beyond Artigas Base confines, further information is required on the detailed life history characteristics of the species. However, given that *T. maculipennis* is not indigenous to South America, and is currently known to breed only within an Antarctic research Base, clearly it fulfills the simple and practicable assessment criteria proposed by Hughes and Convey (2012) for informing decisions assessing the colonization status of newly recorded species in the Antarctic, and leading to subsequent management action. In this case, application of these criteria leads to a very high probability of *T. maculipennis* being a human-assisted alien colonist, and hence requiring urgent eradication, as also recommended in the 'Non-native Species Manual' of the Committee for Environmental Protection of the Antarctic Treaty System (see http://www.ats.aq/documents/atcm34/ww/atcm34_ww004_e.pdf). An urgent and effective eradication operation is therefore required, along with subsequent site monitoring, focusing on the Artigas Base sewage system which at present provides the only location where the species is known to have successfully completed its life cycle.

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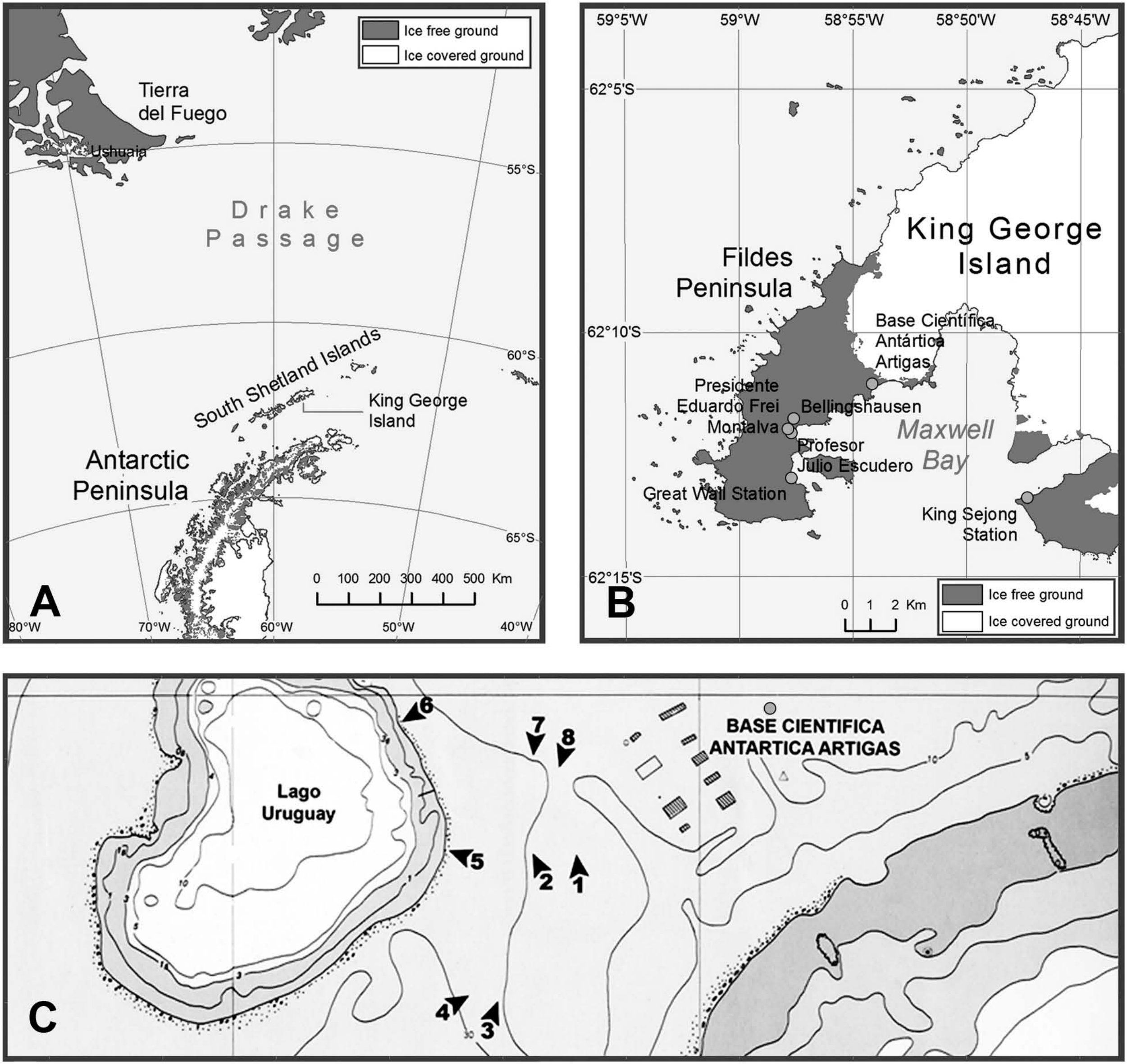
Figure captions

Fig. 1 Collection site. **A**, South Shetland Islands, showing King George Island; **B**, Fildes Peninsula, King George Island; **C**, pitfall sampling sites close to Artigas Base, Fildes Peninsula

Fig. 2 Adult *Trichocera maculipennis*. **A**, Uniform colour of abdomen in specimens from Grottes in Switzerland, scale bar: 2 mm; **B**, specimen on the snow at site 2, Fildes Peninsula; **C**, ringed abdomen in a male from King George Island, scale bar: 2 mm; **D**, ringed abdomen in a sample of specimens from King George Island, scale bar: 6 mm; **E**, magnification of abdominal segments in a specimen from King George Island, showing the pigmentation pattern, scale bar: 300 µm; **F**, wing of a specimen from King George Island, scale bar: 2 mm; **G**, male genitalia of a specimen from King George Island, scale bar: 200 µm; **H**, female genitalia of a specimen from King George Island, scale bar: 200 µm.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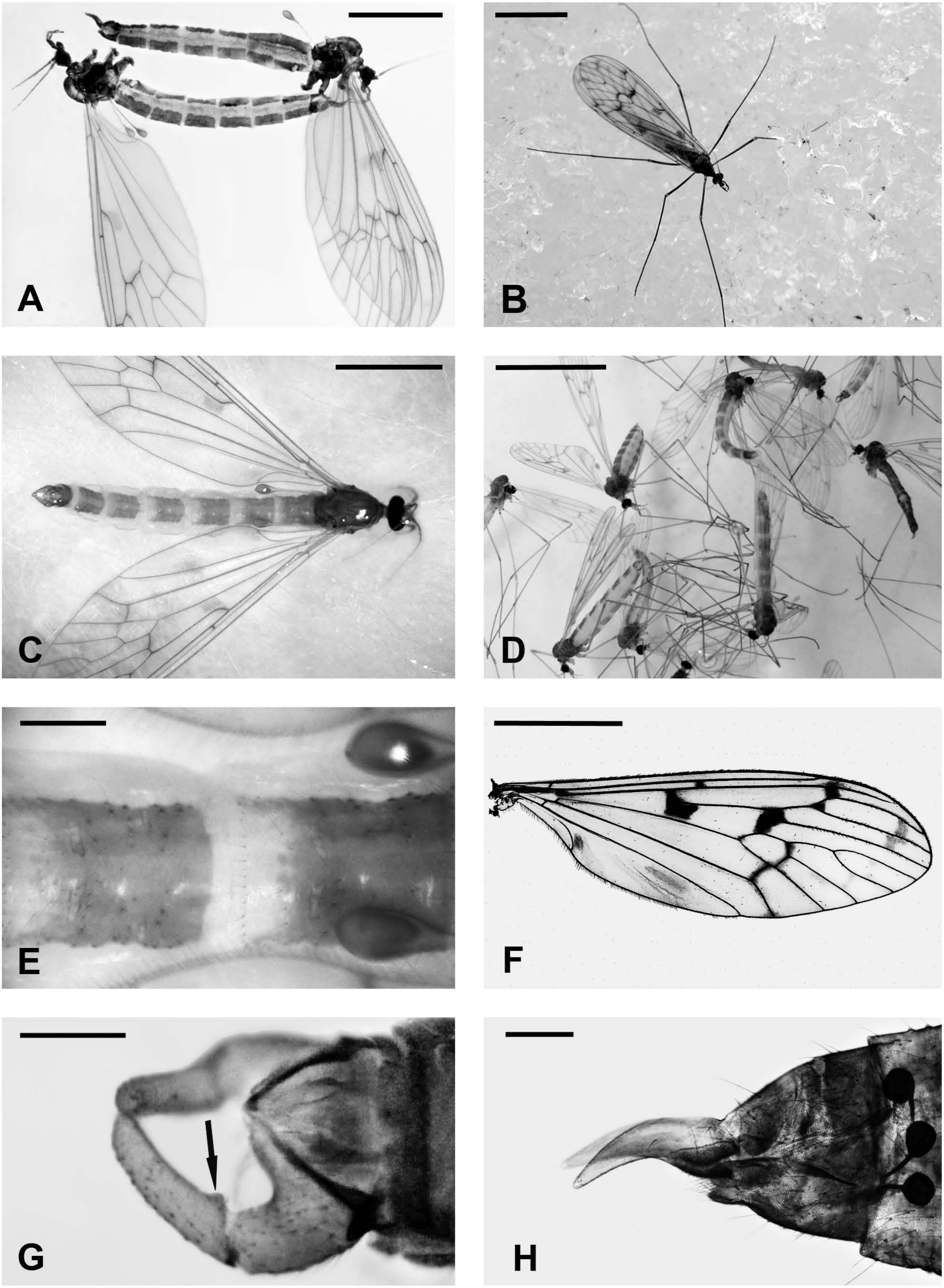
A
B
C
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E
F
G
H