A taxonomic review of Canadian Oestridae (Calyptrate: Oestroidea)

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Abstract

Oestridae, known as bot flies and warble flies, are a small group of flies whose larvae are obligate mammal parasites that cause myiasis in their host. I review eighteen species from five genera of Oestridae in Canada and present new illustrated identification keys and explicit adult morphology diagnoses for all Canadian species. I have confirm that *Cuterebra buccata* (Fabricius, 1776) is distributed in Canada, and I consider *Cuterebra grisea* Coquillett, 1904 a junior synonym of *Cuterebra fontinella* Clark, 1827. Each species is described in detail, with notes on the taxonomy and distribution of species. The updated identification resources of the Canadian Oestridae will facilitate further research of this fauna and support research in parasitology, wildlife ecology, and veterinarian medicine.

Abstrait

La famille Oestridae, communément connue sous le nom de mouches bots et de mouches gazeuses, inclut un petit groupe de mouches dont les larves sont des parasites obligatoires des mammifères qui provoquent une myiase chez leur hôte. J'examine dix-huit espèces de cinq genres d'Oestridae au Canada et présente de nouvelles clés d'identification illustrées et des diagnostics explicites de morphologie adulte de toutes les espèces canadiennes. J'ai confirmé que *Cuterebra buccata* (Fabricius, 1776) est répartie au Canada et je considère *Cuterebra grisea* Coquillett, 1904 comme un synonyme plus récent de *Cuterebra fontinella* Clark, 1827. Chaque espèce est décrite en détail, avec des notes sur la taxonomie et la répartition des espèces. Les ressources d'identification mises à jour des Oestridae canadiens faciliteront la poursuite des recherches sur cette faune et soutiendront la recherche en parasitologie, en écologie de la faune et en médecine vétérinaire.

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Contribution of Authors

I examined and databased all examined Oestridae specimens, created the identification keys, and wrote the original manuscript. My supervisor and co-supervisor, Dr. Jessica Gillung and Dr. Morgan Jackson contributed to the conceptual design of this taxonomic review, to the borrowing of Oestridae specimens from most of the major Canadian entomological collections, and provided advice, comments, and edits on this thesis.

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List of Abbreviations:

aut.: automatic typification.
e.g.: *exempli gratia*, for example.
emend.: emendation.
error: incorrect subsequent spelling
et al.: *et alii*, and others.
ff.: and following pages
fig(s).: figure
H: holotype
ICZN: International Commssion on Zoological Nomenclature.
i.e.: *id est*, that is.
L: Lectotype
mssp. : misspelling
mon.: monotypy
orig. des.: original designation.
preocc.: preoccupied.
q.v.: *quod vide*, which see
sp.: (pural: **spp.**) species.
sub. des.: subsequent designation
T/type: type species.

1. Introduction

1.1 Thesis rationale

Oestridae are a family of medium to large (8-30 mm) files whose adults are mostly robust and hairy, with compact or atrophied mouthparts. The larvae of Oestridae are obligate parasites of mammals, which usually cause characteristic furuncles around the parasitic site. Due to this unique syndrome, they are commonly known as bot flies or warble flies.

All bot flies were first described in the genus *Oestrus* by Linnaeus and divided into multiple families in later taxonomic studies (Brauer 1887; Brues & Melander 1915). In 1987, Wood defined the family Oestridae as a combination of four subfamilies. Most genera lack taxonomic revision, and the current generic revisions (except *Gasterophilus*) have not been updated in the last 50 years (Bennett and Sabrosky 1962; Sabrosky 1986). A catalogue is needed to trace the change of nomenclature and clarify the synonyms and incorrect original spellings in Oestridae.

Canada is a country with an area of 9,985 km^2, containing a myriad of forest, tundra, prairie, wetland and freshwater ecosystems (Islam 2019). These ecosystems support a high diversity of mammals, many of which, such as reindeer, white-tailed deer and white-footed mice, are known primary hosts of bot flies (Breevui 1940, Bennett 1962, Sabrosky 1986). And thus, bot flies, as prolific parasites of wildlife, are an important component of Canadian biodiversity, yet remain difficult to identify and study.

As significant pests in livestock husbandry, some bot fly species have historically caused large economic losses. For example, *Hypoderma bovis* (Linnaeus, 1758), which causes about $6 million in Alberta per year, was researched in-depth in parasite-host association and pest control (Hadwen 1919, Patton 1936, Weintraub 1961, Tarry 1986, Open Government 1991). As well as the parasites of umbrella species, such as *Hypoderma tarandi* (Linaeus, 1758) and *Cephenemyia trompe* (Modéer, 1786) (parasites of reindeer), were studied in biology, ecology and parasite-host association (Cogley and Anderson 1981, Anderson 1989, Anderson and Nilssen 1996, Nilssen 1997a, 1997b, Micheletti et al. 2023). However, the parasites of other mammals, such as rabbits and mice, failed to call as much attention as the ones outlined above.

Identifying a Canadian bot fly is difficult, due to the identification materials being incomplete (such as in the genus *Hypoderma*), lacking character illustrations, asymmetry in couplets and inconsistent use of morphological terminology. The most recent identification keys of *Cephenemyia* and *Cuterebra*, which lack character illustrations, have not been revised and updated for over 40 years (Bennett and Sabrosky 1962; Sabrosky 1986). So far, no identification key is specific to Canadian Oestridae fauna. Identification keys for worldwide or Nearctic regions including many non-Canadian species, make them long and overly complicated for identifying Canadian species (Sabrosky 1986; Li et al. 2019). Thus, an accurate, efficient identification key for Canadian Oestridae is essential as a foundation for further wildlife, agricultural or veterinary medicine research. For this purpose, I produced the identification key for Canadian bot flies.

1.2 Thesis Goal

My research objective is to review the Oestridae fauna of Canada. More specifically, I used adult morphology to assess species identities and limits for the Canadian oestrids, and assessed the geographic and biological ranges.

To accomplish this, I will:

(1) Review the taxonomy of Canadian Oestridae and provide a synoptic species catalogue;

(2) Update the species descriptions and produce distribution maps of Canadian Oestridae;

(3) Provide a digital database of all examined specimens;

(4) Provide generic and species identification keys of Canadian Oestridae for both professional taxonomists and the general public.

I hope my thesis will provide fundamental knowledge of Canadian Oestridae taxonomy and updated identification materials to various readers for amateur entomologists, taxonomists and the field workers. I also hope that this thesis will stimulate further taxonomic study of those neglected genera and species.

2. Literature Review

2.1 Parasitism:

The definition of parasitism is ambiguous in the literature and depends on the researchers' perspectives. In this thesis, I define *parasitism* as an association between two species in which one species (the *parasite*) gains benefits from consuming another (the *host*) but without killing the host directly (Marshall 2012). In contrast to a parasite, a *parasitoid* gradually consumes the host, but eventually kills it as the parasitoid emerges into a free-living adult (De Baets and Huntley 2021). Parasites and parasitoids are commonly categorized as generalists or specialists. A *generalist* parasitizes a wide host range from multiple families or more than one class. In contrast, a *specialist* is restricted to host species in a genus or a few close genera (Wells and Clark 2019). The level of restriction in host species is referred to as *host specificity* of the parasite (Poulin, 2011). Based on the mode of parasitism, parasites can be further categorized as *endoparasites* (residing inside the tissue of a host, such as a tapeworm) and *ectoparasites* (living externally on the host, such as lice) (Hurd 2010).

Parasitism is a common biological interaction in the animal kingdom, in which nearly half of all species undergo a parasitic life stage (Weinstein and Kuris 2016). Animal parasites are believed to have evolved from free-living ancestors but with at least 223 independent origins (Poulin 2011, Weinstein and Kuris 2016). In Insecta, parasitism is an exceptionally common life history strategy, having evolved at least 87 different times, with 60 of those independent origins of parasitism arising within the Diptera (Weinstein and Kuris 2016). As a widely evolved parasite taxon, studying Diptera parasites allows us to have a more detailed understanding of parasites' evolution and develop new technologies to deal with various parasites in humans and animals.

2.2 Myiasis:

The larvae of flies (Diptera) are commonly called maggots, and when parasitic maggots infest the living tissue of vertebrates, it is described as *myiasis* (Marshall 2012). The parasitic maggots feed on living and dead tissues, liquid body substances, or even ingested food, depending on the infested sites (cutaneous or cavitary) (Francesconi and Lupi 2012). Myiasis itself is rarely fatal, although it routinely causes tissue damage and extra metabolic costs, but secondary bacterial infections commonly occur at myiasis sites, which leads to tissue necrosis or death in extreme cases (Colwell 2001, Francesconi and Lupi 2012, Marshall 2012).

Besides tissue damage, some myiasis-causing larvae (i.e., *Lucilia sericata* (Meigen, 1826)) are applied for medical purposes. The therapist introduces pathogen-free maggots within the wound, allowing the maggot to consume the necrotic tissue for disinfection, removing the maggot following treatment. This method known as maggot debridement therapy (MDT) has been proven to be low-cost, safe and efficient in healing chronic ulcers (Sun et al. 2014, Nasoori and Hoomand 2017).

Based on how strongly the fly parasite relies on the host, myiasis is often categorized into three types: accidental, facultative, or obligate (Luong and Mathot 2019). *Accidental myiasis*, also called pseudomyiasis, is caused by non-parasitic saprophagous dipteran larvae, which accidentally enter and remain in a living animal's wound or body orifice; *facultative myiasis* is caused by opportunistic parasites, which can complete either a free-living or a parasitic life cycle; and *obligate myiasis* is caused by parasitic species that cannot complete their life cycle without a suitable proper host (Luong and Mathot 2019).

Myaisis-inducing flies are most common in the superfamilies Muscoidea and Oestroidea. Except for species of *Philornis* Meinert, 1890, which are obligate parasites, Muscoidea are accidental or facultative parasites of mammals, by females directly depositing eggs on the host's wound causing dermal myiasis or the host accidentally swallowing the eggs or larvae to cause intestinal myiasis (such as *Musca domestica* Linnaeus, 1758) (Burgess and Daviks 1991, Shivekar et al. 2008, Dehghani et al. 2012, Sehgal et al. 2012). There is a certain degree of randomness in this process. The larvae are not modified for a parasitic lifestyle, and thus, they are not specialist parasites of a specific host. Species of Oestroidea including facultative parasites (such as *Lucilia sericata* (Meigen, 1826)) and obligate parasites (such as *Cochliomyia hominivorax* (Coquerel, 1858)) (Gomez et al. 2003, Talar et al. 2004, Nasoori and Hoomand 2017). The evolutionary origins and transition mechanisms of parasitism in calyptrate Diptera, including myiasis, are poorly understood currently.

2.3 Evolution and Phylogeny of Oestridae

Calyptratae, as one of the most diverse fly clades, is unquestionably monophyletic, having been established based on strong morphological and molecular data (Hackman and Vaisanen 1985, McAlpine and Wood 1989, Wiegmann et al. 2011, Lambkin et al. 2013, Kutty et al. 2019). Relationships among some family-groups have been well-researched (such as Hippoboscoidea and Muscoidea) (Pape 2001, Savage and Wheeler 2004, Savage et al. 2004, Dittmar et al. 2006, Ding et al. 2015, Cerretti et al. 2017). Still, many others remain largely understudied.

Monophyly of Oestroidea remains controversial, with differing relationships returned depending on the data used and taxa included (Cerretti et al. 2017, Kutty et al. 2019). Based on morphology, Sarcophagidae (house flies) is monophyletic and recognized as three subfamilies, Miltogramminae, Paramacronychiinae and Sacrophaginae, which has been supported with molecular data (Pape 1992, Kutty et al. 2010). Calliphorids (blow flies) are paraphyletic with morphological and molecular evidence producing differing relationships

(Cerretti et al. 2017, Kutty et al. 2019). In contrast, Calliphoridae are redefined as the inclusive group of superfamily Oestroidea that excluded Mesembrinellidae, Mystacinobiidae, Oestridae, Polleniidae, Sarcophagidae, Tachinidae, and Ulurumyiidae (Yan et al. 2021).

Oestridae is currently considered to be monophyletic, with strong support from morphology (Wood 1987, Pape 1992, 2001) and mitogenomic data (Zhang et al. 2016). However, on-going phylogenomic research has suggested that the family Oestridae is paraphyletic (Moran 2023, Yan and Pape 2023).

2.3.1 Classification of Oestridae

Originally, bot fly was a collective common name for all obligate parasites of mammals with adults with *atrophied* mouthparts (mouthparts reduced in size and function) (Wood 1987). Wood integrated four families (Cuterebridae, Gasterophilidae, Hypodermatidae and Oestridae) as one family, Oestridae, and the four families above were defined as four subfamilies (Cuterebrinae, Gasterophilinae, Hypodermatinae, and Oestrinae) (Wood 1987) A later study of Oestridae phylogeny base on shared features (including morphology, ontogeny, physiology and behaviour) corroborated Wood's classification (Pape 2001). Based on the site of infestation by the oestrid larvae, they are commonly classified as gut bot flies (Gasterophilinae.), nasal bot flies (Oestrinae) and skin bot flies or warble flies (Cuterebrinae and Hypodermatinae) (Wood 1987).

Subfamily Cuterebrinae includes two genera, *Cuterebra* Clark, 1815 and *Dermatobia* Brauer, 1861, both only found in the Nearctic region (Sabrosky 1986, Sancho 1988, Maier and Hönigsmann 2004). *Cuterebra*, known as rabbit and rodent skin bot flies, are a large genus including over 60 species (Wood 1987). In contrast, *Dermatobia* is monotypic (*D. hominis* (Linnaeus, 1781)) and restricted to Central America and South America. These flies are known as human bot flies, but are not specialists in humans. Instead, *Dermatobia hominis* are generalists with a wide range of hosts, including humans (Sancho 1988). Cuterebrinae (*Cuterebra* and *Dermatobia*) is the only American subfamily, which is on the base of the Oestridae phylogenetic tree (Pape 2001).

The subfamily Gasterophilinae includes three genera of gut bot flies and two genera of skin bot flies: *Gasterophilus* Leach, 1817, horse gut flies; *Gyrostigma* Brauer, 1884, rhino gut flies; *Cobboldia* Brauer, 1887, elephant gut flies; and *Neocuterebra* Grunberg, 1906 and *Ruttenia* Rodhain, 1924, two monotypic genera of elephant skin flies. Most species of Gasterophilinae are restricted to Africa. Only four *Gasterophilus* spp. are found in the Nearctic region. Two genera of elephant skin bot flies, *Neocuterebra* and *Ruttenia*, are found in West Africa, Zumpt and Pape classified them as Gasterophilinae, and Wood classified them as Cuterebrinae (Zumpt 1965; Wood 1987; Pape 2001).

The subfamily Hypodermatinae includes nine genera: *Ochotonia* Grunin, 1968, *Portschinskia* Semenov, 1902, *Oestroderma* Portschinsky, 1887, *Oestromyia* Brauer, 1861, *Hypoderma* Latreille, 1818, *Pallasiomyia* Grunin, 1949, *Przhevalskiana* Grunin, 1948, *Strobiloestrus* Brauer, 1892, and *Pavlovskiata* Grunin, 1949. Except for *Strobiloestrus* and *Hypoderma*, the other genera are recorded exclusively in Central Asia or dispersed in Eurasia (Wood 1987). *Strobiloestrus* are restricted to Africa, are parasites of kobus (antelope), and occasionally found in sheep and cattle (Horak 1981, Brain 1983, Wood 1987). *Hypoderma* includes eleven species of cattle and reindeer warble flies that likely originated in Eurasia (Wood 1987). Two species of cattle warble flies, *Hypoderma bovis* (Linnaeus, 1758) and *Hypoderma lineatum* (Villers, 1789)) and one species of reindeer warble fly (*Hypoderma tarandi* (Linnaeus, 1758), are found in the Nearctic region (Hadwen 1919, Mote 1928). *Hypoderma tarandi* is sometimes considered belonging to a different genus, *Oedemagena*, which is monotypic; or genus *Hypoderma* and subgenus *Oedemagena* (Latreille 1818, Breevui 1940, Zumpt 1965). *Hypoderma tarandi* has a different primary host from any other

Hypoderma spp., and the atrophy level of the mouthpart is clearly lower than all the others (Wood 1987). Phylogenetic study indicates that *Hypoderma tarandi* entered the Nearctic region prehistorically, much earlier than cattle warbles (Colwell 2006). The putative invasion of cattle warble is via the cattle of European Conquistadores in the 1500s.

Subfamily Oestrinae includes nine genera, including *Cephalophina* Strand 1928*; Cephenemyia* Latreille, 1818*; Gedoelstia* Rodhain & Bequaert, 1915*; Kirkioestrus* Rodhain & Bequaert, 1915*; Oestrus* Linnaeus, 1758*; Pharyngobolus* Brauer, 1866*; Pharyngomyia* Grunin, 1950*; Rhinoestrus* Brauer, 1886 and *Tracheomyia* Townsend, 1916. Two genera, *Cephenemyia* and *Pharyngomyia*, evolved from a common Palaearctic ancestor, and the remaining genera form a monophyletic clade that evolved from an African ancestor (Pape 2001, Colwell et al. 2006). *Cephenemyia* migrated into the Nearctic region in the Cenozoic (Colwell et al. 2006). The sheep nasal bot fly (*Oestrus ovis* Linnaeus, 1758) entered the Nearctic region during the 15th-17th centuries (Colwell et al. 2006).

2.4 Biology of Oestridae

Except for *Dermatobia hominis* (which is generalist), Oestridae are host-specific parasites of mammals. The lifecycle of Oestridae varies in oviposition strategies, larval development, pupal duration and adult biology (Colwell 2001). The number of broods or generations of a species within a year is called *voltinism*. In the Nearctic region, Oestridae is found univoltine or biovoltine (Baird 1975, Jacobson et al. 1978, Cogley 1991, University of Saskatchewan 2021).

2.4.1 Oviposition Strategies

Oviposition is a descriptor of how females behave while depositing their eggs or larvae. Oviposition strategies in oestrids are widely varied from one genus to another.

Females of *Hypoderma* and most *Gasterophilus* land on the host, and attach their eggs on the hair of the hosts (Mote 1928, Cogley 1991), although the female of *Gasterophilius pecorum* is exceptional in that she lays over 2000 eggs on the plant foliage over a wide area (Zhang et al. 2022). Females *G. pecorum* secrete a thin layer of adhesive protein on the surface of eggs (Cogley 1991). These eggs are persistent for months until the ingestion of the foliage by a random grazer (principally horses) (Zumpt 1965). Females in the subfamily Oestrinae hatch their larvae inside their uterus and larviposit on the host (Catts 1964). Female Oestrinae hover around the herd of hosts (i.e., white-tailed deer) and seek an opportunity to expel the larvae into the host's nostrils (Anderson 1975, Toupin et al. 1996).

Instead of directly depositing eggs on the host, Cuterebrinae females look for the nest or burrow of the host via either visual or chemical attractants and stick many eggs on the foliage or rocks close to the nest (Capelle 1970). In this case, eggs are viable for 6 to 10 months and capable of overwintering. *Dermatobia hominis* attacks and attaches eggs to forest mosquitos (Maier and Hönigsmann 2004). The mosquitos carry eggs toward the target mammal host via blood-feeding behaviours (Maier and Hönigsmann 2004).

2.4.2 Larva

The primary hosts of bot fly larvae include a wide range of Perissodactyla (horses, donkeys and rhinoceros), Artiodactyla (deer, sheep, cattle, etc.), Rodentia (mice and squirrels), and lagomorphs (hares and cottontails). A few exceptions include *Cuterebra baeri* Shannon & Greene, 1926 (a specialist of howler monkeys) and *Dermatobia hominis* (a generalist parasite of mammals) (Maier and Hönigsmann 2004, Rondón et al. 2023). Interestingly, no carnivorous mammal is targeted as the primary host of oestrids, but infestation has been recorded while feeding on infested prey (Sun et al. 2014, Ganjali and Keighobadi 2016).

The development stage between the moulting of an arthropod is called *instar*. For example, a larva newly hatched for the egg and before the first moulting is a 1st instar larva. A larva of Oestridae has 3 instar, from 1st instar to 3rd instar (Colwell et al. 2006). The growth curve of Oestridae larvae indicates that they undergo rapid growth in the early first instar and in the third instar (Bennett 1955). At the end of the third instar, mature larvae leave the hosts via different routes: larvae of gut flies leave the host gastrointestinal tract via the defecation of the host; larvae of nasal flies leave the nasal cavity from the nares (the opening of nasal cavity), which often triggers the host sneezing (Anderson 1975); larvae of skin bots simply crawl out of the skin from the pore on host's skin that larva pierce thought for entering and respiration (Catts 1967).

2.4.3 Pupa

Once oestrid larvae leave the host, they bury themselves in soft soil or feces and begin to pupate (Wood 1987). In most cases, larvae take less than two days to pupate, but in an extreme case, mature lab-reared *Hypoderma tarandi* larvae lived for 432 hours without pupating under 8°C (Nilssen 1997b). Pupal duration is highly varied between years and localities, taking longer in lower temperatures. Diapause, a delay in animal development, commonly occurs in *Cuterebra* pupae in response to low temperatures (Baird 1972, Colwell et al. 2006). However, whether diapause occurs in other oestrid genera is still uncertain in the literature (Rogers and Kanpp 1873, Breev et al. 1980; Biggs et al. 1998). The emergence rates of lab-reared reindeer bot flies (*Hypoderma tarandi* and *Cephenemyia trompe*) are mostly between 50% to 70% in optimum temperature and humidity conditions (Nilssen 1997a).

2.4.4 Adult

Adults of many species are wasp or bee mimics, with yellow to orange cuticles or hairs, and cross black-haired bands on the body. The alula (posterior and basal of the wing membrane) is enlarged and flipped upward. Mouthparts are minute or atrophied in all Oestridae and the degree of atrophy is varied. Mouthparts may have been reduced multiple times in different genera or species. For example, *Hypoderma tarandi* has a pair of conspicuous orange palps, which are absent in the other two species of Nearctic *Hypoderma* (Wood 1987). Whether the atrophied mouthparts of bot flies are functional is still controversial, and may depend on genera. Most bot fly species, such as *Oestrus ovis*, do not feed at all in their whole adulthood, which is the major reason for their short longevity (Colwell et al. 2006). However, *Cephenemyia* spp. has been reported to absorb moisture by pressing the highly reduced mouthparts (as three knobs on the ventral of the face plate) on a liquid substrate (Catts and Garcia 1963). The atrophied mouthparts of *Cuterebra* spp. are tubular and concealed behind the genal slit, which is predicted to be somehow functional, but feeding has yet to be observed (Bennett 1955).

Males of many species (including *Gasterophilus* spp., *Hypoderma* spp., *Cephenemyia* spp. and *Cuterebra* spp.) assemble in specific perching sites usually in the early morning or late afternoon, which is known as ‘hilltopping’ behaviour (Catts et al. 1965, Hunter and Webster 1973, Catts 1979, Shiffer 1983, Zhang et al. 2022). When a female approaches the aggregation site, one of the males captures and inseminates the female, and then releases it to seek a host for ovi- or larviposition (Catts 1979, Downes et al. 1985).

2.5 Nearctic Fauna

Previous research recorded all four subfamilies (Cuterebrinae, Gasterophilinae, Hypodermatinae and Oestrinae) in the Nearctic region, including 45 species from five genera (seven *Cephenemyia* spp., 34 *Cuterebra* spp., four *Gasterophilus* spp., three *Hypoderma* spp., and one *Oestrus* sp.) (Fallis 1940, Bennett and Sabrosky 1962, Catts et al. 1965, Sabrosky 1986, Anderson and Nilssen 1996, Li et al. 2019). In Canada, 15 species of Oestridae were reported in 1979 (McAlpine 1979) and increased to 17 species in 2019 (Savage et al. 2019).

Notably, travellers from Central America and South America occasionally carry the larvae of *Dermatobia hominis* into Canada (MacFadden et al. 2015). However, observations or collections of adult *Dermatobia hominis* are absent, and no evidence suggests that *Dermatobia hominis* has been established in Canada.

2.5.1 Genus *Cuterebra*

Swenk published the taxonomy of North American *Cuterebra* in 1905. In Swenk's research, three species were found in Canada, including *Cuterebra buccata* (Fabricius, 1775), *Cuterebra fontinella* Clark, 1827 and *Cuterebra horripililum* (Clark, 1815).

The most recent faunistic study of the Nearctic *Cuterebra* was accomplished by Sabrosky in 1986. He described and redescribed 34 *Cuterebra* spp. in the Nearctic region. Six species of *Cuterebra* were distributed in Canada.

2.5.2 Genus *Gasterophilus*

The most recent taxonomic revision of global *Gasterophilus* was accomplished by Li et al., in 2019. Four species have been introduced to the Nearctic region, three of which were found in Canada, including *Gasterophilus haemorrhoidalis, G. intestinalis*, and *G. nasalis.*

2.5.3 Genus *Hypoderma*

The taxonomy of *Hypoderma* has not been comprehensively reviewed yet. Weintraub et al. published a series of research on cattle warble flies (*Hypoderma bovis* and *H. lineatum*) in Kamloops Livestock Lab (Weintraub et al. 1959, Gooding and Weintraub 1960, Weintraub

1961). *Hypoderma tarandi*, well known as reindeer warble flies, has been well explored in Canada (Breevui 1940, Nilssen and Anderson 1995, Anderson and Nilssen 1996, Nilssen 1997a, 1997b).

2.5.4 Genus *Cephenemyia*

Bennett and Sabrosky (1962) published a taxonomic study of Nearctic *Cephenemyia* in 1962. They described and redescribed five species and discussed an unjustified emendated species name, *Cephenemyia macrostis* Brauer, 1863a. Four species, *Cephenemyia apicata* Bennett & Sabrosky, 1962; *C. jellisoni* Townsend, 1941; *C. phobifer* (Clark, 1815) and *C. trompe* (Modéer, 1786), are distributed in Canada. Taber and Fleenor (2004) described a new species, *Cephenemyia albina* Taber & Fleenor, 2004, from Central Texas in 2004, but it has not been found north of Texas yet (Taber and Fleenor 2004, Fleenor and Taber 2007).

2.5.5 Genus *Oestrus*

Only one species of *Oestrus* (*O. ovis*, known as sheep bot flies) has been introduced to the Nearctic region (Wood 1987). In Canada, they are univoltine or bivoltine and are only found in Canada and the USA (Fallis 1940, Cobbett and Mitchell 1941, Capelle 1966, University of Saskatchewan 2021). In contrast, *Oestrus ovis* is widely distributed and has multiple (up to seven) generations in Africa (Yilma and Genet 2000). Thus, they cause less severe loss and attract less attention in Canada.

2.6 Importance of Oestridae

As significant agricultural pests in animal husbandry, cattle warble flies (e.g., *Hypoderma bovis* and *Hypoderma lineatum*) were infesting almost 100% of British cattle before 1967 and annually caused 13 million pounds of economic losses before the Great

Eradication, a multi-country program warble fly control program to eliminate the cattle warbles in Europe (Tarry 1986). In Canada, there are major cattle pests in Alberta, and the government has established a by-law to control the cattle warble (Country of Camrose, 2003).

Besides agricultural importance, bot flies also draw the attention of mammalogists. Due to the strong parasite-host association, many parasites have been used as indicators (or ‘Natural Tags’) in studying the host species population (Sindermann 1983, MacKenzie 1987). Sindermann listed seven criteria for a parasite species to serve as an ideal ‘natural tag’, and many oestrid species fit most criteria (Sindermann 1983). Potentially, *Hypoderma tarandi* and *Cephenemyia trompe* are great candidates for indicators for studying reindeer, one of the umbrella species in the Canadian tundra ecosystem (Micheletti et al. 2023). The prevalence of parasitism in *Cuterebra* and the influence on rodent populations interests many researchers (Jacobson et al. 1981, Clark and Kaufman 1990, Wolf and Batzli 2001, Cruz et al. 2009).

Parasite evolution is usually associated with their host, as indicated by the topological match between cladograms of Gasterophilinae and their hosts (Colwell et al. 2006). The study of Canadian bot flies can provide an understanding of natural history from a new perspective. Most importantly, Oestridae is a part of the Canadian Diptera fauna and this study will elaborate on the research of Canadian biodiversity (Savage et al. 2019).

2.7 Taxonomy and Identification Resources

Taxonomy, the science of categorizing and classifying species, is modern biology's foundation. Humans are instinctive taxonomists; I can identify different species of animals and plants based on their traits and behaviour, and use such knowledge to improve our lives in many ways (Winston 1999). Linnaeus created the binomial nomenclature system in the 18th Century, a standardized system to describe a species, with a unique two-word (*Genus species*) combination for each species. To justify the species, naturalists usually provided a diagnosis (a short paragraph or telegraphic format) or a description (detailed paragraphs portraying the characters).

In the field of entomology, taxonomists have described over one million species in the last 250 years (Stork 2018). A new estimation indicates that there are 5.5 million species of insect in total, which means about 80% of insect species are yet to be identified and described (Bickford et al. 2007, Stork 2018). However, as molecular biology rapidly develops in the 21^{st} Century, traditional taxonomy becomes 'antiquated' and fading away from society. Taxonomists keep invoking to maintain funding, training and public attention in taxonomy, but their calls have scarcely been responded to (Wilson 1985, Wheeler 2004, Tewksbury et al. 2014, Britz et al. 2020). Nowadays, taxonomy is an overly under-valued science.

A major product of taxonomists is identification keys. They are effective tools for both taxonomists and the public to identify a species by a series of characters. Traditional identification keys, known as single-access keys, are usually dichotomous, which provide pairs of alternative characters (couplets) to choose from. Species-level identification keys are still missing or outdated in many taxa, which causes many identification difficulties (Godfray 2002). Thus, my research will fill the missing gaps and update the identification resources for the Canadian fauna of Oestridae.

2.8 Goals and Objectives

For my thesis, I will accomplish an adult morphology-based faunistic study of Canadian Oestridae. I will examine Oestridae specimens from Canadian entomological collections and diagnose and describe the adult morphology of all Canadian Oestridae species. With these morphological data, I will create identification keys of Canadian Oestridae, for both taxonomic specialists and the general public to use. I will also create a digital database for these specimens. Based on the specimen locality and observation record in iNaturalist, I will provide distribution maps for all Canadian Oestridae. Species of Canadian Oestridae will be diagnosed and described. Distribution maps and identification keys will be provided.

My first objective is to compile a catalogue of Canadian Oestridae, to record and clarify any change in nomenclature of this taxon. The second objective is to review the taxonomy of the Canadian Oestridae and update the descriptions and distribution maps. The third objective is to create a digital database of the Oestridae specimens in major Canadian entomological collections for future research. The last objective is to provide a richly illustrated generic and species identification key, which are accessible to both specialists and non-specialists.

3. Materials and Methods

3.1 Specimens:

See Supplementary Material, which is the database of the examined specimens.vI requested specimens on loan from the following entomological collections:

CNCO: Canada, Ontario, Ottawa, Canadian National Collection of Insects, Arachnids and Nematodes

LEMQ: Canada, Quebec, Ste. Anne de Bellevue, McGill University, Lyman Entomological Museum

LINN: United Kingdom, London, The Linnean Collections, the Linnean Society of London

QMOR: Canada, Quebec, Montreal, University of Montreal, Ouellet-Robert entomological collection

ROMT: Canada, Ontario, Toronto, Royal Ontario Museum

UASM: Canada, Alberta, Edmonton, E.H. Strickland Entomological Museum

UBCZ: Canada, British Columbia, Vancouver, University of British Columbia, Spencer Entomological Museum

USNM: USA, Washington D.C., National Museum of Natural History

3.2 Images:

I used a Stackshot system (Cognisys Inc 2011) controlled by Helicon Remote (Helicon Soft 2023b) with a Canon EOS 70D camera to take the series of photos of specimens and characters. Superimposed photographs were stacked by Helicon Focus (Helicon Soft 2023a).

3.3 Genitalia Dissection:

Specimens were relaxed and rehydrated in a sealed container with water on the bottom for about 12-24 hours, and terminalia were carefully snipped off through the junction between abdominal tergites 4 and 5 with curved size #0 stainless steel insect pins. The treatment of male genitalia is adapted from a published dissection protocol (O’Hara 2002). Dissected genitalia are stored in a 16mm plastic genitalia micro vial which is pinned under the specimen.

3.4 Mapping:

Distribution maps were created based on the database of Canadian specimens and observation records on iNaturalist and BugGuide. Coordinates were recorded in decimal degrees, and estimated to six decimal places. Maps were generated with *SimpleMappr* (Shorthouse, David P. 2010).

3.5 Terminology:

Morphological terminology follows (Sabrosky 1986; Torre-Bueno 1989; Cumming and Wood 2017). Below is a glossary of morphological terms used in the species descriptions.

Bristle: Long and strong, spine-like setae; Oestridae were considered bristleless (Wood 1987). Black bristles on tarsomeres of *Hypoderma* spp. and veins C and Sc on *Oestrus ovis*.

Hair (haired): Long (> 1 mm) and fine setae, which can be observed by unaided eyes; colouration varies.

Microsetae (adj. microsetose): Short (< 1 mm) and fine setae that can hardly be observed by unaided eyes.

Microtomentum (microtomentose): Microscopic outgrowths of the cuticle, curled or curved like minute microsetae, which are found on many *Cuterebra* spp. (Sabrosky 1986).

Pruinosity (adj. pruinose): Fine dust and pollen-like powder on the cuticle, usually white or whitish yellow.

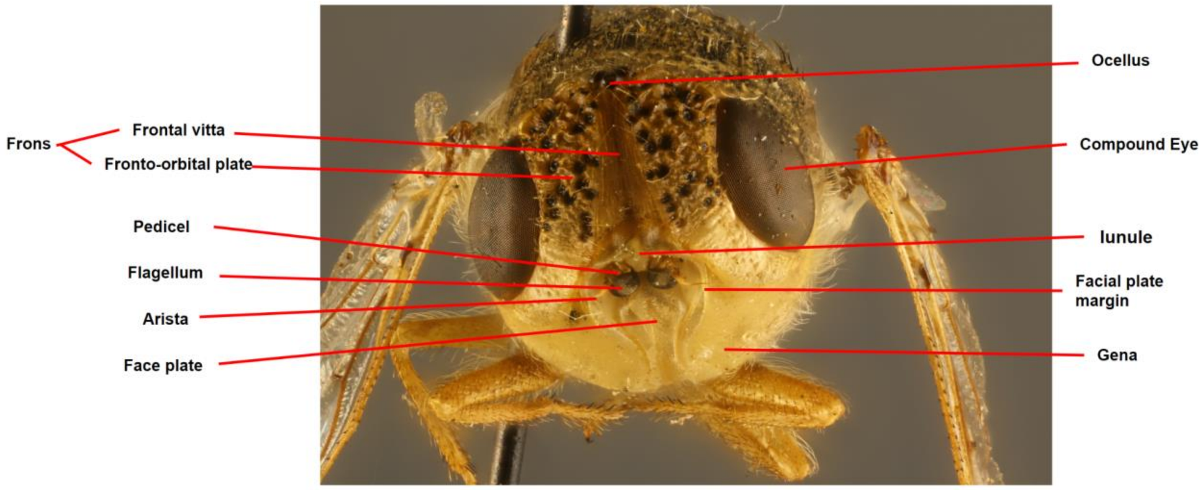


Fig.1: Head of female *Oestrus ovis* (anterior view).

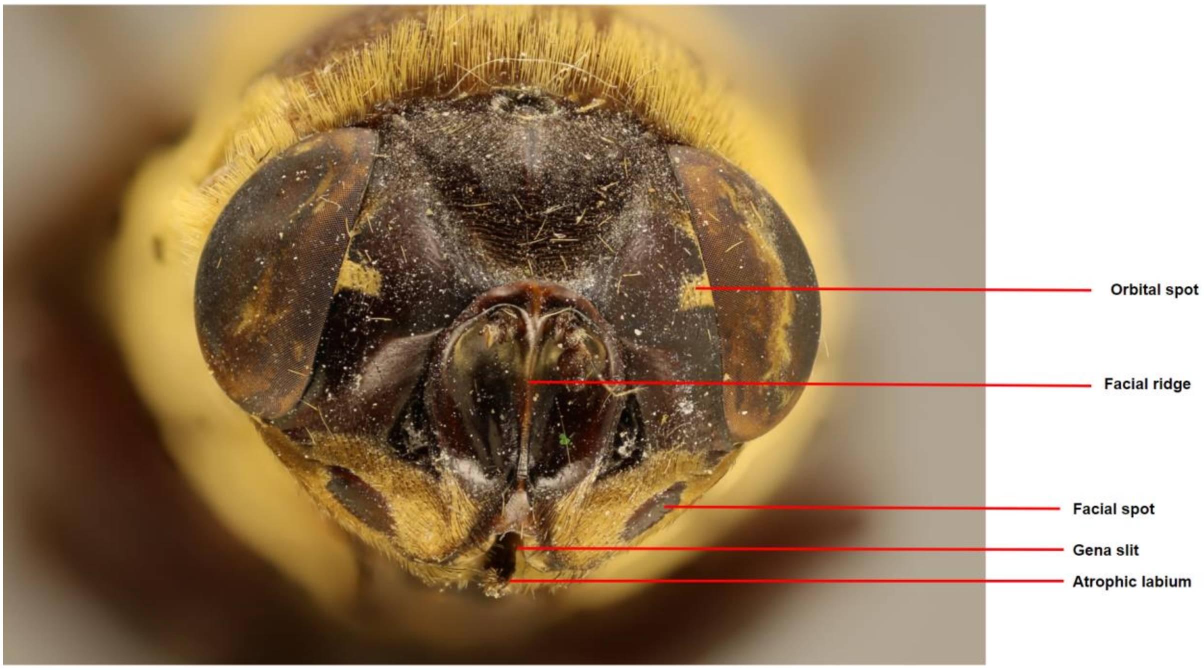


Fig. 2: Head of female *Cuterebra abdominalis* (anterior view).

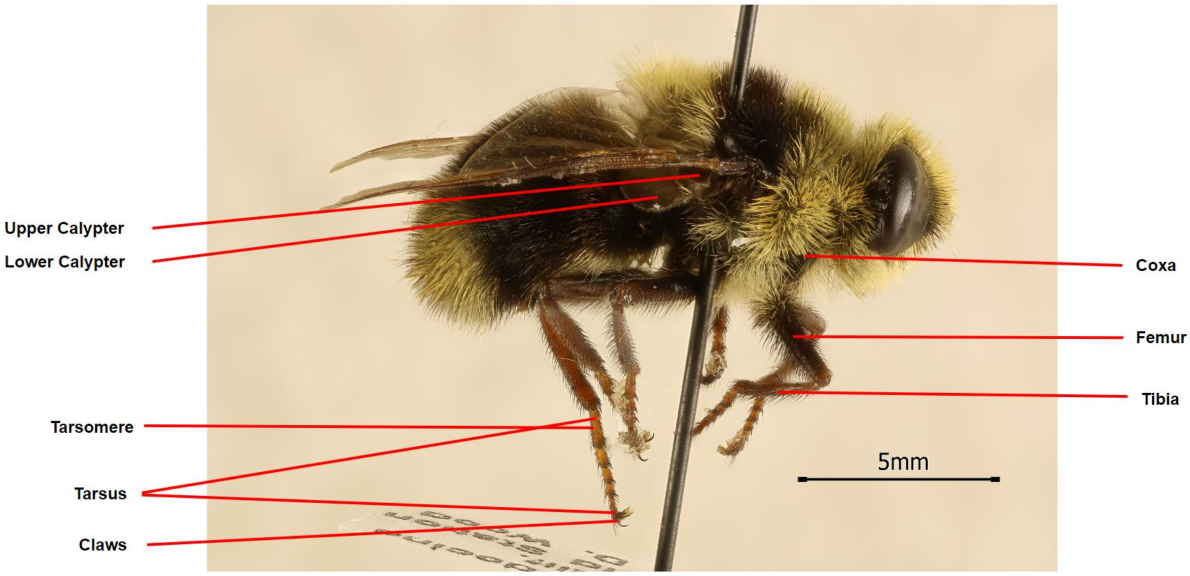


Fig. 3: Lateral view of female *Cephenemyia apicata*.

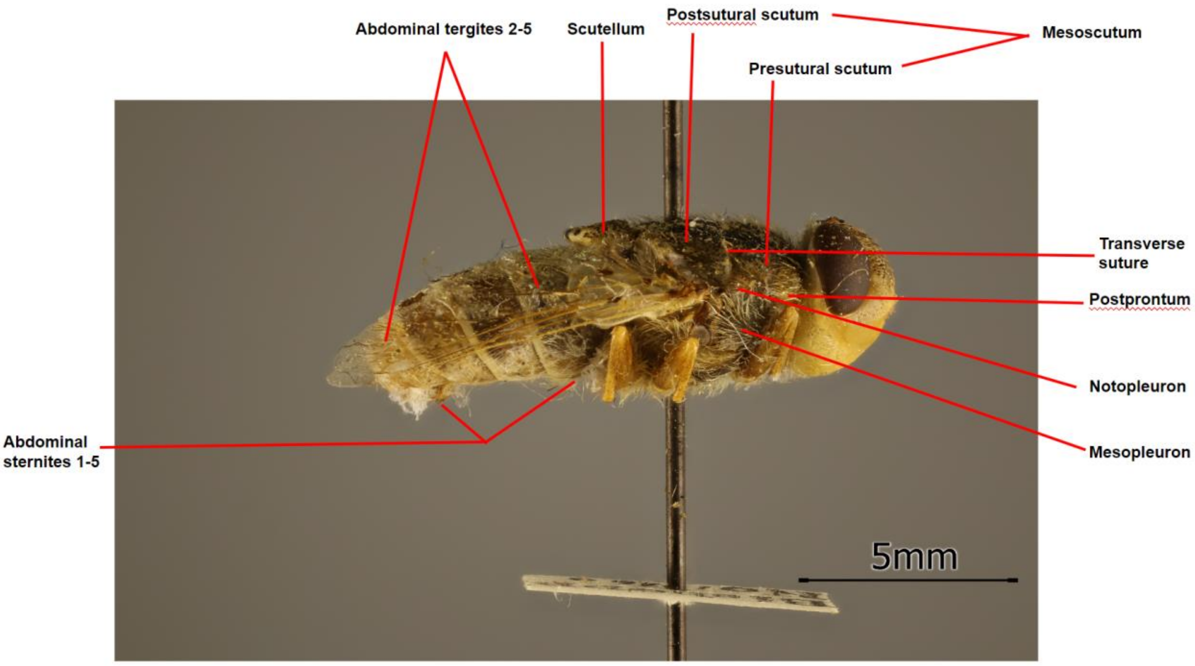


Fig. 4: Lateral view of female *Oestrus ovis*.

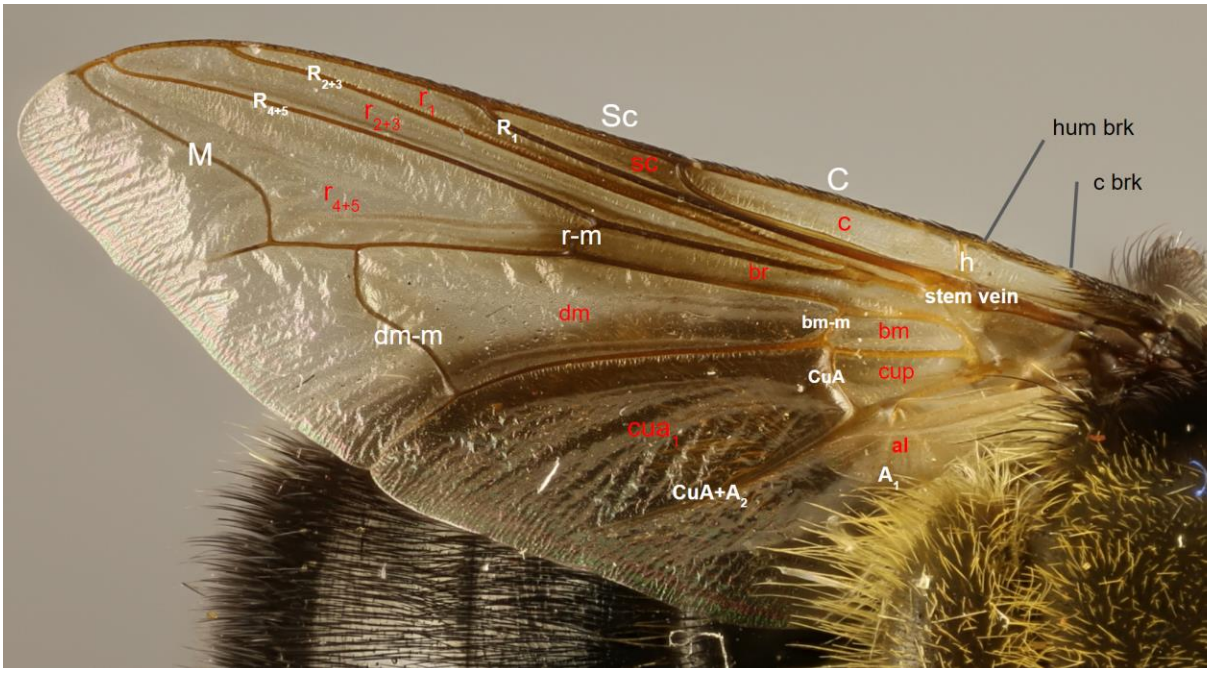


Fig. 5: Left wing of *Cephenemyia trompe*; abbreviation in white stands for veins, and in red stands for cells. A_1 - first anal vein; al - alula; bm - basal medial cell; bm-m - basal medial crossvein; br - basal radial cell; C - costal vein; c - costal cell; c brk - costagial break; CuA - anterior branch of cubital vein; CuA+ A_2 - anterior branch of cubital vein + second anal vein; cua_1 - anterior cubital cell; dm - discal medial cell; dm - discal medial cell; dm-m - discal medial crossvein; h - humeral crossvein; hum brk - humeral break; M - medial vein; R - branches of radius; r - radial cells; Sc - subcostal vein; sc - subcostal cell.

4. Taxonomy

4.1 Catalogue of Canadian Oestridae

This catalogue assembles together taxonomic information from previous research and current databases in one place (Thompson et al. 1999, Pape 2001, Colwell et al. 2006, Evenhuis and Pape, 2023). This catalogue includes all four subfamilies and all genus-group names related to the 18 Canadian species. For each species, I provided all synonyms, incorrect spellings, emendations (whether justified or unjustified) and *nomina nuda* that I can find in previous publications and databases during my research.

As the format, each name is followed by the author, year, page of the original publication, and current status. The type locality and collection locality is provided following if it is available.

FAMILY OESTRIDAE (= Oestrides) LEACH, 1815: 162.

CUTEREBRIDAE Brauer, 1887: 5-15
GASTROPHILIDAE (= *GASTEROPHILIDAE*) Brues & Melander, 1915: 4, 67 (spelling correct; stem: Gasterophil-).
HYPODERMATIDAE Brues & Melander, 1915: 67.

Subfamily CUTEREBRINAE Wood, 1987: 1151

Genus **CUTEREBRA** Clark

CUTEREBRA Clark, 1815: 64, 70. Type species: *Oestrus cuniculi* Clark (SD) Desmaraest 1859: 249

TRYPODERMA Wiedemann, 1820: 14. Type species: *Musca americana* Fabricius, 1775: 774 (orig. des.)

CURTEBRA Blanchard, 1840: 607 (error)

CURTEREBRA Blanchard, 1845: 484 (error)

CUTITEREBRA Agassiz, 1846: 108 (emend.)

ROGENHOFERA Brauer, 1863b: 325. Type species: *trigonophora* Brauer 1863b: 326 (mon.)

CUTIREBRA Wulp, 1890: 99 (error)

BOGERIA Austen, 1895: 391. Type species: *princeps* Austen 1895: 393 (orig. des.)

PSEUDOGAMETES Bischof, 1900: 131. Type species: *hermanni* Bischof 1900: 131 (orig. des.)

ATRYPODERMA Townsend, 1919: 592. Type species: *Musca americana* Fabricius, 1775: 774 (orig. des.)

XYLOCOPODES Townsend, 1927: 207. Type species: *Musca semiatra* Wiedemann 1830: 421 (orig. des.)

ORTHOCUTEREBRA Bau, 1929: 543 (Proposed as a subgenus). Type species: *Cuterebra lepusculi* Townsend 1897: 8 (sub. des.) Aldrich 1931: 117 = *princeps* Austen 1895: 393

PARACUTEREBRA Bau, 1929: 543 (proposed as a subgenus). Type species: *Oestrus cuniculi* Clark 1797: 299 (sub. des.) Aldrich 1931: 117.

PROTOCUTEREBRA Bau, 1929: 544 (proposed as a subgenus). Type species: *Musca americana* Fabricius, 1775: 774 (sub. des.) Aldrich 1931: 117.

METACUTEREBRA Bau, 1929: 544 (proposed as a subgenus). Type species: *Cuterebra apicalis* Guérin-Méneville 1831: 101 (sub. des.) Bau 1931b: 208.

ATRYPOSOMA Bau, 1931a: 20 (error)

ORICUTEREBRA Bau, 1931b: 210. Type species: *Cuterebra sarcophagoides* Lutz 1917: 99 (mon.)

PSEUDOBOGERIA Bau, 1931b: 206. Type species: *Oestrus buccatus* Fabricius 1775: 305 (orig. des.)

GUERINIOESTRUS Townsend, 1931: 318. Type species: *Cephenemyia grandis* Guérin-Méneville, 1844: 548 (orig. des.)

ALOUATTAMYIA Townsend, 1931: 319. Type species: *Cuterebra baeri* Shannon & Greene, 1926: 286 (orig. des.)

CUTEREBRELLA Guimarães, 1984: 24. Type species: *Cuterebra praegrandis* Austen 1933: 706 (orig. des.)

ANDINOCUTEREBRA Guimarães, 1984: 23. Type species: *Cuterebra fassleri* Guimarães, 1984: 23 (orig. des.)

abdominalis

Cuterebra abdominalis Swenk, 1905: 182. TYPE LOCALITY: USA (Nebraska) [H in UNL]

Distribution in Canada: Ontario.

approximata

Cuterebra approximata Walker, 1866: 338. TYPE LOCALITY: Canada (British Columbia) [H in BMNH]

Cuterebra cyanella Jones, 1906: 391. TYPE LOCALITY: USA (Nebraska)

Cuterebra nitida Coquillett, 1898: 10. TYPE LOCALITY: USA (California) [H in USNM]

Distribution in Canada: British Columbia.

buccata

Oestrus buccatus Fabricius, 1775: 305. TYPE LOCALITY: USA (South Carolina) [T: Lost]

Cuterebra buccata (Fabricus, 1775: 305) TYPE LOCALITY: USA (South Carolina) [T: Lost]

Cuterebra purivora Clark, 1815: 70. TYPE LOCALITY: USA. [LT: BMNH]

Bogeria scudderi Townsend, 1917: 27. TYPE LOCALITY: USA (District of Columbia) [LT: USNM]

Distribution in Canada: Quebec, may extend to Nova Scotia.

emasculator

Cuterebra emasculator Fitch 1856: 478. TYPE LOCALITY: USA (New York)

Cuterebra scutellaris Brauer, 1863a: 230. TYPE LOCALITY: North America (H in MCZ)

Distribution in Canada: Ontario, Quebec.

fontinella

Cuterebra fontinella Clark, 1827: 410. TYPE LOCALITY: USA (Illinois) [L in BMNH]

Cuterebra grisea Coquillett, 1904: 11. TYPE LOCALITY: Canada (British Columbia) [H in USNM]

Cuterebra angustifrons Dalmat, 1942: 418. TYPE LOCALITY: USA (Iowa). [H in USNM]

Cuterebra peromysci Dalmat, 1942: 45. TYPE LOCALITY: USA (Iowa). [H in USNM]

Distribution in Canada: British Columbia; Nova Scotia; Ontario; Quebec.

polita

Cuterebra polita Coquillett, 1898: 10. TYPE LOCALITY: USA (Wyoming) [L in USNM]

Cuterebra thomomuris Jellison, 1949: 493. TYPE LOCALITY: USA (Montana) [H in USNM]

Distribution in Canada: Alberta and British Columba.

tenebrosa

Cuterebra tenebrosa Coquillett, 1898: 11. TYPE LOCALITY: USA (Colorado) [LT in USNM] Sabrosky, 1986.

Subfamily GASTEROPHILINAE Rodhain & Bequaert, 1919: 379

Genus **GASTEROPHILUS** Leach

GASTEROPHILUS Leach, 1817: 2. Type species: *Oestrus intestinalis* De Geer, 1776: 584 (orig. des.)

GASTRUS Meigen, 1824: 174. Type species: *Oestrus intestinalis* De Geer, 1776: 584 (orig. des.)

GASTROPHILUS Agassiz 1847: 160 (emend.)

ENTEROMYSA Rondani 1857: 257 (incorrect original spelling)

ENTEROMYZA Rondani, 1857: 20 (spelling correct) Type species: *Oestrus pecorum* Fabricius 1794: 230 (orig. des.)

RHINOGASTROPHILUS Townsend, 1918: 152. Type species: *Oestrus nasalis* Linnaeus 1758: 584 (orig. des.)

ENTEROMYIA Enderlein, 1934: 425. Type species: *Oestrus haemorrhoidalis* Linnaeus 1758: 584 (orig. des.)

HAEMORRHOESTRUS Townsend, 1934: 406. Type species: *Oestrus haemorrhoidalis* Linnaeus 1758: 584 (orig. des.)

PROGASTROPHILUS Townsend, 1934: 406. Type species: *Oestrus pecorum* Fabricius 1794: 230 (orig. des.)

STOMACHOBIA Enderlein, 1934: 425. Type species: *Oestrus pecorum* Fabricius 1794: 230 (orig. des.)

haemorrhoidalis

Oestrus haemorrhoidalis Linnaeus, 1758: 584. TYPE LOCALITY: Sweden.

Oestrus flavipes Olivier, 1811: 467. TYPE LOCALITY: France (Dans les Pyrenees)

Oestrus salutiferus Clark, 1816: 3. TYPE LOCALITY: England [H in BMNH]

Oestrus duodenalis Schwab, 1840: 35. TYPE LOCALITY: Not Given. [Type specimen lost].

Oestrus pallens Bigot, 1885: I viii. TYPE LOCALITY: Sudan (Suakim).

Gasterophilus pseudohaemorrhoidalis Gedoelst, 1923: 272. TYPE LOCALITY: Africa.

Distribution in Canada: Alberta; British Columbia; Manitoba; Nova Scotia; Quebec and Saskatchewan.

intestinalis

Oestrus intestinalis De Geer, 1776: 584. TYPE LOCALITY: Sweden.

Oestrus equi Fabricius, 1787: 321. TYPE LOCALITY: Not Given.

Oestrus equi Clark, 1797: 326. TYPE LOCALITY: England.

Oestrus gastricus ssp. major Schwab, 1840: 31. (Proposed in synonymy with *Oestrus intestinalis* De Geer and *Oestrus equi* Clark, but not available from subsequent use as a valid name for a taxon)

Oestrus bengalensis Macquart, 1844: 25. TYPE LOCALITY: India (Bengal)

Oestrus gasterophilus Gistel, 1848: 153 (emend.)

Gasterophilus equi var. asininus Brauer, 1863a: 71. TYPE LOCALITY: Egypt (Nubia).

Gasterophilus magnicornis Bezzi, 1916: 29. TYPE LOCALITY: Eritrea.

Distribution in Canada: British Columbia; Nova Scotia; Ontario; Quebec; Saskatchewan.

nasalis

Oestrus nasalis Linnaeus, 1758: 584. TYPE LOCALITY: Sweden.

Oestrus veterinus Clark, 1797: 328. TYPE LOCALITY: England.

Oestrus salutaris Clark, 1815: pl. 1. TYPE LOCALITY: Not Given.

Gasterophilus clarkii Leach, 1817: 2. TYPE LOCALITY: Western England.

Gastrus jumentarium Meigen, 1824: 179. TYPE LOCALITY: Not Given. [NHMD]

Oestrus gastricus ss. minor Schwab, 1840: 40. (proposed synonymy with *Oestrus nasalis* Linnaeus and *Oestrus veterinus* Clark, but not available from subsequent use as a valid name for a taxon)

Oestrus schwabianus Gistel, 1848: 153. TYPE LOCALITY: Germany (Bavaria)

Oestrus stomachius Gistel, 1848: 153. TYPE LOCALITY: Germany (Bavaria)

Gastrus subjacens Walker, 1849: 687. TYPE LOCALITY: Canada (Nova Scotia) [T in BMNH]

Gasterophilus crossi Patton, 1924: 963. TYPE LOCALITY: India (Punjab)

Gastrophilus albescens Pleske, 1926: 228. TYPE LOCALITY Egypt (Cairo).

Gastrophilus nasalis var. nudicolis Dinulescu, 1932: 28. TYPE LOCALITY: Not Given.

Gastrophilus veterinus var. aureus Dinulescu, 1938: 315. TYPE LOCALITY: Not Given.

Distribution in Canada: British Columbia; Manitoba; Nova Scotia; Ontario; Saskatchewan.

Subfamily HYPODERMATINAE Wood, 1987: 1151

Genus **HYPODERMA** Latreille

HYPODERMUS Rafinesque, 1815: 132 (*nomen nudum*)

HYPODERMA Latreille, 1818: 272. Type species: *Oestrus bovis* Linnaeus 1758: 584.

OEDEMAGENA Latreille, 1818: 272. Type species: *Oestrus tarandi* Linnaeus (orig. des.)

OEDEMAGENUS Berthold, 1827: 272 (error)

OEDEMATOGENA Agassiz, 1846: 256 (emend.)

HEDEMAGENA Rondani, 1856: 43 (error)

OEDAMAGENA Williston, 1896: 137 (error)

ATELECEPHALA Townsend, 1916: 617. Type: *Hypoderma diana* Brauer 1858: 397 (orig. des.)

LITHOHYPODERMA Townsend, 1917: 129. Type: *Musca ascarides* Scudder, 1877: 756 (orig. des.)

ATELOCEPHALA Soós & Minár, 1986: 250 (error)

bovis

Oestrus bovis Linnaeus, 1758: 584. TYPE LOCALITY: Europe. [T in LINN]

Oestrus ericetorum Clark,1815: 38. TYPE LOCALITY: England (Plymouth)
Oestrus subcutaneus Greve, 1818: 2. TYPE LOCALITY: France.
Oestrus bovis ssp. bovinus Schwab, 1840: 43. TYPE LOCALITY: Not Given.
Hypoderma heteroptera Macquart, 1844: 24. TYPE LOCALITY: Aleria (Oran).
Hypoderma bellieri Bigot, 1862: 113. TYPE LOCALITY: France (Corsica)
Distribution in Canada: British Columbia; Manitoba; Ontario; Nova Scotia.

lineatum

Oestrus lineatus Villers, 1789: 349. TYPE LOCALITY: Europe.
Hypoderma bonassi Brauer, 1875: 75. TYPE LOCALITY: USA (Colorado)
Distribution in Canada: British Columbia.

tarandi

Oestrus tarandi Linnaeus, 1758: 584. TYPE LOCALITY: Sweden. [T in LINN]
Oestrus terrandi Scopoli, 1779: 133 (error)
Hypoderma terraenovae Knab, 1913: 155 TYPE LOCALITY: Canada (Newfoundland).
Distribution in Canada: British Columbia; Labrador; Manitoba; Northwest Territories; Yukon.

Subfamily OESTRINAE Wood, 1987: 1151

Genus **CEPHENEMYIA** Latreille

CEPHENEMYIA Latreille, 1818: 271. Type species: *Oestrus trompe* (Modéer, 1786): 134 (mon.)
ACROCOMYIA Papavero, 1977: 54. Type species: *Oestrus auribarbis* Meigen, 1824: 171 (orig. des.)
PROCEPHENEMYIA Papavero, 1977: 62. Type species: *Oestrus stimulator* Clark, 1815: 69 (orig. des.)

apicata

Cephenemyia apicata Bennett & Sabrosky, 1962: 438. TYPE LOCALITY: USA (California) [H in USNM]
Distribution in Canada: Alberta; British Columbia; Saskatchewan.

jellisoni

Cephenemyia jellisoni Townsend, 1941: 161. TYPE LOCALITY: USA (Montana)
Distribution in Canada: Alberta; British Columbia; Quebec.

phobifer

Oestrus phobifer Clark, 1815: 68. TYPE LOCALITY: USA (Georgia)
Cephenemyia abdominalis Aldrich, 1915: 149. TYPE LOCALITY: USA (New York)
Cephenemyia phobifera Bennett & Sabrosky, 1962: 438 (mssp.)

Distribution in Canada: New Brunswick; Nova Scotia; Ontario; Quebec.

trompe

Oestrus trompe Modéer, 1786: 134. TYPE LOCALITY: Finland (Lapland).

Distribution in Canada: Manitoba; Northwest Territories; Quebec; Yukon.

-

Genus **OESTRUS** Linnaeus

OESTRUS Linnaeus, 1758: 594. Type species *Oestrus ovis* Linnaeus, 1758: 584.

OESTREUS Radermacher, 1779: 100 (error)

CEPHALEMYIA Latreille, 1818: 273. Type species *Oestrus ovis* Linnaeus, 1758: 584.

CEPHALEMYA Robineau-Desvoidy, 1830: 26 (emend.)

CEPHALEMYIA Agassiz, 1846: 71 (emend.)

CEPHALEMYA Rondani, 1856: 43 (error)

AESTRUS Rondani, 1857: 257 (error)

GASTROMYSA Rondani, 1857: 258 (nomen nudum)

CEPHALEMYA Robineau-Desvoidy, 1863: 53 (error)

AESTRUS Lioy, 1864: 84 (error)

ESTRUS Lioy, 1864: 84 (error)

GASTROMYZA Scudder, 1882: 141 (error)

OESTROIDES Gedoelst, 1912: 431. Type species: *Oestrus macdonaldi* Gedoeist, 1912: 430. (sub. des.) Townsend 1916: 8.

LEOWIOESTRUS Loewioestrus Townsend, 1918: 152. Type species: *Cephalomyia variolosus* Loew, 1863: 15 (orig. des.)

ovis

Oestrus ovis Linnaeus, 1758: 585. TYPE LOCALITY: Sweden. [T in LINN]

Oestrus argalis Pallas, 1776: 29. TYPE LOCALITY: Not Given.

Oestrus perplexus Hudson, 1892: 63. TYPE LOCALITY: New Zealand (Wellington).

Distribution in Canada: Alberta; British Columbia, and Ontario.

4.2 Identification Key to the Genera of Canadian Oestridae

1) Arista pectinate (fig. 6); genal slit open below facial plate (eg., figs. 44); scutellum strongly projecting, and subscutellum obscured; wing membrane completely brownish infuscate (e.g., figs. 45.); alula larger than lower calypter (fig. 8) ……………………………………..……….... ***Cuterebra*** Clark, 1815

1') Arista bare (fig. 7); genal slit fused below facial plate; scutellum short, and subscutellum unobscured or barely obscured; wing membrane completely transparent or with infuscated patches; alula equal or smaller than lower calypter (fig. 9) ……………………….…..…2

2) M vein fairly straight, ending posteriorly to the wing apex (fig. 10); male abdomen elongated and deflexed, female abdomen deflexed more than 90° (figs. 69, 72 and 75) ……………………………………………………………….. ***Gasterophilus*** Leach, 1817

2') M vein curved or sharply angled forward, ending anteriorly to the wing apex (fig. 10); both male and female abdomen conical or round, straight or slightly curved ……………………………..…………………………………..…………………..…… ……...3

3) Lower facial plate broad, subquadrate (fig. 11); flagellum bare and round (fig. 11); tarsomere with black bristle pairs posterolaterally (fig. 13 A); ovipositor tubular (fig. 14) ……..……………………………………………………..…… ***Hypoderma*** Latreille, 1818

3') Lower facial plate narrow, round (fig. 12); flagellum microsetose and oval (fig. 66); tarsomere without bristles (fig. 13 B); ovipositor concealed in abdominal tergite 5 …...……..…………………………………………………………………………..……… .4

4) Body predominantly yellow and black; thorax and abdomen covered with dense, yellow and black hairs (e.g,. figs. 24.) ………..……………..……….. ***Cephenemyia*** Latreille, 1818

4') Body predominantly grey and brown; thorax heavily punctate; abdomen with sparse short hairs, dorsally with cuticular grey and brown checkered pattern (figs. 89 and 90) ………………………..……………………. …………………... ***Oestrus*** Linnaeus, 1758

Fig. 6: Pectinate arista in *Cuterebra emasculator*

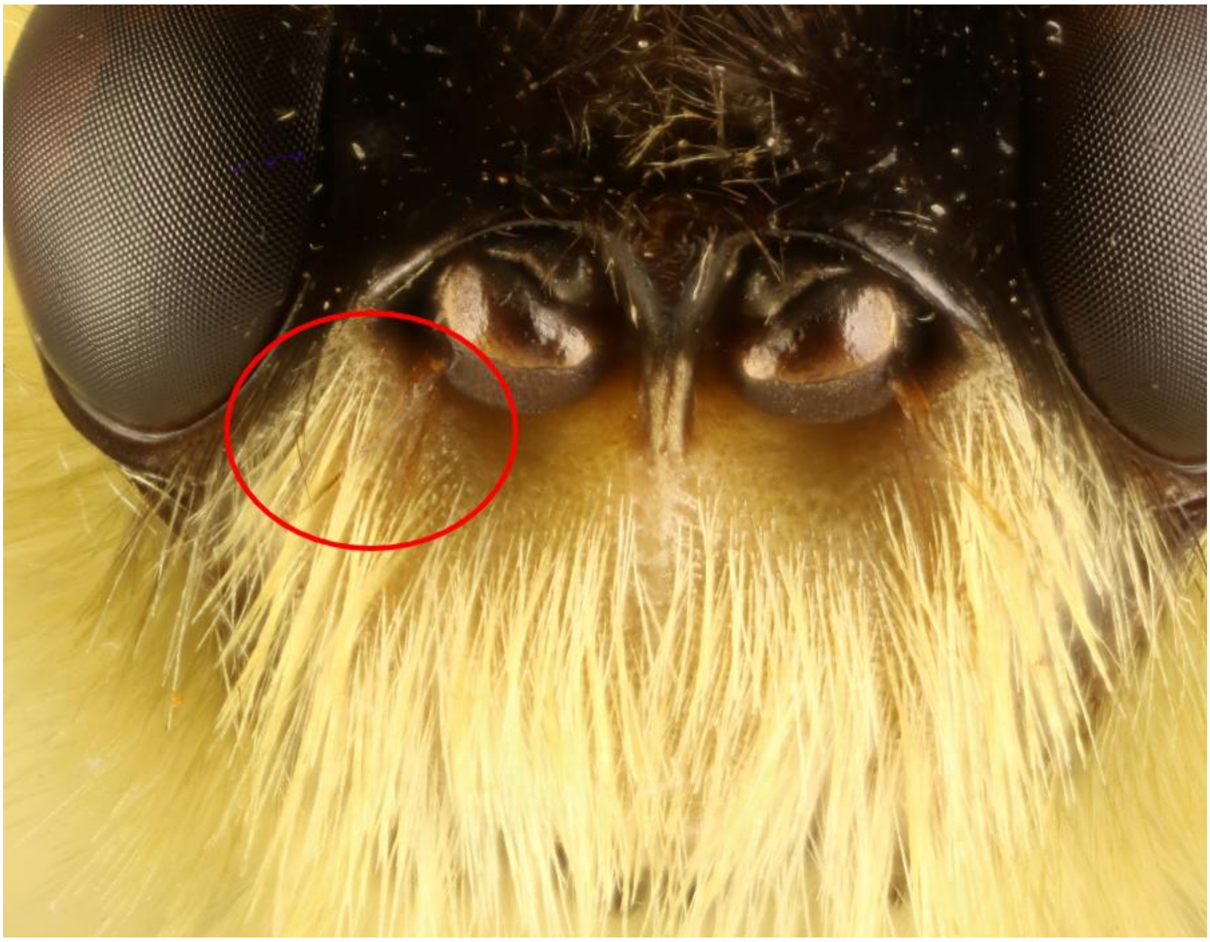


Fig. 7: Bare arista in *Hypoderma tarandi*.

Fig. 8: Strongly projecting scutellum and enlarged, upper flap alula in *Cuterebra fontinella*.

Fig. 9: Short scutellum and small, upper flap alula in *Cephenemyia jellisoni*.

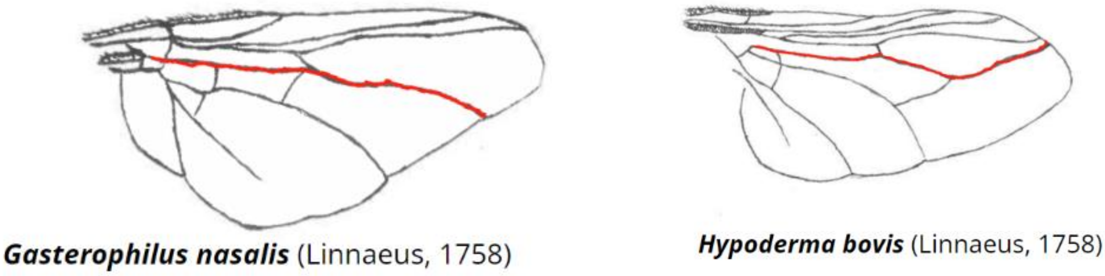


Fig. 10: Veins M ending after the wing apex in *Gasterophilus* and before the wing apex in other Oestridae genera.

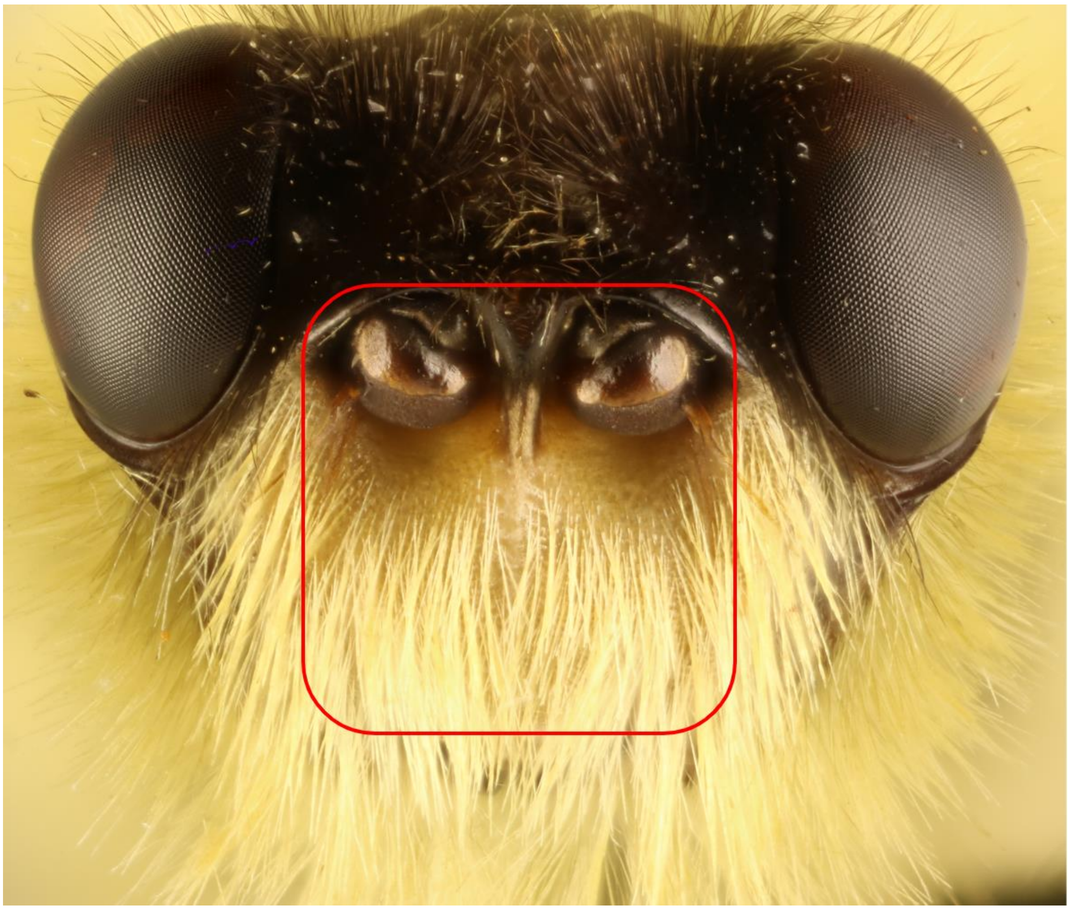


Fig. 11: Subquadrate facial plate of *Hypoderma tarandi*.

Fig. 12: Subrounded facial plate of *Cephenemyia apicata*.

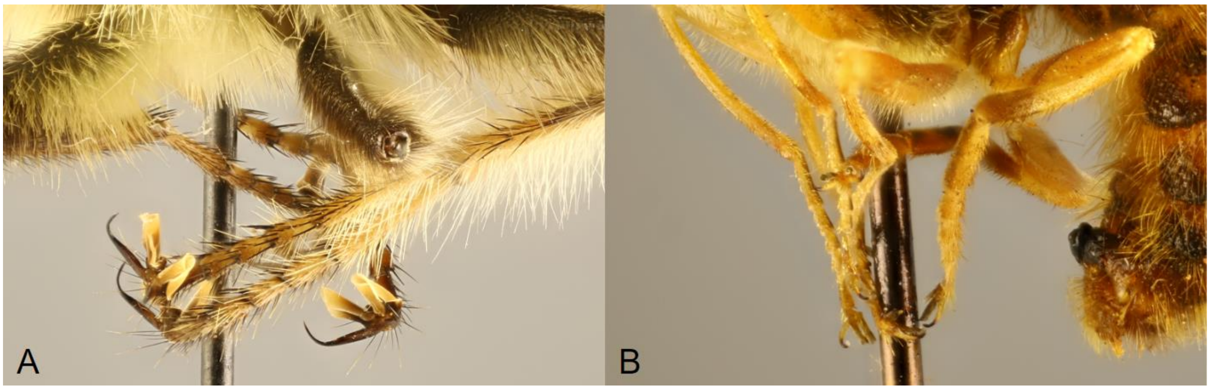


Fig. 13: Bristle pairs on posterolateral tibia and tarsomeres of *Hypoderma bovis* (A), which absent in *Gasterophilus intestinalis* (B).

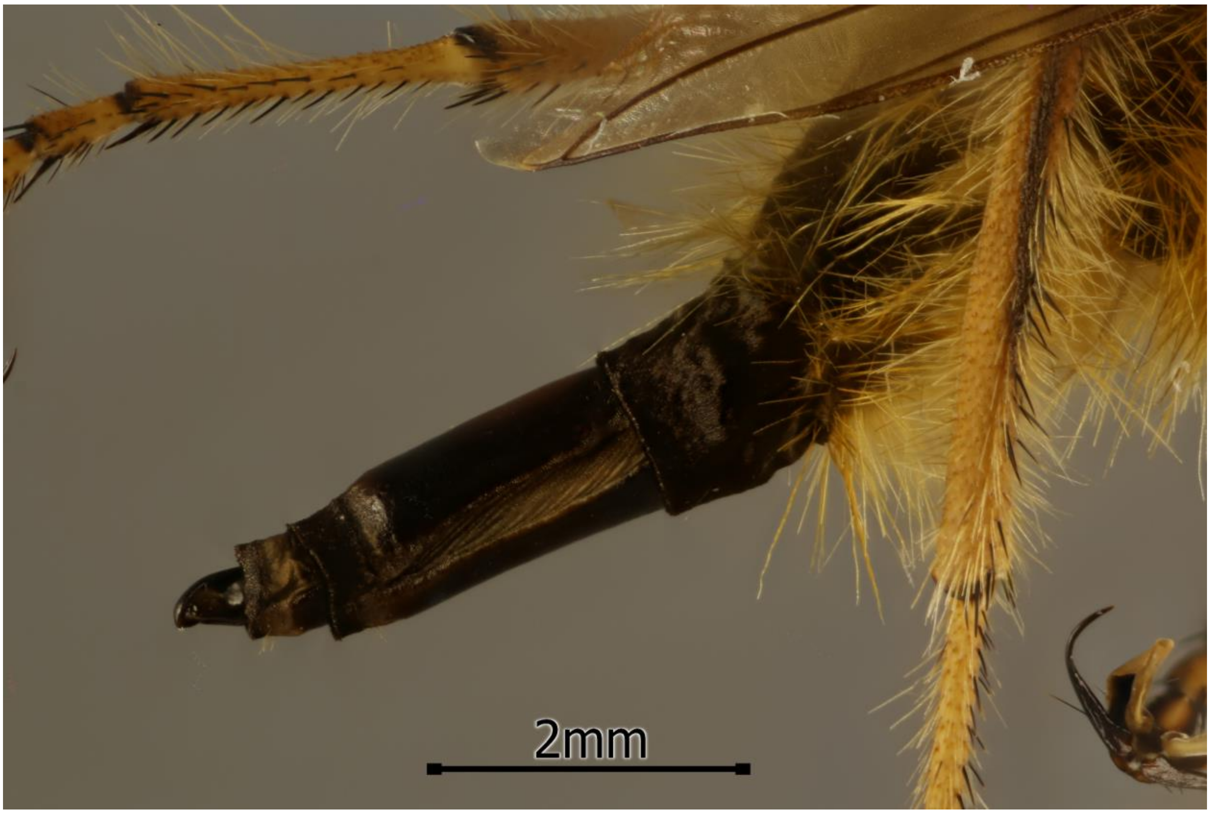


Fig. 14: Tubular ovipositor of female *Hypoderma tarandi*.

5. ***Cephenemyia*** Latreille, 1818: 271

Current global taxonomy:

Nine species are recognized worldwide:

Cephenemyia albina Taber & Fleenor, 2004: 76
Cephenemyia apicata Bennett & Sabrosky, 1962: 438
Cephenemyia auribarbis (Meigen, 1824): 171
Cephenemyia jellisoni Townsend, 1941: 161
Cephenemyia phobifer (Clark, 1815): 69
Cephenemyia pratti Hunter, 1916: 170
Cephenemyia stimulator (Clark, 1815): 69
Cephenemyia trompe (Modéer, 1786): 134
Cephenemyia ulrichii Brauer, 1862: 974

Nomen Dubium:

- *Cephenemyia macrostis* Brauer, 1863a: 211, 279

Diagnosis:

Arista bare. Facial plate margins converge ventrally. Gena with dense yellow hairs. Scutellum short and semicircular, with dense yellow hairs dorsally. Wing membrane completely transparent or with infuscated patches. Vein M curved, ending before wing apex, and sharp angled with extending branch posterior crossing with crossvein dm-m (fig. 15). Abdomen oval, with dense black, yellow, or orange hairs. Female lacking external ovipositor.

Biology:

Like other Oestrinae, eggs are retained and hatched in the female's uterus until ready to be dispersed. Each female produces 900-1000 eggs (Catts 1964, Anderson and Nilssen

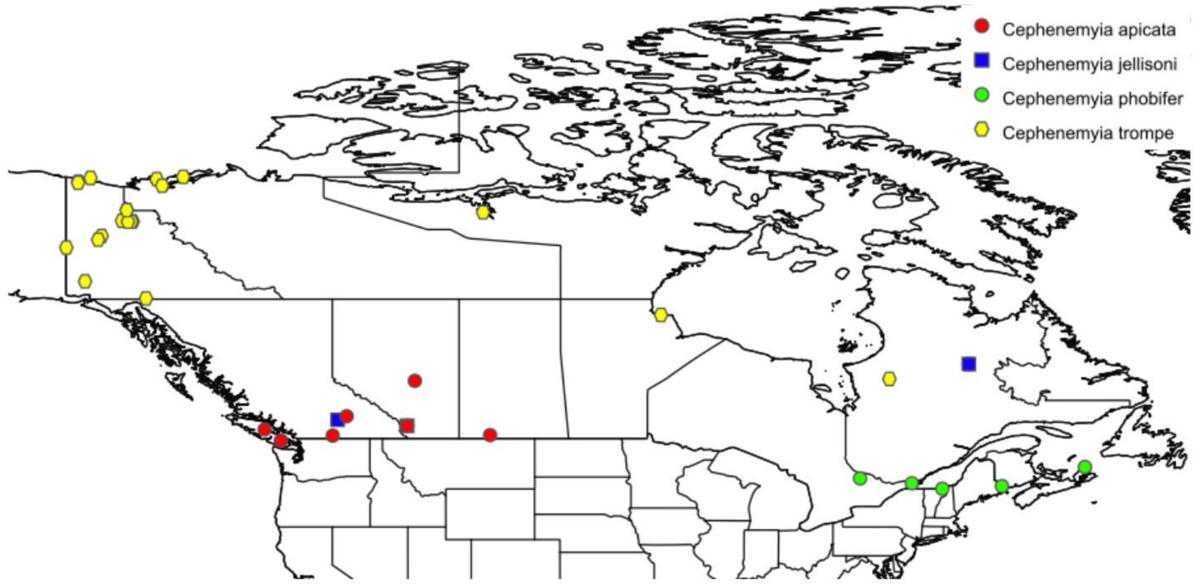
1990, Anderson 2013). The common understanding of *Cephenemyia* larviposition is that the pregnant females expel a droplet or spray tiny droplets of fluid with larvae toward the host's nasal passage (Cowan 1943, Anderson 1975, Cogley and Anderson 1981, Anderson and Nilssen 1990). However, observation has shown that the first instar larvae of *C. apicata* and *C. jellisoni* crawl down toward the upper lip and enter the oral cavity (Cogley and Anderson 1981). Developing larvae live in the nasopharyngeal cavity and feed on blood and secretions. Larvae overwinter in the host and crawl back to the nostrils. Following snorting and sneezing of the host, the mature larvae is ejected from the host allowing for pupation underground (Wood 1987).

Host:

Except for two extremely rare cases of *Cephenemyia urichii* infesting a dog and a human (Jaenson 2011, Helkiö et al. 2023), all *Cephenemyia* use hosts in the family Cervidae (Bennett and Sabrosky 1962).

Distribution:

Species of *Cephenemyia* are distributed in North America and Eurasia. Three species are found in Eurasia, and six are found in North America (Evenhuis and Pape 2023). In Canada, four species of *Cephenemyia* are found in Canada (Bennett and Sabrosky 1962).



Map. 1: Distribution of *Cephenemyia* spp. in Canada.

Remark:

According to Sabrosky (1957), '*Oestrus nasalis*' was a collective nomenclature of *Gasterophilus* spp. and *Cephenemyia* spp., and Modéer identified '*Oestrus trompe*' (*Cephenemyia* spp.), to differentiate from '*Oestrus nasalis*' (*Gasterophilus* spp.) (Modéer 1786).

Identification Key to Adult *Cephenemyia* of Canada:

1) No black band on scutum (fig. 17); hairs on dorsal abdomen predominantly black, occasionally with a few fine, white hairs laterally (fig. 18) ………………………………………………………***Cephenemyia phobifer*** (Clark, 1815)

1') Black band present on the scutum, between the bases of wings (fig. 17); hairs on dorsal abdomen predominantly yellow or orange with a black crossing band ……………………...2

2) Male frons as wide as the eye (fig. 19); wing membrane completely transparent (fig. 20) ………………………………………………………***Cephenemyia trompe*** (Modéer, 1786)

2') Male frons narrower than the eye (fig. 19); wing membrane with infuscated patches (fig. 21) ………………………………………..…………..……………………..…………...3

3) Wing cells r_1 and r_{2+3} completely infuscated (fig. 21); medial stripe of black hairs absent on abdominal tergite 5 (fig. 22) …………...…………… ***Cephenemyia jellisoni*** Townsend, 1941

3') Basal portion of wing cells r_1 and r_{2+3} infuscated, and the rest tranparent (fig. 21); medial stripe of black hairs on abdominal tergite 5 (fig. 22) ……………………………………...……***Cephenemyia apicata*** Bennett & Sabrosky, 1962

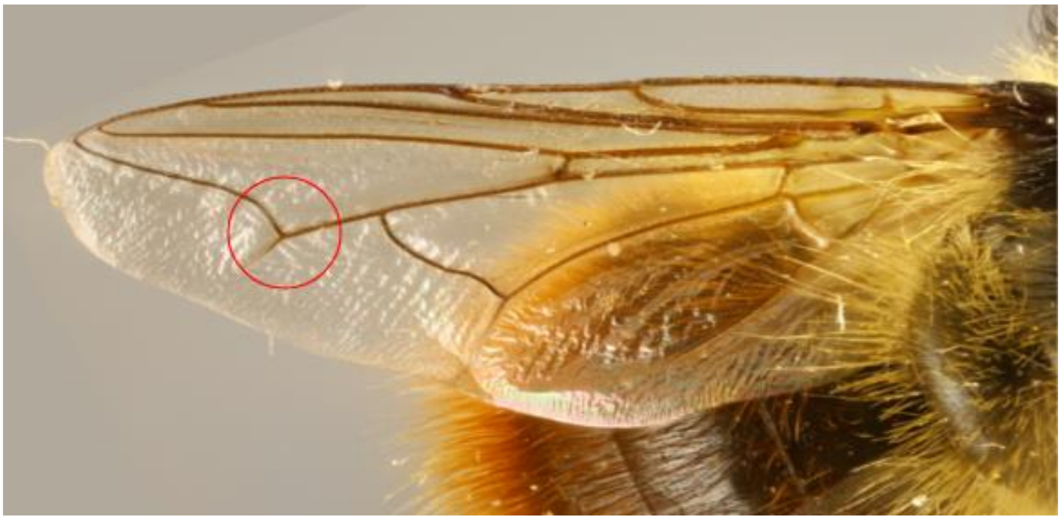


Fig. 15: Wing vein m sharply angled, with a short extension pointing posteriorly in *Cephenemyia* spp..

Fig. 16: Ventral margin of scutellum with rows of white hairs laterally.

Fig. 17: Black-haired crossing band between wing base absent in *Cephenemyia phobifer* (A), and present in other species (B, which is a *Cephenemyia trompe*).

Fig. 18: *Cephenemyia phobifer* abdomen is entirely covered with black hairs.

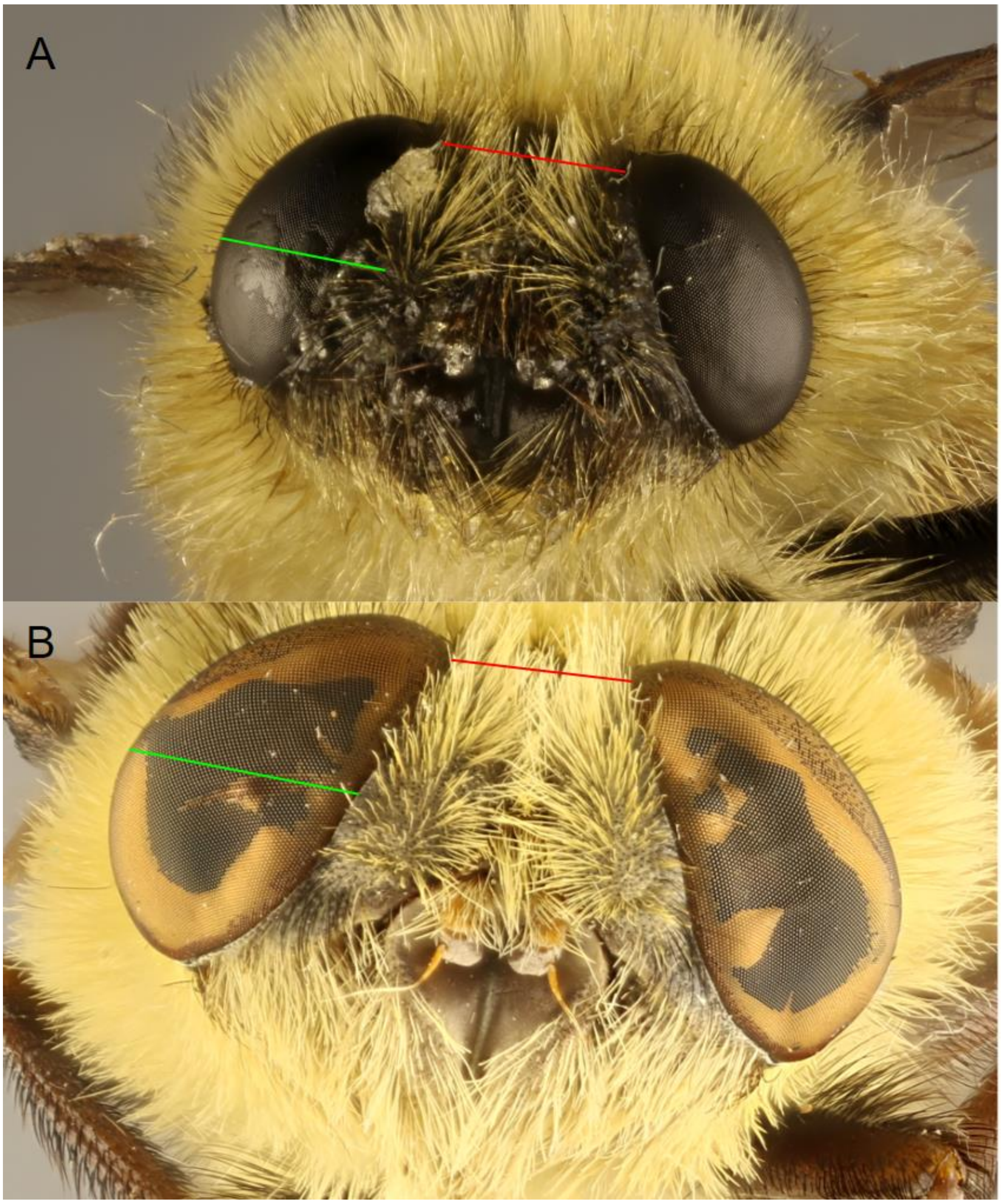


Fig. 19: Width of frons (red) and an eye (green) of a male *C. trompe* (A) and a male *C. apicata* (B).

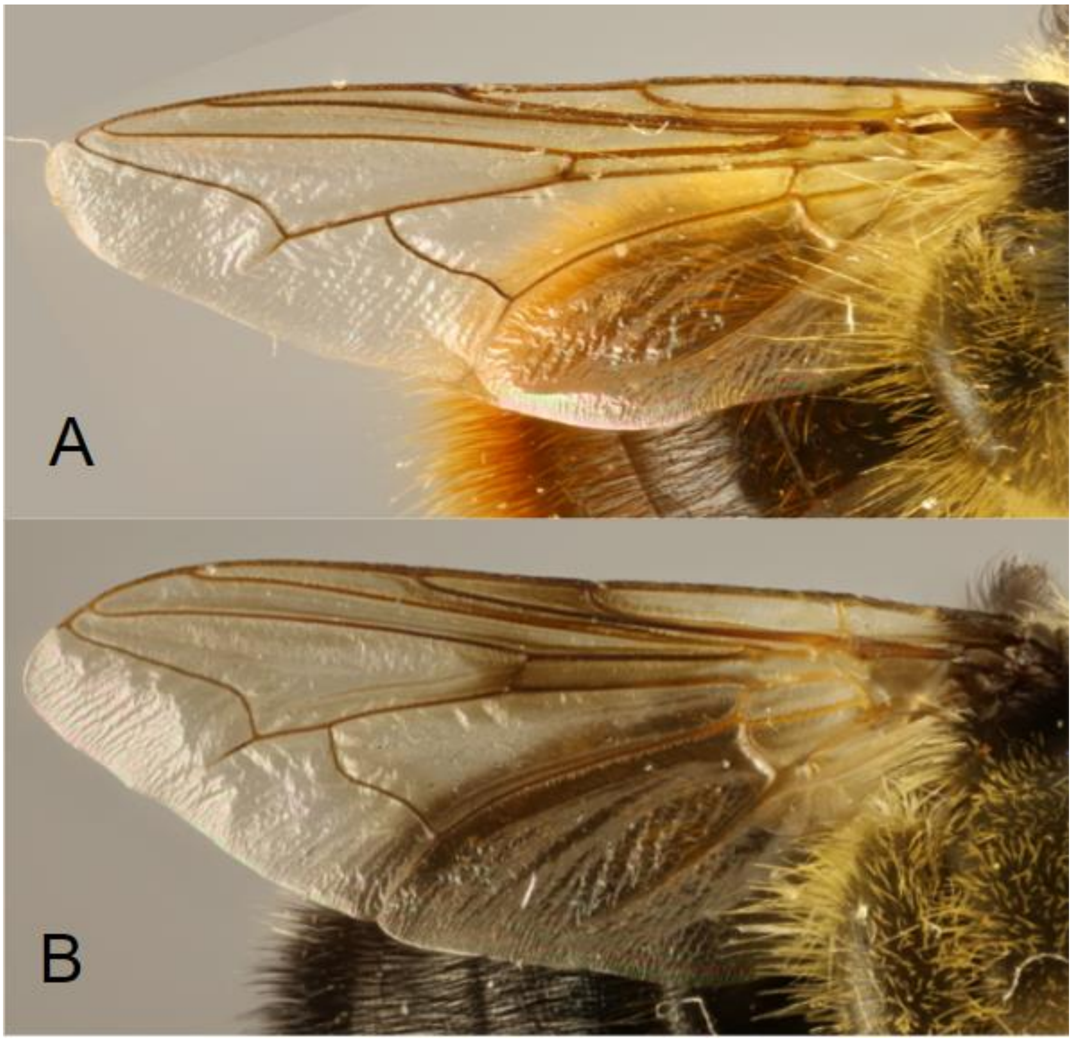


Fig. 20: The transparent wing of *C. trompe* (A) and infuscate patched wing of *C. jellisoni* (B)

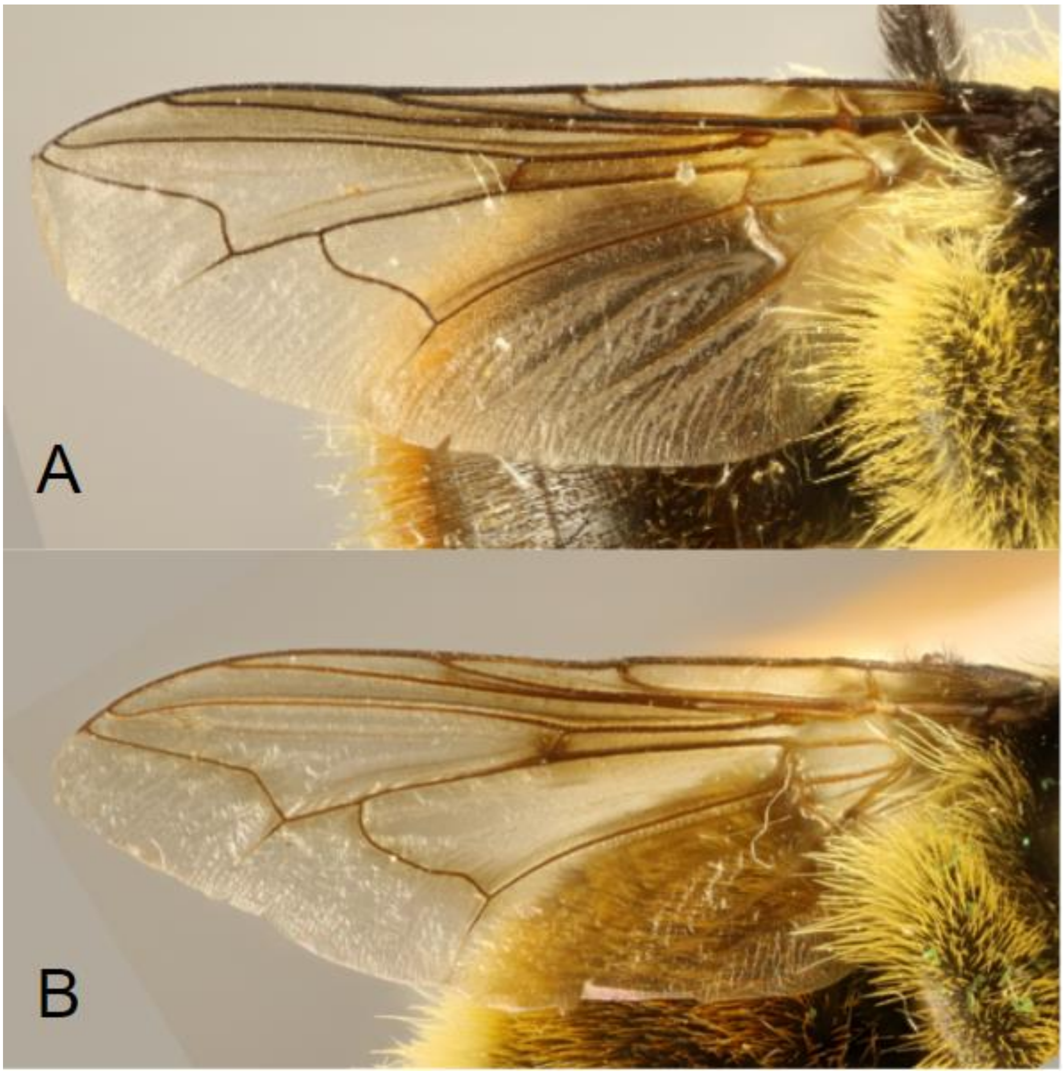


Fig. 21: The infuscate patches on wings of (A) *C. jellisoni* and (B) *C. apicata*.

Fig. 22: Black-haired median stripe on abdominal tergite 5 of (A) *C. apicata* and which is absent in (B) *C. trompe.*

5.1 ***Cephenemyia apicata*** Bennett & Sabrosky, 1962: 438

Diagnosis:

Male frontal vitta and fronto-orbital plate narrower than the width of the eye. Postsutural scutum with a transverse cross band of black hairs between wing bases. Wing cells r_1 and r_{2+3} infuscated in the basal half. Upper calypter with predominantly black hairs along the margin. Abdominal tergites 2-4 with dense orange or black hairs. Abdominal tergite 5 concealed in whitish yellow hairs, with a median stripe of black hairs.

Description (figs. 23-25):

Body Length: 9-13 mm. **Wing Length:** 8-10 mm.

Head: frontal vitta concealed in dense yellow hairs; fronto-orbital plate black, punctate, with little or without white pruinosity, with sparse black hairs; arista orange and bare; flagellum reddish brown, with white pruinosity; pedicel orange, with white pruinosity and sparse yellow hairs; facial plate with white pruinosity or glossy dark brown, margin tapered ventrally; gena black, concealed in whitish yellow hairs; mouthpart reduced and concealed in hairs.

Thorax: mesoscutum covered with whitish yellow hairs, with a transverse cross band of black hairs between the wing bases; scutellum short and semicircular, dorsal with whitish yellow hairs; underside of scutellum with white hairs laterally and bare medially; wing veins orange or brown; veins C and Sc with 3-4 rows of bristles; wing cells r_1 and r_{2+3} infuscated on basal portion; alula folded dorsally, more than 90° in relation to the rest of the wing membrane; upper calypter margin folded upward, with predominantly black hairs; lower calypter brownish infuscated and microsetose; legs orange to reddish brown; tarsomeres with dense black hair tufts posterolaterally.

Abdomen: oval, with dense hairs; abdominal tergites metallic black; abdominal tergite 2-4 with dense orange or black hairs; abdominal tergite 5 with whitish yellow hairs laterally, and a stripe of black hairs medially; abdominal sternites black, with white pruinosity and sparse black hairs.

Male: frons narrower than the eye width.

Female: frons wider than the eye width.

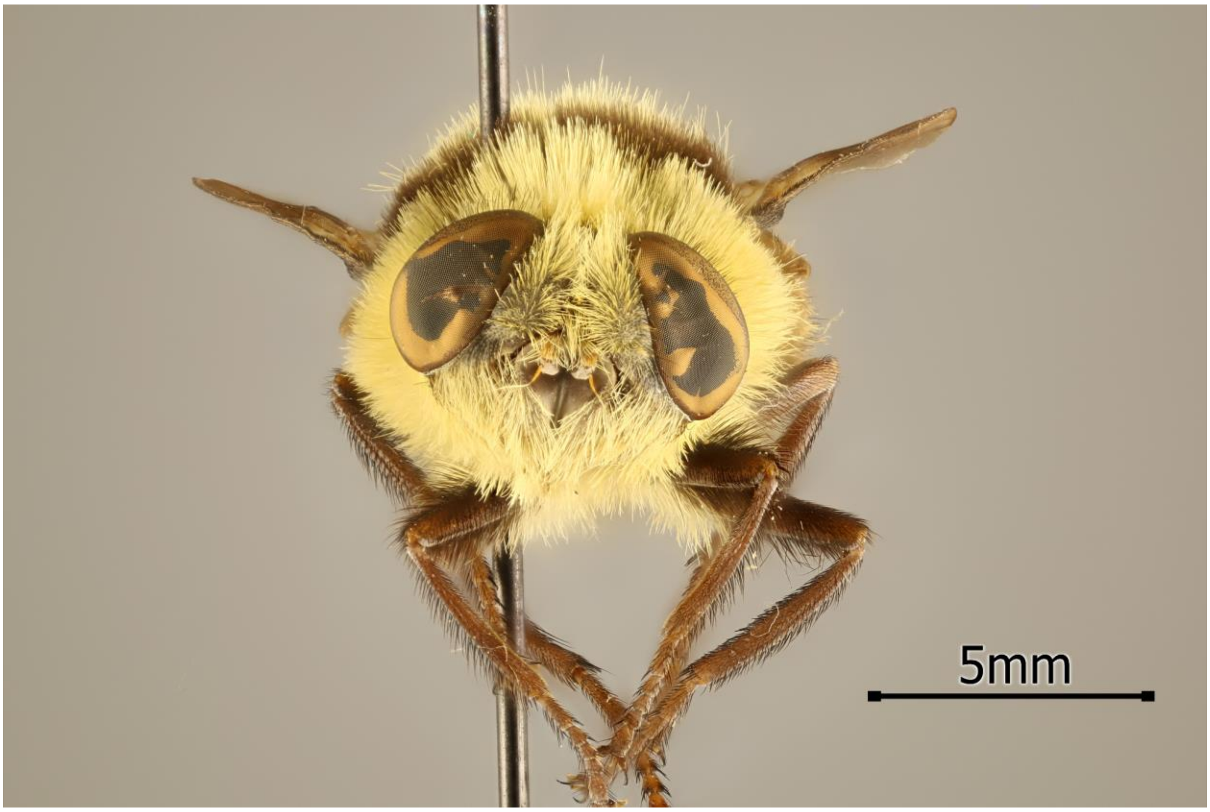


Fig. 23: Anterior view of male *Cephenemyia apicata* (specimen code: CNC-1011)

Fig. 24: Dorsal view of male *Cephenemyia apicata* (specimen code: CNC-1011)

Fig. 25: Lateral view of male *Cephenemyia apicata* (specimen code: CNC-1011)

Host:

The only known host of *Cephenemyia apicata* is mule deer (*Odocoileus hemionus* Rafinesque, 1817) (Bennett and Sabrosky 1962).

Biology:

Males are known to exhibit hilltopping behaviour, which occurs from April through October (Catts 1964). Mated females are attracted to CO_2-baited traps and deer models (Anderson and Olkowski 1968, Anderson 2022). Species of Oestrinae expel the 1st instar larvae into the nostrils of hosts. However, critical observation has shown that 1st instar larvae crawl downward towards the upper lip and enter the oral cavity (Cogley and Anderson 1981). Larvae live in the host over the winter, for up to 6-8 months (Anderson 2012). Larvae are obligated to migrate into the lung and live in the bronchi during development; they return to the nostrils in the spring (Anderson 2012).

Distributions:

See Map. 1. In Canada, *Cephenemyia apicata* specimens were collected in BC: Ashnola River, Cowichan Lake, Mara Mountain, Forbidden Plateau; Alberta: Edmonton, Porcupine Hill; Saskatchewan: 15km E Val Marie.

Remarks:

Cephenemyia apicata has two morphotypes. Specimens I examined from the United States of America have a band of black hairs on abdominal tergites 2-4, with or without minor orange hairs. In contrast, all Canadian specimens of *Cephenemyia apicata*, have only orange hairs on abdominal tergites predominantly. The posterior ⅓ of each tergite (of tergites 2-4) is covered with reddish-orange hairs.

Cephenemyia apicata is very difficult to distinguish from *Cephenemyia pratti*. As Bennett wrote in the original description: “In most of the specimens, the black hairs clearly predominate, and even the brightest-colored examples are far from the completely bright-colored abdomen of *C. pratti*, to which it is most similar” (Bennett and Sabrosky 1962). The other diagnostic character Bennett used to distinguish *C. apicata* and *C. pratti* is the number of spine rows on the larval upper anal plate.

Material examined:

See Supplementary Material; I examined 15 Canadian specimens, including 1 female and 14 males. The large difference in the proportion of males and females in specimens may be caused by collecting methods. Specimens were collected during hilltopping, when the males were aggregated looking for females.

5.2 ***Cephenemyia jellisoni*** Townsend, 1941: 161

Diagnosis:

Male frontal vitta and fronto-orbital plate conspicuously narrower than the width of a compound eye. Postsutural scutum with a transverse cross band of black hairs between wing bases. Wing cells r_1 and r_{2+3} completely infuscated. Upper calypter with predominantly white hairs along the margin. Abdominal tergites 2-3 concealed in black hairs. Abdominal tergites 4-5 concealed in yellow to orange hairs.

Description (figs. 26-28):

Body Length: 10-12 mm. **Wing Length:** 10-12 mm.

Head: frontal vitta black; with dense yellow hairs; fronto-orbital plate black, with white pruinosity and yellow hairs, few black hairs close to eyes; arista reddish brown and bare; flagellum reddish brown, with white pruinosity; pedicel dark brown, with white pruinosity and few black hairs; facial plate dark brown, with white pruinosity, margin tapered ventrally; gena black, concealed in whitish yellow hairs; palps as a pair of dark brown knobs.

Thorax: mesoscutum covered with whitish yellow hairs, with a transverse cross band of black hairs between the wing bases; some specimens with yellow hairs interrupted the middle of cross band; scutellum short and semicircular, with dorsal whitish yellow hairs; underside of scutellum with white hairs laterally and bare medially; wing veins orange or brown; veins C and Sc with 3-4 rows of bristles; wing cells r_1 and r_{2+3} completely infuscated; alula folded dorsally, more than 90° to the rest of the wing membrane; upper calypter margin folded upward, with predominantly white hairs; lower calypter brownish infuscated and microsetose; legs black; tarsomeres with dense black hair tufts posterolaterally.

Abdomen: oval, with dense yellow and black hairs; abdominal tergite 1 with long and whitish yellow hairs; abdominal tergites 2 and 3 with dense black hairs predominantly mix with less yellow hairs; abdominal tergites 4 and 5 with dense yellow to orange hairs; abdominal sternites black, slightly white pruinose, with sparse black hairs.

Male: frons apparently narrower than the width of a compound eye.

Female: frons apparently wider than the width of a compound eye.

Fig. 26: Anterior view of male *Cephenemyia jellisoni* (specimen code: CNC-1046)

Fig. 27: Dorsal view of male *Cephenemyia jellisoni* (specimen code: CNC-1046)

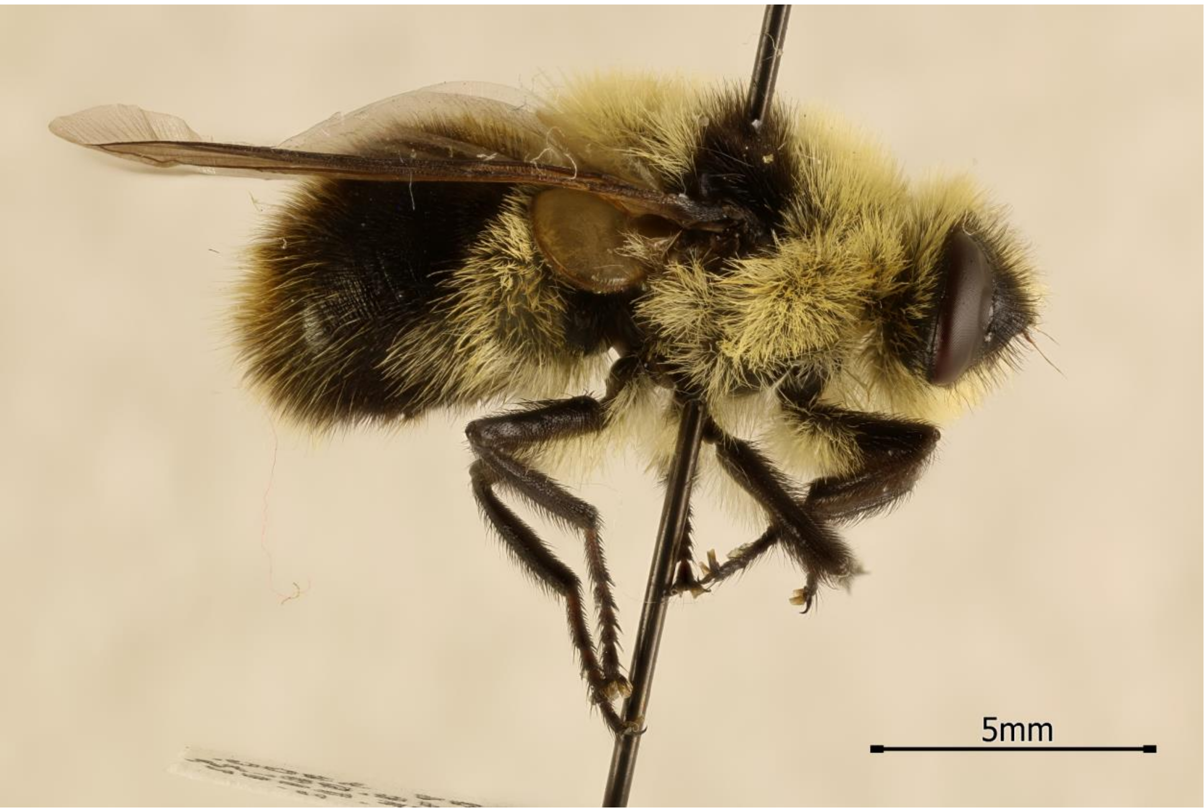


Fig. 28: Lateral view of male *Cephenemyia jellisoni* (specimen code: CNC-1046)

Host:

The known hosts of *Cephenemyia jellisoni* include mule deer, white-tailed deer (*Odocoileus virinianus* (Zimmermann, 1780)), eastern moose (*Alces alces americanus* (Clinton, 1822)), elk (*Cervus canadensis* (Erxleben, 1777)) and red deer (*Cervus elaphus* Linnaeus, 1758) (Bennett and Sabrosky 1962, Colwell et al. 2006).

Biology:

The lifecycle is like *Cephenemyia apicata* (Bennett and Sabrosky 1962), with the following exceptions: females spray microdroplets of larvae-contained fluid instead of expelling one droplet to the host. Unlike *Cephenemyia apicata*, *Cephenemyia jellisoni* hilltopping behaviour has not been observed during summer, only happening in March and April, September, and October (Anderson 1975). The aggregation site and time may overlap with *Cephenemyia apicata*. An explicit stratification of *Cephenemyia apicata* and

Cephenemyia jellisoni was observed on one shrub. *Cephenemyia jellisoni* occupied the higher branches (Anderson 1975).

Distributions:

See Map. 1. In Canada, *Cephenemyia jellisoni* specimens were collected in British Columbia: Tuktakamin; Alberta: Porcupine Hill; Quebec: Lake Delorme.

Remarks:

Cephenemyia jellisoni may be confused with *Cephenemyia apicata*. They can be distinguished by the completely transparent wing membrane and the median stripe of black hair on *Cephenemyia apicata* abdominal tergite 5.

Material examined:

See Supplementary Material examined 21 Canadian specimens, including 2 females and 21 males. Similar difference

5.3 ***Cephenemyia phobifer*** (Clark, 1815): 69

Diagnosis:

Male frontal vitta and fronto-orbital plate narrower than the width of a compound eye. Postsutural scutum covered with only yellow hairs, without a transverse cross band of black hairs. Wing cells r_1 and r_{2+3} infuscated in the basal half. Upper calypter with predominantly black hairs along the margin. Abdominal tergites 2-5 concealed in predominantly black hairs, laterally with sparse white hairs.

Description (figs. 29-31):

Body Length: 12-13 mm. **Wing Length:** 8- 10 mm.

Head: frontal vitta concealed in dense yellow hairs; fronto-orbital plate black and punctate, with white pruinosity and sparse black hairs; arista reddish brown and bare; flagellum black, with white pruinosity; facial plate dark brown, with white pruinosity, margin tapered ventrally; gena black, concealed in whitish yellow hairs; palps as a pair of dark brown knobs.

Thorax: mesoscutum covered with yellow hairs; scutellum short and semicircular, dorsally with whitish yellow hairs; underside of scutellum with white hairs laterally and bare medially; veins C and Sc with 3-4 rows of bristles; wing cells r_1 and r_{2+3} infuscated on basal portion; alula folded dorsally, more than 90° in relation to the rest of the wing membrane; upper calypter margin folded upward, with predominantly white hairs; lower calypter infuscated and microsetose; legs dark brown; tarsomeres with dense black hair tufts posterolaterally.

Abdomen: oval, with dense hairs; abdominal tergite 2 with orange hairs dorsally; abdominal tergites 3-5 concealed in predominantly black, and laterally with sparse white hairs; abdominal sternites black, with little white pruinosity, with sparse black hairs.

Male: frons apparently narrower than the width of one compound eye.

Female: frons apparently wider than the width of one compound eye.

Fig. 29: Anterior view of male *Cephenemyia phobifer* (specimen code: CNC-1093)

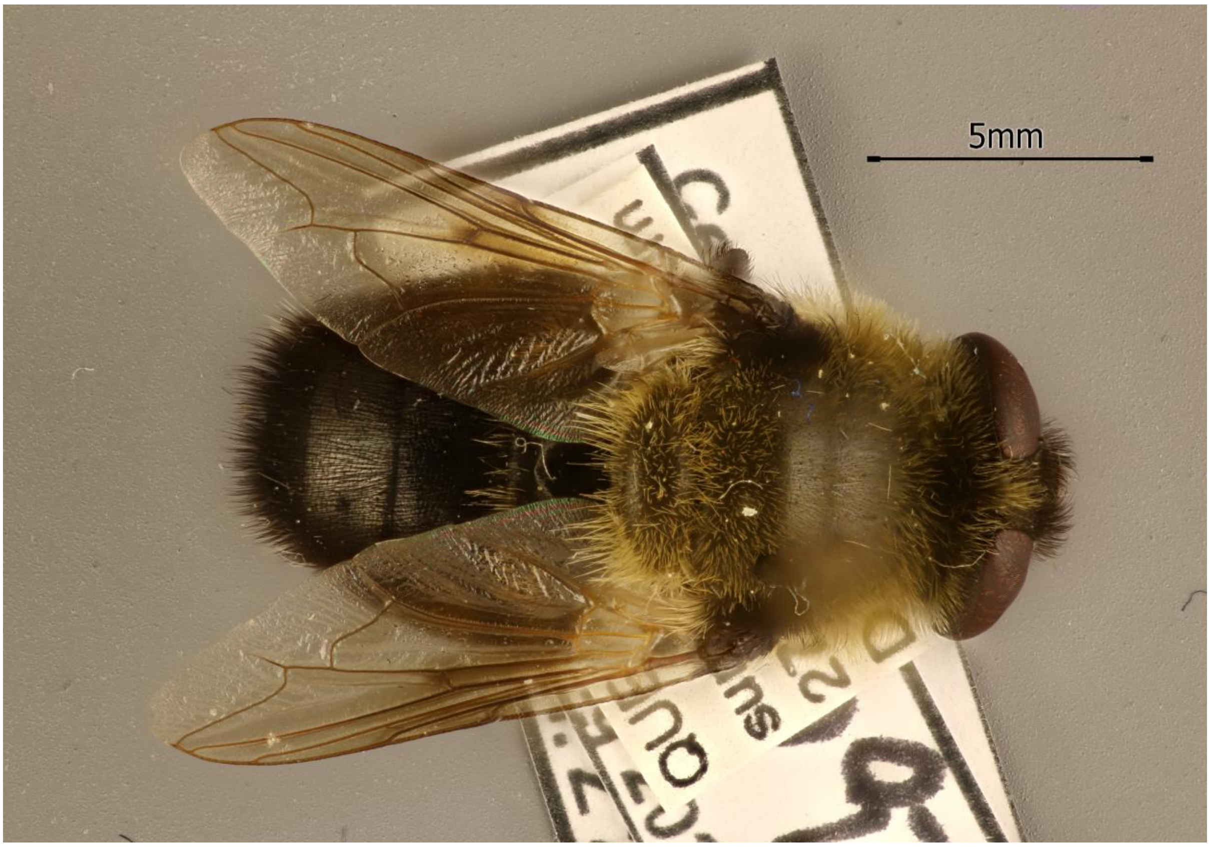


Fig. 30: Dorsal view of male *Cephenemyia phobifer* (specimen code: CNC-1093)

Fig. 31: Lateral view of male *Cephenemyia phobifer* (specimen code: CNC-1093)

Host:

The known hosts of *C. phobifer* includes white-tailed deer and eastern moose (Bennett and Sabrosky 1962, Colwell et al. 2006a).

Biology:

A detailed study indicated that *Cephenemyia phobifer* has two generations per year (Bennett 1962). The summer cycle takes about three months, and the winter cycle takes about six months (Bennett 1962). The abdomen of a female *C. phobifer* was dissected in 1968, and 320 hatched larvae were found in the uterus (Golini et al. 1968).

Distributions:

See Map. 1. In Canada, *Cephenemyia phobifer* specimens were collected in New Brunswick: Oak Bay; Nova Scotia: Cape Breton Highlands National Park; Ontario: Algonquin Park; Quebec: Mountain Rigaud, Mountain Pinnacle, Parc de la Gatineau.

Remarks:

Cephenemyia phobifer can be easily distinguished from other species of *Cephenemyia* by two diagnostic characters: 1) the absence of the dorsal black band between wing bases; and 2) the hairs on abdominal tergites are predominantly black.

Two specimens from Pinnacle Mountain (from May 28 to June 3, 1991) and one unlabeled specimen were found with bare scutum and scutellum (fig. 32). I was unable to determine whether they are a variant in setation or specimens lost their setation during collecting and storing.

Fig. 32: The bare scutum and scutellum on a *C. phobifer* specimen.

Material examined:

See Supplementary Material; I examined 88 specimens, including 4 females and 84 males.

5.4 *Cephenemyia trompe* (Modéer, 1786): 134

Diagnosis:

Male frontal vitta and fronto-orbital plate subequal to or slightly wider than the width of a compound eye. Postsutural scutum with a transverse cross band of black hairs. Wing membrane completely transparent. Upper calypter with predominantly white hairs along the margin. Abdominal tergites concealed in predominantly yellow or orange hairs. Abdominal tergite 5 concealed in yellow or reddish-orange hairs.

Description (figs. 33-35):

Body Length: 12-15 mm. **Wing Length:** 8-11 mm.

Head: frontal vitta concealed in dense yellow hairs; fronto-orbital plate black and punctate, with white pruinosity and sparse black hairs; arista reddish brown and bare; flagellum black, with white pruinosity; facial plate dark brown, with white pruinosity, margin tapered ventrally; gena black, concealed in whitish yellow hairs; palps as a pair of dark brown knobs.

Thorax: mesoscutum covered with whitish yellow hairs, with a cross band of black hairs between the wing bases; some individuals with yellow hairs interrupted the middle of cross band; scutellum with whitish yellow hairs dorsally, underside of scutellum with white hairs laterally and bare medially; wing veins orange or brown; veins C and Sc with 3-4 rows of bristles; wing membrane completely transparent; alula folded dorsally, more than 90° in relation to the rest of the wing membrane; upper calypter margin folded upward, with predominantly white hairs; lower calypter infuscated and microsetose; legs dark brown; tarsomeres with dense black hair tufts posterolaterally.

Abdomen: oval, with densely hairs; abdominal tergites 2-5 concealed in whitish yellow to orange hairs; abdominal sternites black, with little white pruinosity, with sparse black hairs.

Male: frons subequal to or slightly wider than the width of a compound eye.

Female: frons apparently wider than the width of a compound eye.

Fig. 33: Anterior view of male *Cephenemyia trompe* (specimen code: CNC-1254).

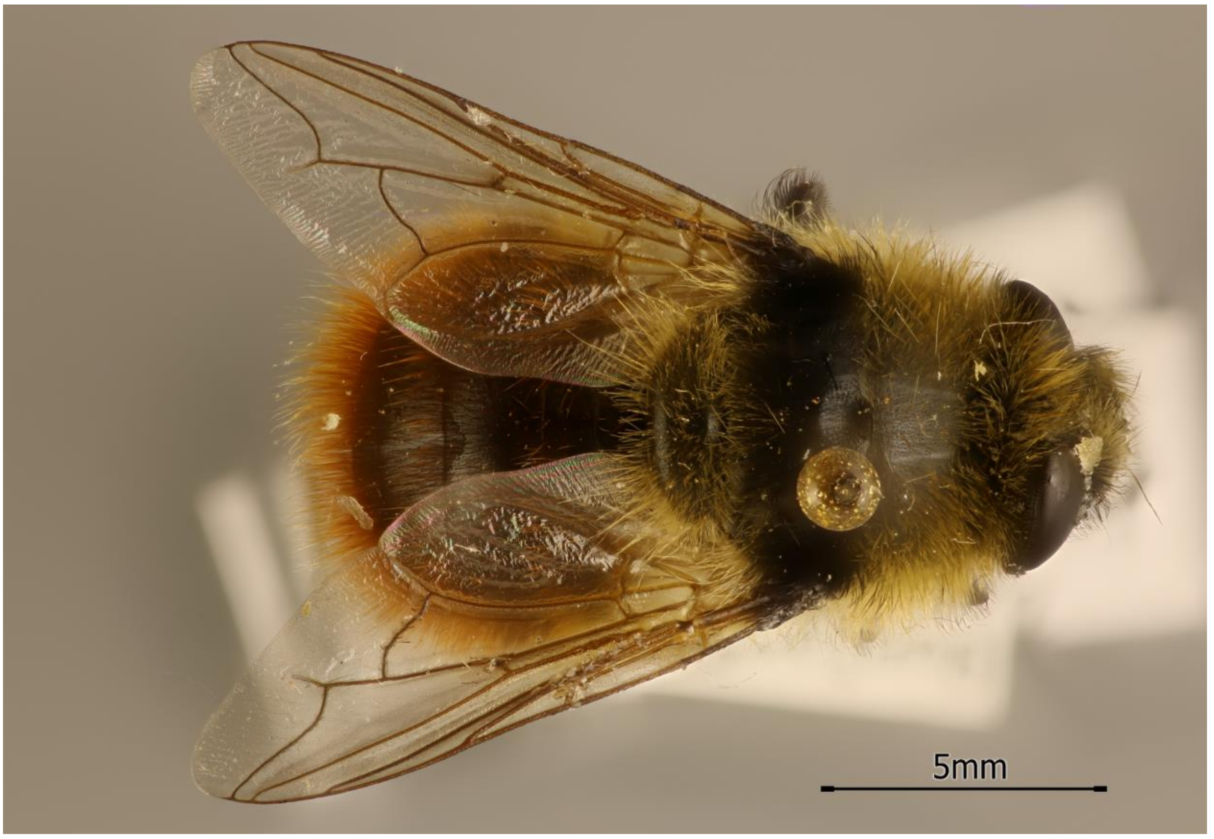


Fig. 34: Dorsal view of male *Cephenemyia trompe* (specimen code: CNC-1254).

Fig. 35: Lateral view of male *Cephenemyia trompe* (specimen code: CNC-1254).

Host:

The primary host of *C. trompe* is reindeer (*Rangifer. sp* (Linnaeus, 1758)) and mule deer (Bennett and Sabrosky 1962, Colwell et al. 2006).

Biology:

Females of *Cephenemyia trompe* have been recorded carrying 882-1518 larvae (Anderson and Nilssen 1996). Mature larvae are found to leave the host at the end of April, usually at night or during low-temperature periods of the day (Nilssen and Haugerud 1994). Pupal duration varies from 7 to 44 days. Development is slower at low temperature and totally stops below 15°C (Nilssen 1997b). Adult longevity of *C. trompe* is 4 to 44 days (Nilssen 1997a, Colwell et al. 2006)

Distributions:

See Map. 1. In Canada, *Cephenemyia trompe* specimens were collected in Yukon: British Mountains, Richardson Mountains, Herschells, Tombstone Territorial Park (Butterfly Hill north of Surbird Mountain), 10km south of Carcross, Yukon Delta, Dempster Highway, top of the world highway (near Alaska border), 14 Southwest of Burwash flats; Northwest Territories: Bathurst Inlet, Kidluit Bay, Pingo along Inuvik-Tuktoyaktuk Highway; Manitoba: Churchill; Quebec: Lac Delorme, Sakami (LG3).

Remarks:

Cephenemyia trompe is the only species of *Cephenemyia* that infests reindeer, and it is also the only species of *Cephenemyia* found in Yukon and Northwest Territories. A variation of the orange abdominal hairs are found: in eighty-four specimens dull yellow hairs were observed on abdominal tergites 2-5, while nine specimens from Lac Delorme, Duplanter QC have orange hairs on abdominal tergites 2-5. The population in colder area has lighter coloration, which is the opposite of the thermal melanism hypothesis (melanic individuals are more commonly found in colder climates, under the assumption that darker colours increase radiation thermoregulation) (Fedorka et al. 2013).

Fig. 36: Hair colouration variation in *C. trompe.*

Material examined:

See Supplementary Material; I examined 93 specimens, including 16 females and 77 males.

6. ***Cuterebra*** Clark, 1815: 64, 70

Current global taxonomy:

Sixty-two species are recognized worldwide:

- *Cuterebra abdominalis* Swenk, 1905: 182
- *Cuterebra albata* Sabrosky, 1986: 129
- *Cuterebra albipilosa* Sabrosky, 1986: 177
- *Cuterebra almeidai* (Guimarães & Carrera, 1941): 2
- *Cuterebra americana* (Fabricius, 1775): 774
- *Cuterebra apicalis* Guérin, 1835: pl. 101
- *Cuterebra approximata* Walker, 1866: 338
- *Cuterebra arizonae* Sabrosky, 1986: 186
- *Cuterebra ascarides* (Scudder, 1877): 756
- *Cuterebra atrox* Clark, 1848: 1
- *Cuterebra austeni* Sabrosky, 1986: 189
- *Cuterebra baeri* Shannon & Greene, 1926: 286
- *Cuterebra bajensis* Sabrosky, 1986: 163
- *Cuterebra bibosa* (Scudder, 1877): 757
- *Cuterebra buccata* (Fabricius, 1775): 305
- *Cuterebra bureni* (Dalmat, 1942): 25
- *Cuterebra cayennensis* Macquart, 1844: 23
- *Cuterebra chiquibulensis* Disney, 1969: 190
- *Cuterebra clarki* Sabrosky, 1986: 145
- *Cuterebra cochisei* Sabrosky, 1986: 112
- *Cuterebra cuniculi* (Clark, 1797): 299
- *Cuterebra dasypoda* (Brauer, 1896): 16
- *Cuterebra detrudator* Clark, 1848: 1
- *Cuterebra emasculator* Fitch, 1856: 478
- *Cuterebra enderleini* Bau, 1929: 5 (validated in key)
- *Cuterebra fasciata* Swenk, 1905: 184
- *Cuterebra fassleri* (Guimarães, 1984): 23
- *Cuterebra flaviventris* (Bau, 1931): 219
- *Cuterebra fontinella* Clark, 1827: 410
- *Cuterebra funebris* (Austen, 1895): 378
- *Cuterebra grandis* (Guérin-Méneville, 1844): 548
- *Cuterebra gilvopilosa* (Bau, 1932): 11
- *Cuterebra histrio* Coquillett, 1902: 103
- *Cuterebra indistincta* Sabrosky, 1986: 171
- *Cuterebra infulata* Lutz, 1917: 99

- *Cuterebra jellisoni* Curran, 1942: 78
- *Cuterebra latifrons* Coquillett, 1898: 10
- *Cuterebra lepivora* Coquillett, 1898: 9
- *Cuterebra lepusculi* Townsend, 1897: 8
- *Cuterebra lopesi* (Guimarães, 1990): 256
- *Cuterebra maculosa* Knab, 1914: 187
- *Cuterebra megastoma* Brauer, 1863a: 247
- *Cuterebra mirabilis* Sabrosky, 1986: 102
- *Cuterebra neomexicana* Sabrosky, 1986: 194
- *Cuterebra ornata* Bau, 1928: 50
- *Cuterebra patagona* Guérin-Méneville, 1844: 548
- *Cuterebra pessoai* Guimarães & Carrera 1941: 4
- *Cuterebra polita* Coquillett, 1898: 10
- *Cuterebra postica* Sabrosky, 1986: 140
- *Cuterebra praegrandis* Austen, 1933: 706
- *Cuterebra princeps* (Austen, 1895): 393
- *Cuterebra ruficrus* (Austen, 1933): 711
- *Cuterebra rufiventris* Macquart, 1844: 21
- *Cuterebra sabroskyi* (Guimarães, 1984): 26
- *Cuterebra semiatra* (Wiedemann, 1830): 421
- *Cuterebra simulans* Austen, 1933: 709
- *Cuterebra sterilator* Lugger, 1897: 229
- *Cuterebra tenebriformis* Sabrosky, 1986: 202
- *Cuterebra tenebrosa* Coquillett, 1898
- *Cuterebra terrisona* Walker, 1849: 683
- *Cuterebra townsendi* (Fonseca, 1942): 483
- *Cuterebra trigonophora* (Brauer, 1863b): 326

Numen Dubia or Unplaced:

- *Cuterebra ephippium* Latreille, 1818: 271
- *Cuterebra lutzi* Bau, 1930: 81
- *Cuterebra semilutea* Bau, 1929: 1

Diagnosis:

Arista pectinate. Facial plate margins converge ventrally. Gena with sparse microsetae or microtomentose. Scutellum shield-like, strongly projecting, with dense black or yellow hairs dorsally. Wing membrane completely infuscated. Vein M curved, ending before wing apex, and no extension crossing with crossvein dm-m. Abdomen oval, with sparse black microsetae. Female without external ovipositor.

Biology:

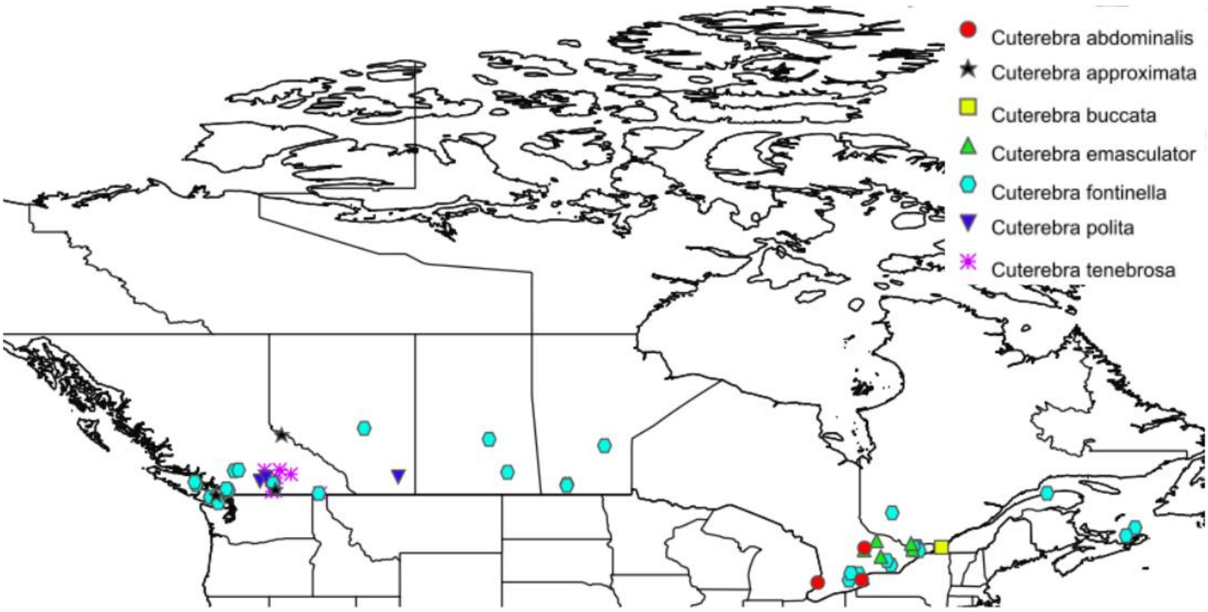
Female *Cuterebra* spp. glue eggs on grass blades or stones near the host's nest site, which will remain viable for 6 to 10 months, allowing eggs to overwinter. Eggs hatch spontaneously or respond to heat and elevated CO_2 from the host (Catts 1982). Larvae enter the host by natural body openings (mouth, nostrils, eyes, anus, etc.) or skin lacerations. During their migration inside the host, larvae become cryptic from 5 to 12 days until they arrive at the subdermal site of parasites (Gingrich 1981). The duration of larval development of rodent bot flies is from 19 to 42 days. The duration of rabbit bot flies is from 26 days to 73 days (Sabrosky 1986). Mature larvae leave the host from the warble pore, burrow 8–25 cm into the soil or debris and form the puparium in 12 to 24 hours. The length of the pupal period in *Cuterebra* spp. is from 14 days to 340 days (Catts 1967, Bennett 1972). Some species are found to form aggregations during the morning when the temperature reaches 20 °C (Catts et al. 1965). A female *Cuterbera* contains 1000–3000 eggs, about 1000–1500 in rabbit-parasite species, and 2000–3000 in rodent-parasite species (Smith 1977, Scholl 1991). Females scattered and distributed 5–15 eggs at each site (Capelle 1970, Smith 1977).

Host:

Except for *C. baeri* (a neotropical species) known as a howler monkey (genus *Alouatta* Lacepede, 1766) specialist, all other *Cuterebra* are parasites of rodents or lagomorphs (Colwell et al. 2006). Based on the host specification, Catts and Sabrosky categorized the genus *Cuterebra* into two subgenera, *Cuterebra* and *Trypoderma*, and four species groups: *buccata*, *cuniculi*, *fontinella* and *americana* (Catts 1982, Sabrosky 1986). Subgenera and species groups have not been reviewed in the last 40 years yet. For the purposes of this thesis, these groups are considered synonyms of the genus *Cuterebra*. In rare cases, *Cuterebra* spp. infest non-mammal hosts (i.e., American woodcock *Scolopax minor* Gmelin, 1789 and Grand Canyon rattlesnakes *Crotals viridis abyssus* Klauber, 1930) (Garrigues 1964, Artmann 1975).

Distribution:

Cuterebra are restricted to North America and South America (Evenhuis and Pape 2023). There are 34 species found in the Nearctic region (Sabrosky 1986). In Canada, seven species of *Cuterebra* are recorded (Sabrosky 1986, Vlaine 2022, Ouellette 2023).



Map. 2: Distribution of *Cuterebra* spp. in Canada.

Remarks:

Cuterebra can be easily distinguished from the other genera by their completely infuscated wing, enlarged alula, flattened tarsi and apparently larger body size than the other genera. The presence of mesopleuron hair spots was used in diagnosing species of *Cuterebra* in Clark's description (Clark 1815). However, more specimens show that mesopleuron hair spots are variable and do not make good characters for species differentiation (*Cuterebra horripilum*, *Cuterebra angustifrons*, e.g.) (Sabrosky 1986). Thus, the research avoids using mesopleuron spots to diagnose species.

Identification Key to Adult *Cuterebra* of Canada:

1) Facial plate with or without weakly ridged vertically (fig. 37 A); abdominal tergite 5 with yellow hairs (fig. 38 A) …………………………………………………...……………2

1') Facial plate strongly ridged vertically (fig. 37 B); abdominal tergite 5 with black hairs (fig. 38 B) …..………………………………………………………..……………… 3

2) Mesoscutum with golden-yellow hairs (fig. 39 A); abdominal tergite 5 slightly pruinose, but not microtomentose (fig. 40 A) …………………….. ***Cuterebra emasculator*** Fitch, 1856

2') Mesoscutum with white or black hairs (fig. 39 B&C); abdominal tergite 5 whitish yellow microtomentose (fig. 40 B) ………………………………...***Cuterebra fontinella*** Clark, 1827

3) Thorax completely covered with dense golden yellow hairs; basal portion of tibia without microtomentum (fig. 41 B) ……………………………***Cuterebra abdominalis*** Swenk, 1905

3') Thorax predominantly covered with black hairs; basal portion of tibia with white microtomentum (fig. 41 A) ……………………………………………………….……. 4

4) Lower face with white microtomentum; mesoscutum with white pruinosity …………………,………………………………… ***Cuterebra buccata*** (Fabricius, 1775)

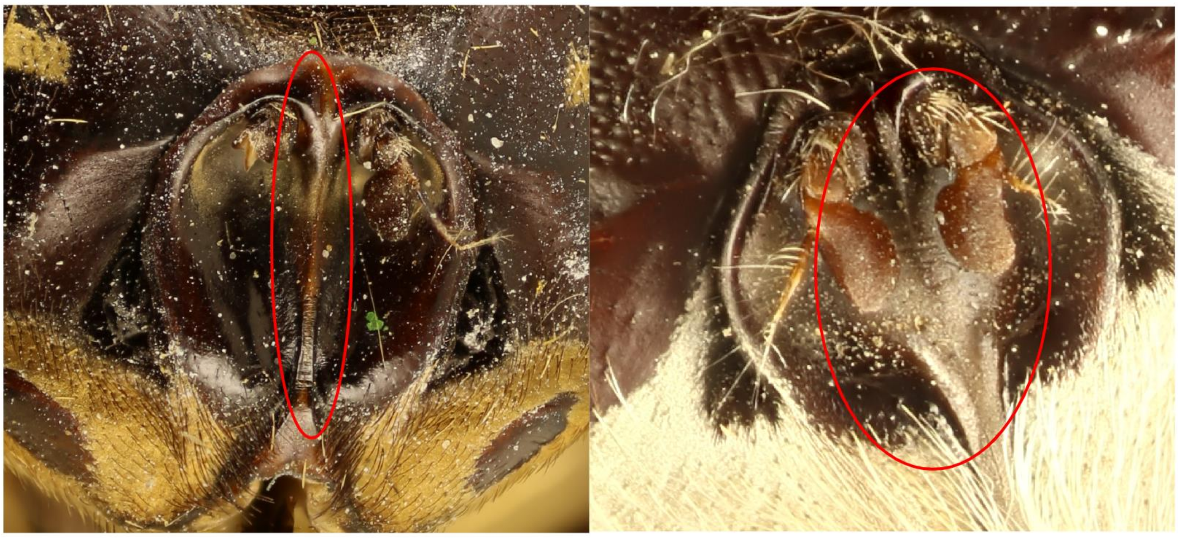
4') Lower face bare or with sparse black microsetae, without microtomentum; mesoscutum without pruinosity…………………………………….……………………………5

5) Abdominal tergites cuticle glossy purplish brown, with whitish yellow scattered microtomentose pattern laterally (fig. 42) …….……***Cuterebra approximata*** Walker, 1866

5’) Abdominal tergites cuticle entirely glossy purplish brown, without microtomentose pattern (fig. 42) ……………………………………..……...…………………………..….6

6) Body length around 14 mm; fringe of upper calypter white (fig. 43 B) ……………………………………..…….………………..…..***Cuterebra polita*** Coquillett, 1898

6’) Body length around 20 mm; fringe of upper calypter brown to black (fig. 43 C) …………………………………………...…………..***Cuterebra tenebrosa*** Coquillett, 1898



A B

Fig. 37: A strong vertical facial ridge on (A) *Cuterebra abdominalis*, which is absent in (B) *Cuterebra fontinella*.

Fig. 38: Abdominal tergite 5 covered with yellow hairs in (A) *Cuterebra emasculator*, which is black in (B) *Cuterebra approximata*.

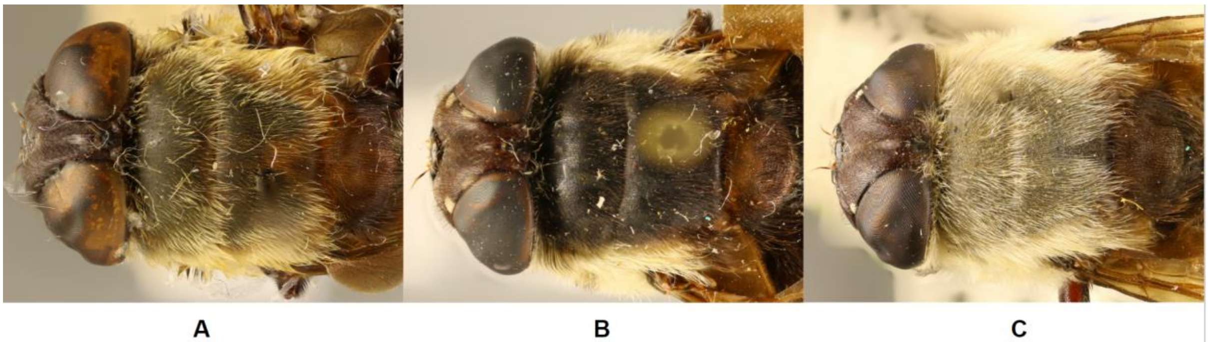


Fig. 39: Mesoscutum covered with golden yellow hairs in (A) *Cuterebra emasculator*, which is black or white in (B and C) *Cuterebra fontinella*.

Fig. 40: Abdominal tergite 5 brown in (A) *Cuterebra emasculator*, which is whitish yellow microtomentose in (B) *Cuterebra fontinella*.

Fig. 41. Basal portion of the tibia is white microtomentose in *Cuterebra approximata* (A), microtomentose is absent in *Cuterebra fontinella* (B).

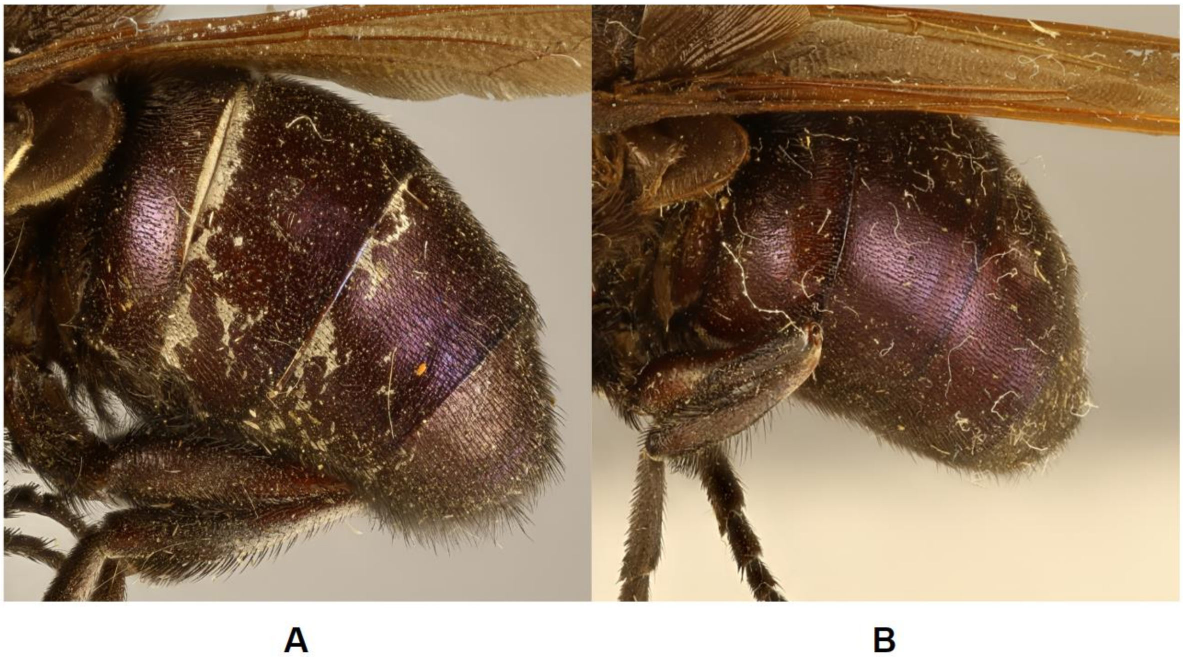


Fig. 42: Abdomen laterally with whitish yellow scattered microtomentose in (A) *Cuterebra approximata*, which is absent in (B) *Cuterebra tenebrosa* or *Cuterebra polita*.

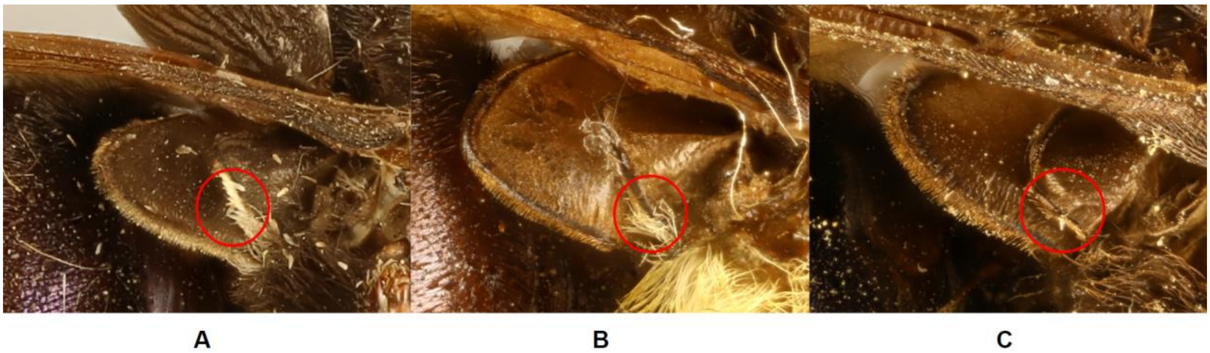


Fig. 43: Upper calypter fringe in (A) *Cuterebra approximata*, (B) *Cuterebra polita* and (C) *Cuterebra tenebrosa*.

6.1 *Cuterebra abdominalis* Swenk, 1905: 182

Diagnosis:

Facial plate with a strong vertical ridge. Gena yellow with whitish yellow microtomentum and a pair of dark brown facial spots. Mesopleuron covered with dense golden-yellow hairs in both sexes. Upper calypter margin with short white hairs on the basal portion. Tibia reddish brown, without microtomentum on the basal portion. Abdomen glossy brown, with scattered whitish yellow microtomentose patterns laterally. Abdominal tergite 5 black microsetose.

Description (figs. 44-46):

Body Length: 25-30 mm. **Wing Length:** 17-19 mm.

Head: frontal vitta with white pruinosity and dense short black hairs; fronto-orbital plate punctate and sparse microsetose, with two pairs of orbital spots; lunule dark brown, thick and bare; arista pectinate; flagellum cuticle black, with white pruinosity; pedicel brown, with black hair tuft; facial plate predominantly smooth glossy and tapered ventrally, with a strong vertical ridge on the midline; gena yellow microtomentose, with a pair of bare cuticular brown facial spots; labium tubular and concealed in gena slit; palps absent.

Thorax: Mesoscutum covered and obscured with golden yellow hairs; scutellum strongly projecting posteriorly, dorsally with dense yellow hairs, ventrally with white pruinosity, and edge with yellow hairs; pleuron covered with dense golden yellow hairs, with a black hair spot; wing membrane completely brownish infuscated; veins r_{2+3}, r_{4+5} amber, remaining veins yellow; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter folded and infuscate, with a black edge and whitish yellow fringe; lower calypter unfolded and slightly convex and infuscated, with yellow edge and yellow fringe; legs cuticle reddish brown; femur laterally compressed, ventral edge with dense black hair fringe, lateral surface with sparse black hairs; tibia predominantly with sparse black hairs, basal portion bare, dorsal and ventral with dense black hair rows; tarsomeres flattened, with dense black hair tufts posterolaterally.

Abdomen: oval and cuticle glossy brown; abdominal tergite 2 with whitish yellow hairs dorsally; abdominal tergites 3-5 black microsetose, laterally with yellowish scattered microtomentose patterns; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, about ¼ of the head width

Female: frontal vitta and fronto-orbital plate board, about ½ of the head width.

Fig. 44: Anterior view of female *Cuterebra abdominalis* (specimen code: CNC-2039).

Fig. 45: Dorsal view of female *Cuterebra abdominalis* (specimen code: CNC-2039).

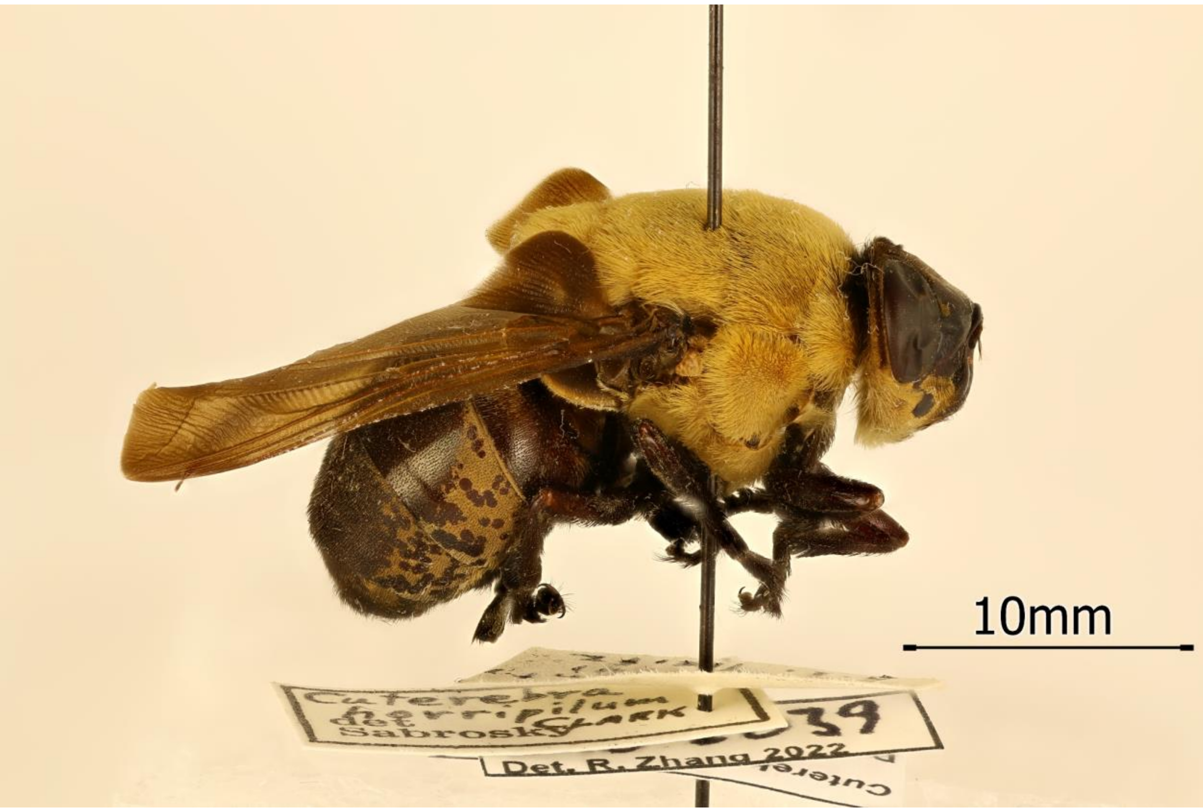


Fig. 46: Lateral view of female *Cuterebra abdominalis* (specimen code: CNC-2039).

Host:

The primary host is the eastern cottontail (*Sylvilagus floridanus* (Allen, 1890)). The species has been reared from swamp rabbits under artificial laboratory conditions (*S. aquaticus* (Bachman, 1837)).

Biology:

The parasitic sites are typically on the throat or neck of the host (Sabrosky 1986). Geis, Haas and Dicke studied the biology of *C. abdominalis* (misidentified as ‘‘*C. horripilum*’’, a junior synonym of *C. cuniculi*) in Michigan and Wisconsin (Geis 1957, Haas and Dicke 1958).

Distribution:

See Map. 2. In Canada, *C. abdominalis* specimens were collected from Ontario: Chaffey, Sarnia, and Vineland.

Remarks:

Cuterebra abdominalis is the only *Cuterebra* species that parasitizes rabbits and hares. While alive, individuals have a diagnostic red stripe on their compound eyes. In Canada, it can also be easily distinguished by the dense, robust short hairs on the thorax, and abdominal cuticle reddish-brown. The close-relative species, *C. cuniculi* (or labelled as synonym *C. horripilum*) are constantly misidentified.

Beyond Canada, the closest species, *Cuterebra cuniculi*, can be distinguished by the non-microtomentose gena and subquadratic black hair patch on the anterior half of the male scutum. So far, no *Cuterebra cuniculi* specimen has been collected in Canada.

Material examined:

See Supplementary Material. In total, I examined four Canadian specimens, including two female specimens from CNC and two female specimens from ROM.

6.2 *Cuterebra approximata* Walker, 1866: 338

Diagnosis:

Facial plate with a strong vertical ridge. Gena dark brown, bare, or sparsely microsetose, without facial spot. Mesopleuron covered with white hairs tuft and black hair spot in male, and with black hair tuft on females. Upper calypter margin with short white hairs on the basal portion. Tibia dark brown, with white micromentum on the basal portion. Abdomen glossy purplish brown, with scattered whitish yellow microtomentose pattern laterally. Abdominal tergite 5 with short black hairs, not microtomentose.

Description (figs. 47-49):

Body Length: 15-19 mm. **Wing Length:** 10-13 mm.

Head: frontal vitta and fronto-orbital plate dark brown, punctate, with sparse microtomentum; fronto-obital plate with three pairs orbital spots and a pair of lunule spots; lunule dark brown, thick and bare; arista pectinate; flagellum cuticle brown, with dense whitish microtomentum; pedicel amber, with 4-5 black microsetae; facial plate predominantly smooth glossy and tapered ventrally, with a strong vertical ridge on the midline; gena dark brown, black microsetose; labium tubular and concealed in gena slit; palps absent.

Thorax: Mesoscutum covered with black hairs dorsally and laterally; scutellum strongly projecting, dorsally with black hairs, ventrally with white pruinosity, and edge with black hairs; wing membrane completely brownish infuscated; veins amber or brown; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter and lower calypter unfolded and slightly convex, infuscated, with brown median edge and white fringe; legs cuticle dark brown; femur laterally compressed, with a row of black hairs ventrally; tibia predominantly with black hairs, basal portion without hairs, and with white microtomentose; tarsomeres flattened, with dense black hair tufts posterolaterally.

Abdomen: oval and cuticle glossy purplish brown; abdominal tergite 2 with white hairs dorsally; abdominal tergites 3-5 black microsetose, laterally with yellowish scattered microtomentum patterns; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, less than 1⁄2 the head width; pleural hair tuft white, with black hair spot.

Female: frontal vitta and fronto-orbital plate board, about ½ of the head width; pleural hair tuft black.

Fig. 47: Anterior view of female *Cuterebra approximata* (specimen code: CNC-2044).

Fig. 48: Dorsal view of female *Cuterebra approximata* (specimen code: CNC-2044).

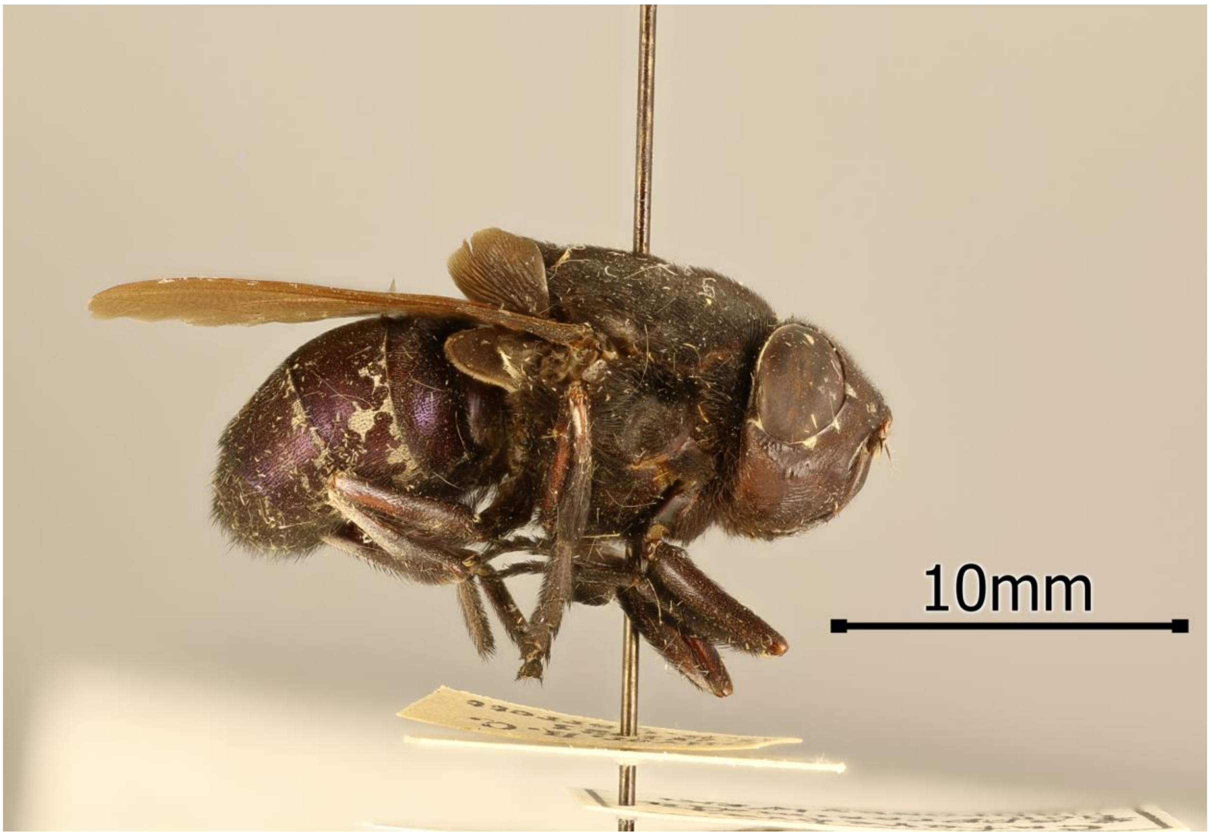


Fig. 49: Lateral view of female *Cuterebra approximata* (specimen code: CNC-2044).

Host:

The primary host of *C. approximata* is the eastern deer mouse (*Peromyscus maniculatus* (Wagner, 1845)) (Sabrosky 1986). *Cuterebra approximata* has also been reared from red tree vole (*Arborimus longicaudus* (True, 1890)) and house mice (*Mus musculus* Linnaeus, 1758) (Cole and Lovett 1921, Sabrosky 1986).

Biology:

Catts and Smith studied the biology of *C. approximata* in laboratories and the wild, respectively (Catts 1964, Smith 1975, 1977). The sexual ratio found in the lab-reared *C. approximata* was close to 2:1, in favour of males (Catts 1964). Oviposition occurs at least 5 days after emerging from pupa (Smith 1977). *Cuterebra approximata* larvae have the highest growth rate of body length in the third instar (Catts 1964).

Distribution:

See Map. 2. In Canada, *Cuterebra approximata* specimens were collected from British Columbia: Kuper Island, Okanagan Falls, Oliver, and Robson.

Remarks:

Unfortunately, I did not examine any male specimens of *Cuterebra approximata*. Based on the photo and previous literature (Smith 1977, Sabrosky 1986), *Cuterebra approximata* is sexual dimorphic with a diagnostic white hair tuft on pleuron. Female *Cuterebra approximata* are hard to distinguish from *C. tenebrosa*. I could only differentiate them by the upper calypter fringe colour and scattered microtomentose patches on the lateral abdomen.

Material examined:

See Supplementary Material. In total, I examined five Canadian specimens from CNC, including two males and three females.

6.3 *Cuterebra buccata* (Fabricius, 1775): 305

Diagnosis:

Facial plate with a strong vertical ridge. Gena white microtomentose with facial spots. Mesopleuron white pruinose with fine black hairs in both sexes. Upper calypter margin with long white hairs on the basal portion. Tibia reddish brown, with microtomentum on the basal portion. Abdomen dorsally glossy brown, laterally whitish yellow microtomentose with spots. Abdominal tergite 5 black microsetose and whitish yellow microtomentose with spots.

Description: (figs. 50-52)

Body Length: 22-25 mm **Wing Length:** 18-21 mm

Head: frontal vitta black with sparse white hairs; fronto-orbital plate punctate and sparse microsetose, with two pairs of orbital spots; lunule dark brown, thick and bare; arista pectinate; flagellum cuticle black, with white pruinosity; pedicel brown, with dense white hair tuft; facial plate predominantly smooth glossy and tapered ventrally, with a strong vertical ridge on the midline; gena with white microtomentum and h a pair of bare cuticular brown facial spots; labium tubular and concealed in gena slit; palps absent.

Thorax: Mesoscutum with fine black hairs and white pruinosity dorsally; notopleural hair tuft yellow; scutellum strongly projecting posteriorly, dorsally with dense yellow hairs, ventrally with white pruinosity, and edge with yellow hairs; pleuron covered with dense white hairs, with a black hair spot; wing membrane completely brownish infuscated; veins r_{2+3}, r_{4+5} amber, remaining veins yellow; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter folded and infuscate, with a black edge and whitish yellow fringe; lower calypter unfolded and slightly convex and infuscated, with brown edge and yellow fringe; legs cuticle reddish brown; femur laterally compressed, ventral edge with dense black hair fringe, lateral surface with sparse black hairs; tibia predominantly sparse black haired, basal portion with white microtomentum, dorsal and ventral with dense black hair rows; tarsomeres flattened, with dense black hair tufts posterolaterally.

Abdomen: oval and cuticle glossy brown dorsally; abdominal tergite 2 with whitish yellow hairs dorsally; abdominal tergites 3-5 black microsetose, laterally with white scattered microtomentose patterns; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, about ¼ of the head width

Female: frontal vitta and fronto-orbital plate board, about ½ of the head width.

Fig. 50: Anterior view of male *Cuterebra buccata* (specimen code: CNC-2123).

Fig. 51: Dorsal view of male *Cuterebra buccata* (specimen code: CNC-2123).

Fig. 52: Laterial view of male *Cuterebra buccata* (specimen code: CNC-2123).

Host:

The primary host is eastern cottontails (*Sylvilagus floridanus* (Allen, 1890)). In Texas, *Cuterebra buccata* has been reared from jack rabbits (*Lepus americanus* Gray 1837)

Biology:

Knipling and Brody record two generations of *Cuterebra buccata* in South Georgia. The larvae of *Cuterebra buccata* were found in cotton-tail rabbit during June and November. The mature larvae were collected, and pupated in June, emerging as adults in August. The larvae collected in November emerged in March and April. (Knipling and Brody 1940). Similar research was also done by Beamer and Penner (Beamer and Penner 1942, Penner 1958).

Jacobson has done further research on Virginia *Cuterebra buccata*. He found *Cuterebra buccata* infesting eastern cottontails during June and January. The myiasis rate in eastern cottontail is found to be higher than 25% between July and October. The preferred parasitic site is the neck and shoulder (Jacobson et al. 1978). However, Catts has a different opinion on the preference of parasitic sites. According to his observation, bots of *Cuterebra buccata* are more common around the inguinal, belly and rib cage (Catts 1982). I have not found any infested cottontail during my research, and I can not verify either statement

As a newly confirmed Canadian species, there is no study on the biology of *Cuterebra buccata* in Canada.

Distribution:

See Map. 2. In Canada, *Cuterebra buccata* is observed on Notre-Dame-de-l'Île-Perrot and Blainville, Quebec. A specimen was collected in Nova Scotia in 1848, verified by Sabrosky (1986).

Remarks:

Cuterebra buccata and *Cuterebra abdominalis* infest the same primary host, eastern cottontail, and the mixed infestation of both species has been recorded in Michigan before (Boisvenue 1955). *Cuterebra buccata* had not been found in Canada since 1849, until a record was posted to iNaturalist in 2022 (Vlaine 2022). Boettner proposed that they were outcompeted by *Cuterebra abdominalis* in Canada (Boettner 2022).

Material examined:

I did not examine any Canadian specimens. Alternatively, I examined three specimens from the United States of America. Two individuals were observed and posted on iNaturalist from Notre-Dame-de-l'Île-Perrot and Blainville, Quebec (Vlaine 2022, Ouellette 2023).

6.4 ***Cuterebra emasculator*** Fitch, 1856: 478

Diagnosis:

Facial plate without or with a weak vertical ridge. Gena yellow to amber, with yellow hairs, and a pair of facial spots. Mesopleuron covered with white hairs, with or without black hair spots in both sexes. Upper calypter margin with long white hairs on the basal portion. Tibia reddish brown, without microtomentum on the basal portion. Abdomen dull brown, laterally without or with unobvious, scattered, whitish yellow microtomentose pattern laterally. Abdominal tergite 5 with yellow hairs and white pruinosity, but not microtomentose.

Description (figs. 53-55):

Body Length: 15-17 mm. **Wing Length:** ~13 mm.

Head: frontal vitta brown, with short black hairs and little white pruinosity; fronto-orbital punctate, without or with up to two pairs of orbital spots; with or without a pair of lunule spot; lunule reddish brown to dark brown, thick and bare; arista pectinate; flagellum reddish brown or brown, with white pruinosity; pedicel brown with black hair tuft; facial plate with white pruinosity, ventrally with small bare brown cuticle exposure; facial ridge absent; gena covered with yellowish hairs but not obscured, cuticle orange with white pruinosity and a pair of brown to black gene spot; labium tubular and concealed in gena slit; palps absent.

Thorax: Mesoscutum covered with bicolored hairs, blight yellow to white apical and black basal but not obscured; cuticle of scutum black; scutellum strongly projecting posteriorly, dorsally covered with black hairs and ventrally microsetose; cuticle of scutellum orange; pleuron covered and obscured with whitish yellow hairs, pleural spot present or absent; wing membrane completely brownish infuscated; wing veins amber; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter brown and folded, with dense white fringe on the basal; lower calypter brown, slightly convex or folden, with thin black fringe; legs cuticle reddish brown; femur laterally compressed, with dense black hair fringe on ventral edge, lateral surface with sparse black hairs; fore femur with whitish yellow hairs mix with black hairs; tibia predominantly with black hairs, the basal portion bare; all tarsomeres flattened, with black hairs posterolaterally.

Abdomen: oval and cuticle reddish brown; each abdominal tergite with a pair of black spots laterally; abdominal tergite 2 covered with white hairs dorsally; abdominal tergites 3-4 black microstose and unobscured; abdominal tergite 5 covered with golden yellow hairs and white pruinosity and unobscured, cuticular light brown; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, around ¼ of the head width.

Female: frontal vitta and fronto-orbital plate broad, around ½ of the head width.

Fig. 53: Anterior view of female *Cuterebra emasculator* (specimen code: ROM-2006).

Fig. 54: Dorsal view of female *Cuterebra emasculator* (specimen code: ROM-2006).

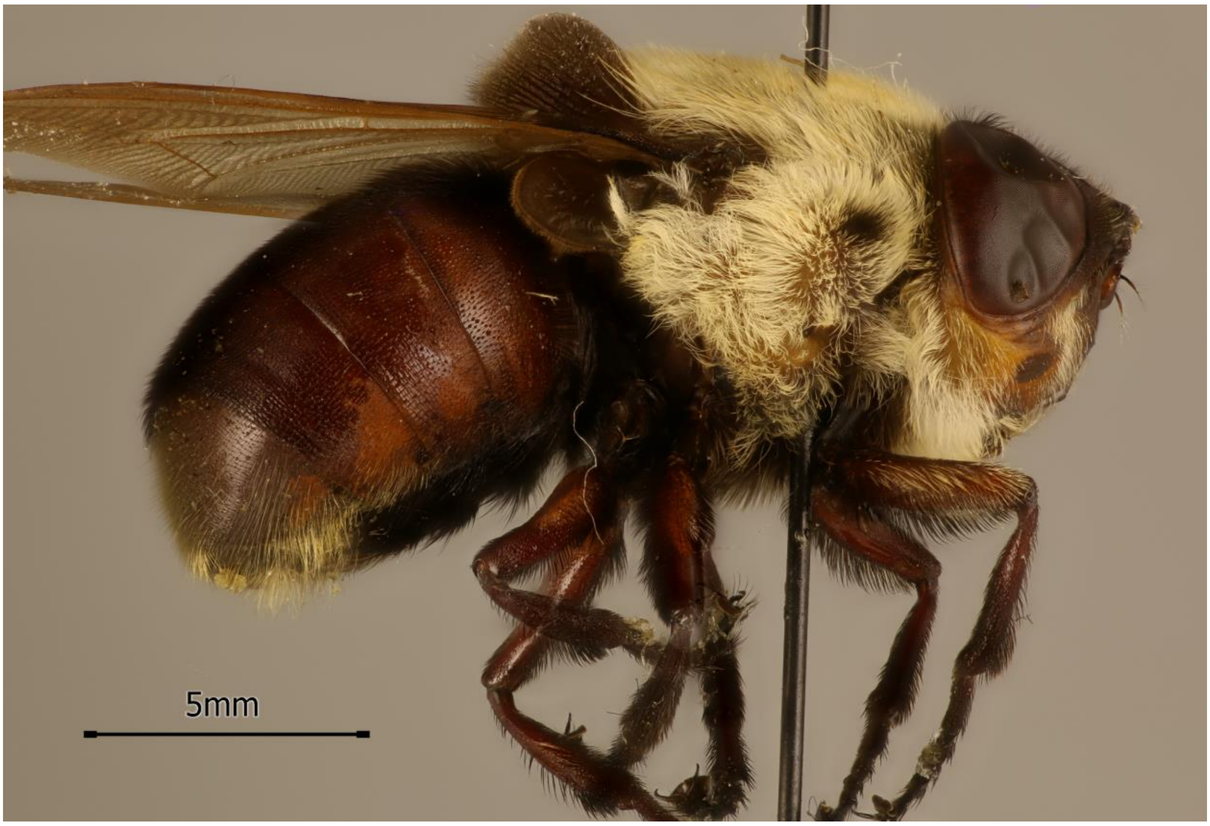


Fig. 55: Lateral view of female *Cuterebra emasculator* (specimen code: ROM-2006).

Host:

The primary hosts of *Cuterebra emasculator* are eastern chipmunks (*Tamia striatus* (Linnaeus, 1758)) and eastern grey squirrels (*Sciurus carolinensis* Gmelin, 1788) (Sabrosky 1986).

Biology:

The biology of *Cuterebra emasculator* was extensively studied (Coquillet 1898, Bennett 1955, 1972, 1973, Ubelaker and Keller 1964, Timm and Lee Jr 1981). Eggs are observed to be laid in the range of host activity, and Bennett predicts that they remain viable for 2-3 months (Bennett 1972). Larval growth is biphasic, with periods of rapid growth in the first instar and late third instar stages (Bennett 1955). Larvae take 12- 24 hours to pupate, and the pupal stage varies from 134-315 days at room temperature 20-24 °C, which is the stage for overwintering (Bennett 1955). Later studies indicate that lower temperatures increase the metamorphosis rate, which has the greatest success at around 6°C (Bennett 1972). As Fitch in his original description of *C. emasculator*, he suggests that the larvae would castrate the mammalian host. However, in following research using laboratory infections, *Cuterebra emasculator* shows no destruction to testicular tissue in eastern chipmunks, and only in extremely rare occasions *C. emasculator* larvae may slightly damage the testis; this may temporarily reduce host fertility (Timm and Lee Jr 1981).

Distribution:

See Map. 2. In Canada, *C. emasculator* were collected from Ontario: Algonquin Park, Stanley Corner, Apsley, Clearwater West Lake; Quebec: Masham Township.

Remarks:

Based on Sabrosky's research, the holotype of *C. emasculator* is lost, and the "Fitch's type" does not agree with the original description. Townsend identified it as *C. fasciata*, and Sabrosky identified it as *C. fontinella*. *Cuterebra emasculator* were sometimes misidentified as *C. fontinella*, which can be distinguished by two characters: 1) *Cuterebra emasculator* abdominal tergite 5 is haired and with lighter cuticle colour than abdominal tergite 2-4, but it is never microtomentose. On the other hand, abdominal tergite 5 of *C. fontinella* is heavily white microtomentose, with a few bare cuticular spots; 2) *Cuterebra emasculator* is like *C. fontinella*, but the hairs on the dorsal thorax are biocolored, instead of plain white or black. The dorsal thorax presents from golden to dark grey, depending on different angles of observation. Coquillet (1900) suggests it is not a valid diagnostic character, which is caused by the difference in light brightness of different observers. However, I believe it is a valid diagnostic character in my examination. It might be a mechanism used for both courtship and antipredator avoidance.

Material examined:

See Supplementary Material. I examined 19 Canadian specimens from CNC, including three females and sixteen males.

6.5 ***Cuterebra fontinella*** Clark, 1827: 410

Diagnosis:

Facial plate with a weak or without a vertical ridge. Gena with white microtomentum, whitish yellow hairs, and a pair of dark brown facial spots. Mesopleuron covered with white hairs, with or without black hair spots in both sexes. Upper calypter margin with long white hairs on the basal portion. Tibia reddish brown, without microtomentum on the basal portion. Abdomen dull brown, laterally with obvious, scattered, whitish yellow microtomentose pattern laterally. Abdominal tergite 5 with yellow hairs and heavily whitish yellow microtomentose.

Description (figs. 56-58):

Body Length: 14-17 mm. **Wing Length:** 12-14 mm.

Head: frontal vitta dark brown, with little white pruinosity, and black or white microsetae; fronto-orbital plate punctuate, with up to two pairs of orbital spots and a pair of lunule spots; lunule reddish brown to dark brown thick and bare; arista pectinate; flagellum brown, with little white pruinosity; pedicel brown with black hair tuft; facial plate with white pruinosity, ventrally with small bare brown cuticle exposure; facial ridge absent; gena white to yellow microtomentose, covered with white or yellow hairs, with a pair of cuticle brown or black gena spot; labium tubular and concealed in gena slit; palps absent.

Thorax: Scutum covered with either white or black hairs (few intermediate forms with mixed black and white hairs) and unobscured; cuticle of scutum black; scutellum strongly projecting posteriorly, covered with black hairs dorsally and microsetose ventrally; cuticle of scutellum orange; pleuron covered and obscured with whitish yellow hairs, pleural spot present or absent; wing membrane completely brownish infuscated; wing veins amber; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter infuscated and folded, with dark brown edge and dense white fringe on the basal; lower calypter infuscated and folded, with dark brown edge and thin yellow fringe; legs cuticle reddish brown; femur laterally compressed, with dense black hair fringe on ventral edge, lateral surface with sparse black hairs; tibia predominantly black with black hairs, basal portion no hairs; tarsomeres flattened, with black hairs posterolaterally.

Abdomen: oval and cuticle reddish brown; abdominal tergite 2 with white hairs dorsally; abdominal tergites 3-4 black microsetose and unobscured and with white microtomentose scattered patterns; abdominal tergite 5 golden yellow haired, predominantly white microtomentose with brown cuticular spots; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, around ¼ of the head width.

Female: frontal vitta and fronto-orbital plate broad, around ½ of the head width.

Fig. 56: Anterior view of female *Cuterebra fontinella* (specimen code: CNC-2159).

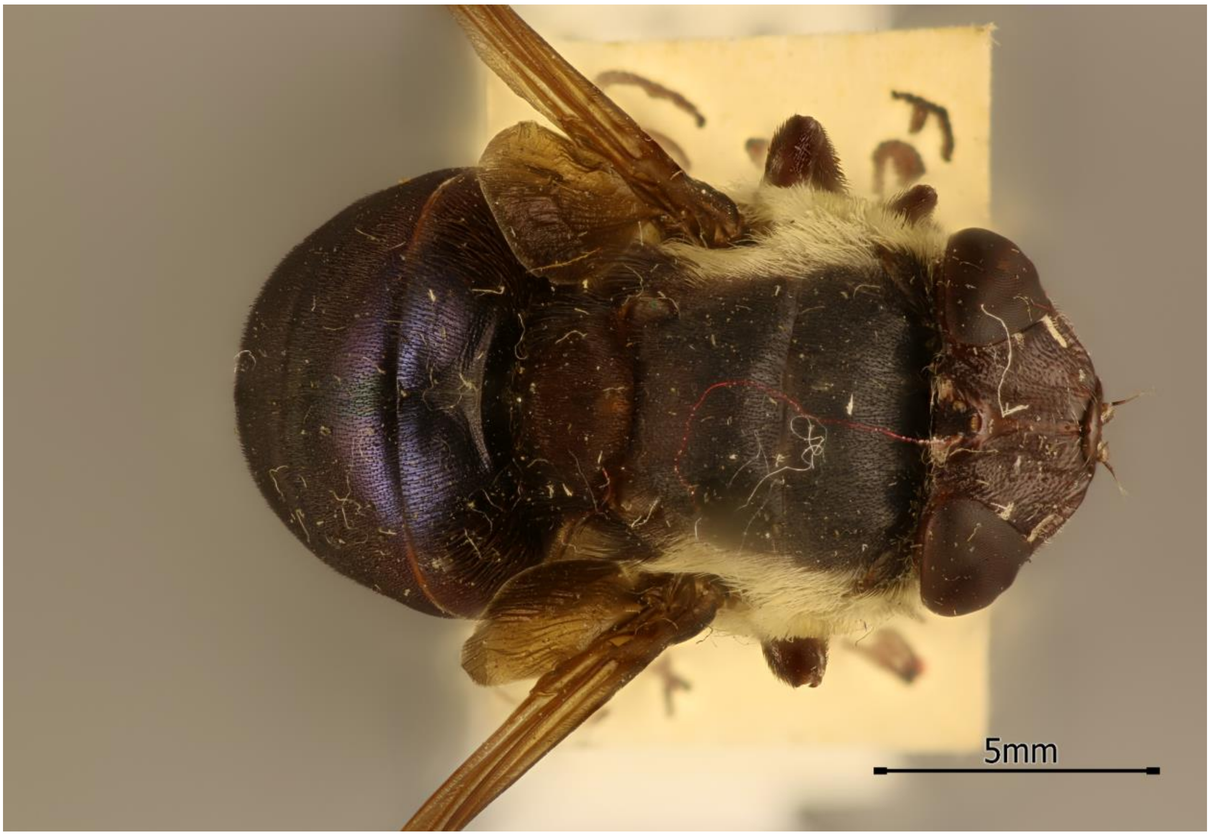


Fig. 57: Dorsal view of female *Cuterebra fontinella* (specimen code: CNC-2159).

Fig. 58: Lateral view of female *Cuterebra fontinella* (specimen code: CNC-2159).

Host:

The primary hosts of *C. fontinella* are white-footed mouse (*Peromyscus leucopus* Rafinesque, 1818) and cotton mouse (*P. gossypinus* (Le Conte, 1850)). Recorded hosts also include eastern deer mouse (*Peromyscus maniculatus* (Wagner, 1845)), golden mouse (*Ochrotomys nuttallii* (Harlan, 1832)), yellow-pine chipmunk (*Neotamias amoenus* (Allen, 1890)), Mexican spiny pocket mouse (*Heteromys irroratus* (Gray, 1868)), woodland jumping mouse (*Napaeozapus insignis* (Preble, 1899)), house mouse (*Mus musculus* Schwarz and Schwarz, 1943), black rat (*Rattus rattus* (Linnaeus, 1758)), and brown rat (*R. norvegicus* (Berkenhout, 1769)). The primary host of *C. fontinella grisea* is the eastern deer mouse and a few records from creeping vole (*Microtus oregoni* Bachman, 1839), and occasional records from white-footed mouse, meadow jumping mouse (*Zapus hudsonius* (Zimmermann, 1780)) and Townsend's vole (*M. townsendii* (Bachman, 1839)).

Biology:

Cuterebra fontinella is one of the most well-documented species of *Cuterebra* (Hadwen 1915, Gingrich 1981, Pruett and Barrett 1983, Cogley 1991, Wolf and Batzli 2001, Cramer and Cameron 2006, 2007, Jennison et al. 2006). *Cuterebra fontinella* aggregation has been observed and recorded. Both forms of *C. fontinella* were collected from the same aggregation sites, which are creek basin landmarks. Mating of both forms was observed and recorded, but no intra-subspecies mating was observed (Hunter and Webster 1973, Catts 1982, Shiffer 1983). Infested white-footed mice do not show any negative effect on social behaviours and behave significantly more aggressively than the uninfested ones. Additionally, females do not present a significant bias in the male choice between infested or uninfested, which indicates that *C. fontinella* infestation does not cause reproductive costs in male mice (Cramer and Cameron 2007). Gonotrophic development of *C. fontinella* has been extensively studied by Scholl (Scholl 1991). Larvae growth is biphasic like *C. emasculator* (Cogley 1991). Hunter and Webster reported that adults survived up to eight days after mating (Hunter and Webster 1973).

Distribution:

See Map. 2. In Canada, *C. fontinella* specimens were collected from British Columbia: Anderson Lake, Coquitlam, Courtenay, Cowichan Lake, Langford, Peachland, Saratoga Beach, Seton Lake, Seymour, Vancouver Island and West Creston; Ontario: Belleville, Brantford, Cooksville, Gloucester, Marmara, Ottawa, Rockwood, Stanley Corner, Vernon; Quebec: Aylmer; Nova Scotia: Cape Breton Highlands National Park, Kenloch.

Remarks:

Cuterebra fontinella is a small species of *Cuterebra* , which can be easily recognized by the heavy white pruinosity on abdominal tergite 5. Based on the combination of scutum hair coloration and the presence of pleural spots, *Cuterebra fontinella* was descriptive as four different species (Clark 1828, Coquillet 1898, Dalmat 1942). Sabrosky discovered a few intermediate forms (Sabrosky 1986), and I also examined intermediate individuals in the specimens at my disposal. I believe these two characters are intraspecies variation, and treat *C. grisea*, *C. peromysci* and *C. angustifrons* as junior synonyms of *C. fontinella*. In the original description of *C. fontinella,* " a black chest with white sides," "the thorax flat in the middle and hairy on the sides, white marked with three black dots on each side," and "abdomen short, dark shiny, shining violet above; the last two segments hairy, whitish and raised with various black points, glabrous." (Clark, 1828; translated from Latin) Thus, I treat the individuals with black scutum and with pleural spots as the common form.

Material examined:

See Supplementary Material. I examined 60 Canadian specimens from CNC.

6.6 ***Cuterebra polita*** Coquillett, 1898: 10

Diagnosis:

Facial plate with a strong vertical ridge. Gena dark brown, bare, or microsetose, without facial spot. Mesopleuron covered with white hairs and black hair spots in males, and with black hair tuft on females. Upper calypter margin with short white hairs on the basal portion. Tibia dark brown, with white micromentum on the basal portion. Abdomen completely glossy purplish brown, with little or without microtomentose pattern. Abdominal tergite 5 with short black hairs, without microtomentum.

Description (figs. 59-61):

Body Length: 14-15 mm. **Wing Length:** 12-13 mm.

Head: frontal vitta dark brown, with sparse black microsetose; fronto-orbital plate brown, punctate and sparse black microsetose, without or with up to two pairs of orbital spots; lunule dark brown to black, thin and bare; arista pectinate; flagellum amber to brown, microsetose; pedicel dark brown with 4-6 black hairs; facial plate predominantly smooth glossy and tapered ventrally, with a strong vertical ridge on the midline; gena brown and microsetose; labium tubular and concealed in gena slit; palps absent.

Thorax: Mesoscutum predominantly dark brown cuticle, covered with black hairs; scutellum strongly projecting posteriorly, dorsally with black hairs, and ventrallywith white pruinosity; wing membrane completely brownish infuscated; wing vein amber to brown; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter infuscated and folded, with dark brown edge and dense white fringe on the basal; lower calypter infuscated and slightly convex, with dark brown edge and thin brown fringe; legs cuticle reddish brown; femur and tibia predominantly covered with black hairs; femur laterally compressed; tibia with dense black hair fringe dorsally and ventrally, basal portion no hairs, with white pruinosity; tarsomeres flattened, with dense black hair tufts posterolaterally.

Abdomen: oval and cuticle reddish brown; abdominal tergite 2 dorsally with white hairs, laterally with little or without microtometose; abdominal tergites 2-5 black microsetose; abdominal sternites with black hairs.

Male: frontal vitta and fronto-orbital plate narrow, around ¼ of the head width; pleuron covered with a whitish yellow hair tuft (fig. 62).

Female: frontal vitta and fronto-orbital plate broad, around ½ of the head width; pleuron covered with black hairs (fig. 62).

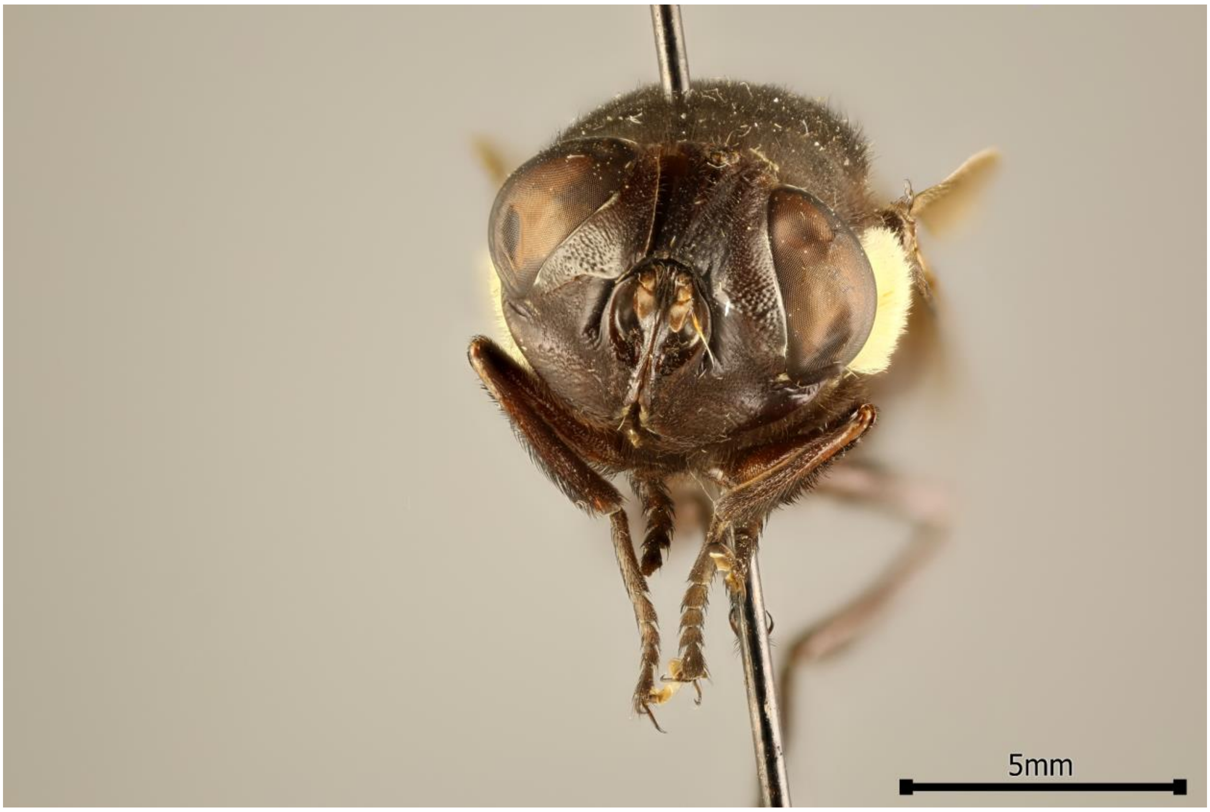


Fig. 59: Anterior view of male *Cuterebra polita* (specimen code: CNC-2133).

Fig. 60: Dorsal view of male *Cuterebra polita* (specimen code: CNC-2133).

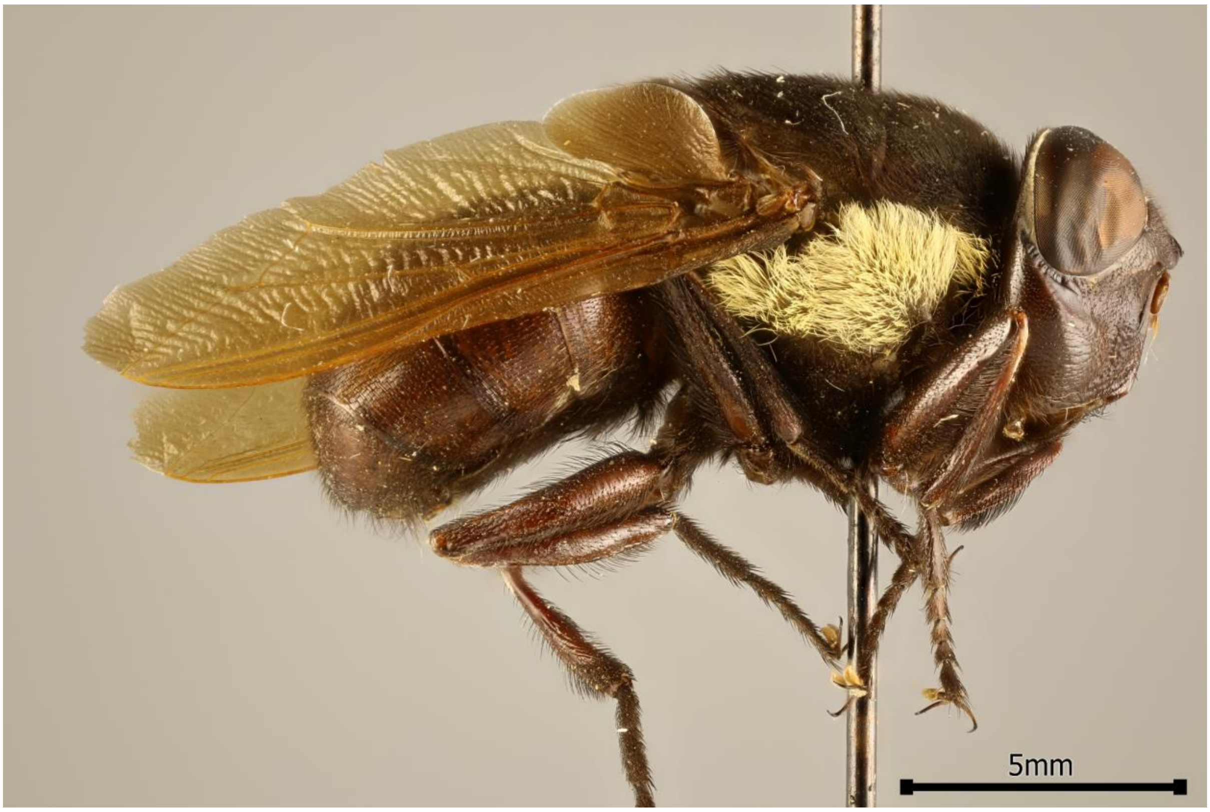


Fig. 61: Lateral view of male *Cuterebra polita* (specimen code: CNC-2133).

Host:

The primary host is the northern pocket gopher (*Thomomys talpoides* (Richardson, 1828)). However, pocket gophers have not been found in Middle Sand Hills, but *Cuterebra polita* is found there. Hansen (1960) suggested that *C. polita* may infest Ord's kangaroo rats (*Dipodomys ordii* Woodhouse, 1853) as their primary host in Middle Sand Hills. Sabrosky (1986) believe it is misidnetification, because *Cuterebra polita* had not been found in any other host besides pocket gopher.

In the laboratory, deer mice (*Peromyscus maniculatus*), domestic mice (*Mus musculus*), hamsters (*Mesocricetus auratus*), and meadow voles (*Microtus montanus*) were artificially infested with *C. polita,* which did not show a significant difference in development time, but larvae establishment rate is different between hosts (Capelle 1970).

Biology:

Cuterebra polita has been observed in male aggregations at steep slope sites (Graham and Capelle 1970, Catts 1982). Adult females laid their eggs on the rock or vegetation about 20 cm above the gopher burrow, which may visually found by *C. polita* (since CO_2 bait traps failed to collect them) (Catts 1969, Capelle 1970).

The parasitic sites are usually found on the ventral surface of the gopher in the wild (Richens 1965, Graham and Capelle 1970). Females produce 883 to 1243 eggs, and larvae develop in the host from 18 to 24 days (Capelle 1970).

Distribution:

See Map. 2. In Canada, *Cuterebra polita* specimens were collected from: British Columbia: Aspen Grove, Douglas Lake; Alberta: Suffield.

Remarks:

Cuterebra polita is apparently the smallest *'americana* group' species, and one of the smallest in the genus *Cuterebra* (~ *C. fontinella* and *C. emasculator*). Beside the size, morphological characters are highly similar to *C. approximata*. Females are slightly larger than males. In rare cases, the female abdomen has little microtometose laterally, but much less so than *Cuterebra approximata.*

Fig. 62. Sexual dimorphism in *Cuterebra polita*, (A) male and (B) female.

Material examined:

See Supplementary Material, I examined 5 Canadian specimens from CNC, including three males and two females.

6.7 *Cuterebra tenebrosa* Coquillett, 1898: 11

Diagnosis:

Facial plate with a strong vertical ridge. Gena dark brown, bare, or microsetose, without facial spot. Mesopleuron covered with white hair tuft and black hair spot in male, and with black hair tuft on females. Upper calypter margin with short brown to black hairs on the basal portion. Tibia dark brown, with white micromentum on the basal portion. Abdomen completely glossy purplish brown, without microtomentose pattern. Abdominal tergite 5 with short black hairs, non-microtomentose.

Description (figs. 63-65):

Body Length: ~20 mm. **Wing Length:** 16-18 mm.

Head: frontal vitta dark brown and sparsely black microsetose; fronto-orbital plate brown, punctate and sparsely microsetose; lunule amber, thin, and bare; arista pectinate; flagellum orange to amber, slightly microsetose; facial plate predominantly smooth glossy and tapered ventrally, with a strong vertical ridge on the midline; gena dark brown with sparse short hairs; palps absent; labium tubular and concealed in gena slit.

Thorax: Scutum and scutellum covered with black hairs but unobscured; cuticle of scutum and scutellum purplish brown; scutellum strongly projecting posteriorly, dorsally with black hairs, and ventrally with white pruinosity; pleuron covered with a dense black hair patch; wing membrane completely brownish infuscated; vein C with dense black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula enlarged and folded more than 90° in relation to the rest of the wing membrane; upper calypter infuscated and folded, with dark brown edge and dense black fringe on the basal; lower calypter infuscated and slightly convex, with dark brown edge and thin brown fringe; legs cuticle dark brown; femur and tibia predominantly covered with black hairs; femur laterally compressed; tibia with dense black hair fringe dorsally and ventrally, basal portion no hairs, with white pruinosity; tarsomeres flattened, with dense black hair tufts posterolaterally.

Abdomen: oval and cuticle purplish brown; abdominal tergite 2 with white hairs dorsally; abdominal tergites 2-5 black microsetose; abdominal sternites with black hairs.

Male: Frontal vitta and fronto-orbital plate narrow, around ¼ of the head width.

Female: Frontal vitta and fronto-orbital plate broad, around ½ of the head width.

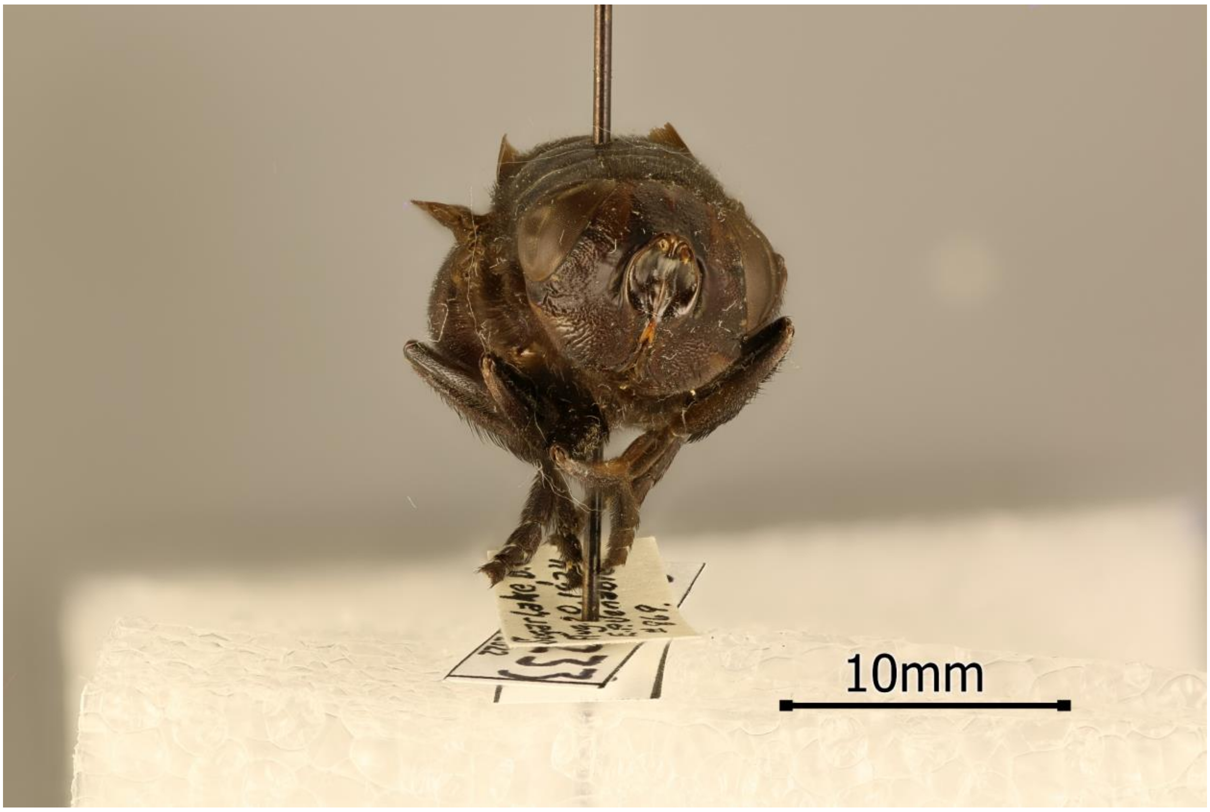


Fig. 63: Anterior view of female *Cuterebra tenebrosa* (specimen code: CNC-2233).

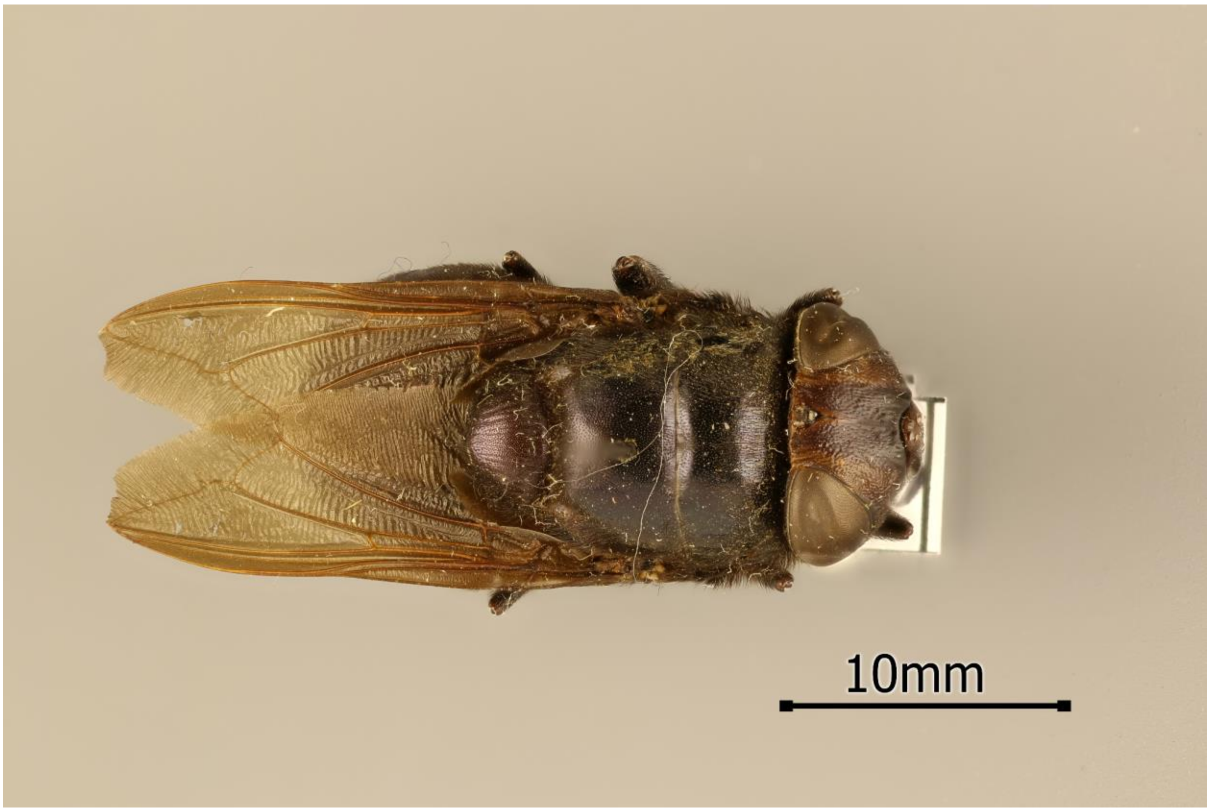


Fig. 64: Dorsal view of female *Cuterebra tenebrosa* (specimen code: CNC-2233).

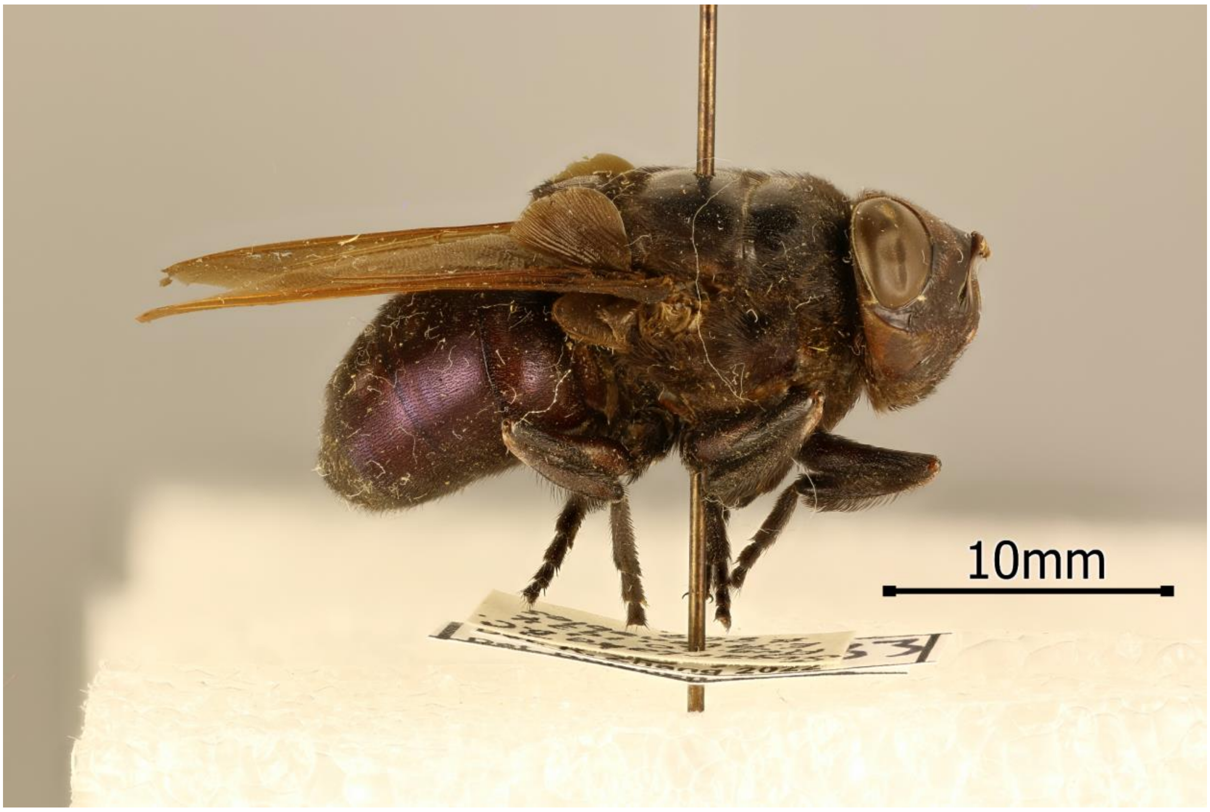


Fig. 65: Lateral view of female *Cuterebra tenebrosa* (specimen code: CNC-2233).

Host:

The primary hosts are bushy-tailed woodrat (*Neotoma cinerea* (Ord, 1815)) and desert woodrat (*Neotoma lepida* Thomas, 1893). From a record in Utah, *Cuterebra tenebrosa* was reared from a black-tailed jackrabbit (*Lepus californicus* (Gray, 1837)); Sabrosky suggests this host record is aberrant (Sabrosky 1986).

Biology:

Cuterebra tenebrosa was studied and illustrated by Baird in 1973, and he widely used it as a study subject in a series of papers (Baird 1972, 1974, 1975, 1979, Baird and Graham 1973). Aggregation behaviours in *Cuterebra tenebrosa* have been observed at cliff face sites (Hunter and Webster 1973, Catts 1982).

Distribution:

Map. 2. In Canada, *Cuterebra tenebrosa* specimens were collected from British Columbia: Creston, Ewings Landing, Kamloops, Keremeos, Salmon Arm, Sugar Lake; Summerland.

Remarks:

Cuterebra tenebrosa is the only Canadian species in the '*americana* group' where the male is completely black setose and not sexual dimorphic. The female is hard to differentiate from *C. approximata* and *C. polita*. Sabrosky described a closely related species, *C. tenebriformis* that is only found in California and Nevada, and can only be differentiated from the shape of the 2nd tarsomere (Sabrosky 1986). Limited by the capacity of this research, I did not examine the USA *C. tenebriformis* specimen, and I did not find any Canadian specimens that fit his description.

Material examined:

In total, I examined 21 Canadian specimens from CNC, including eight males and thirteen females.

7. *Gasterophilus* Leach, 1817: 2

Current global taxonomy:

Seven species are recognized worldwide:

Gasterophilus haemorrhoidalis (Linnaeus, 1758): 584
Gasterophilus inermis Brauer, 1858: 464
Gasterophilus intestinalis (De Geer, 1776): 292
Gasterophilus meridionalis Pillers and Evans, 1926: 264
Gasterophilus nasalis (Linnaeus, 1758): 584
Gasterophilus nigricornis Loew, 1863: 38
Gasterophilus pecorum (Fabricius, 1794): 230

Diagnosis:

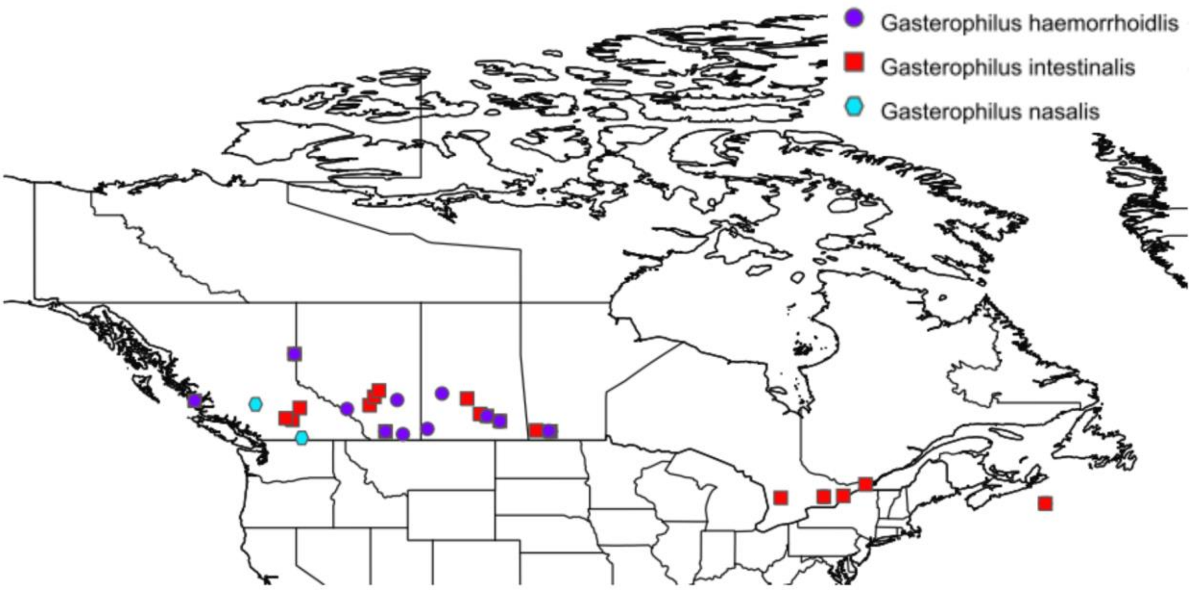
Arista bare. Facial plate margins converge ventrally. Gena cuticle whitish yellow to orange, with sparse to medium-dense yellow hairs. Scutellum short and semicircular, with dense whitish yellow to orange hairs dorsally. Wing membrane completely transparent or with infuscated patches. Vein M curved, ending before wing apex, and no extension crossing with crossvein dm-m. Abdomen tapered and bent ventrally from abdominal segment 3; cuticle amber unobscured with black microsetae, or concealed within long yellow hairs. Female with a scalloped-shaped ovipositor.

Biology:

Gasterophilus are exclusively parasites of the genus *Equus*. Except for Grévy's zebra (*E. greyi* Oustalet) and Tibetan wild ass (*E. kiang* Moorcroft), all other *Equus* have been recorded as hosts of *Gasterophilus* spp. (Colwell et al. 2006, Li et al. 2019). Females lay eggs on the hairs of the host, and eggs hatch spontaneously or are stimulated by the moisture from the host licking. Larvae live in the gastrointestinal system of the host. Third-instar larvae leave the host from the anus and pupate under excrement piles (Zumpt 1965, Colwell et al. 2006). Adult lifespan lasts 7 to 28 days (Li et al. 2019).

Distribution:

Species of *Gasterophilus* are mostly Afrotropical, except *Gasterophilus nigricornis*, which is restricted to the middle and far east (Li et al. 2019). In Canada, three cosmopolitan species, *Gasterophilus haemorrhoidalis*, *Gasterophilus intestinalis,* and *Gasterophilus nasalis* can be found (Map 3).



Map. 3: Distribution of *Gasterophilus* spp. in Canada.

Identification Key to Adult *Gasterophilus* of Canada:

1). Wing membrane with infuscated patches (fig. 66 B); female abdomen dull yellow, with brown patches; male cercus elongated, exposed from abdominal tergite (fig. 72) ……………………………………………………***Gasterophilus intestinalis*** (De Geer, 1776)

1'). Wing entirely transparent (fig. 66 A & C); female abdomen brown or black, without patches, male cercus short, concealed by abdominal tergite 5 ……………………..………2

2). Gena light yellow (fig. 67); flagellum red or brown (fig. 67); crossvein r-m distally separated from dm-m (fig. 66 A) …………… ***Gasterophilus haemorrhoidalis*** (Linnaeus, 1758)

2’). Gena yellow or amber (fig. 73); flagellum yellow or orange (fig. 73); crossvein r-m aligned with crossvein dm-m on vein m (fig. 66 C) ... ***Gasterophilus nasalis*** (Linnaeus, 1758)

Fig. 66: Wing veins r-m and dm-m structure and infuscate patches of wing membrane on (A) *Gasterophilus haemorrhoidalis,* (B) *G. intestinalis* and (C) *G. nasalis.*

7.1 *Gasterophilus haemorrhoidalis* (Linnaeus, 1758): 584

Diagnosis:

Flagellum red or brown. Gena cuticle whitish yellow. Wing membrane completely transparent. Crossvein r-m separate from dm-m distally. Abdominal cuticle black.

Description (figs. 67-69):

Body Length: 8-14 mm. **Wing Length:** 7-9 mm.

Head: fronto-orbital plate white and hollow, with yellow frontal setae; frontal vitta white and ridged; lunule white to whitish yellow, thick, and bare; arista bare; flagellum red or brown, with whitish pruinosity; facial plate with whitish yellow hairs, ventrally tapered; gena cuticle white or white yellow, with sparse to medium dense whitish yellow hairs; labium and palpi atrophied, as small knobs behind facial plate ventrally.

Thorax: mesoscutum with dense yellow hairs, with black haired band between wing base; notopleural hair tuft whitish yellow; mesopleuron with dense whitish yellow hairs; scutellum dark yellow, short and semicircular, dorsally with dense white or whitish yellow hairs, ventrally white microsetose; vein C and vein Sc with dense black hairs laterally; crossvein r-m separate from crossvein dm-m distally; alula small and folded dorsal over 90° in relation to the rest of the wing membrane; lower calypter semi-transparent or white, with white hairs on the margin; femur dorsally black and ventrally dull yellow, basally with long white hairs; tibia dull yellow, with white hairs.

Abdomen: abdominal tergites 1-2 with long white or light yellow hairs; abdominal tergites 3-4 brown or black, with sparse hairs or with dense yellow hairs, tapered and bent ventrally; abdominal sternites yellow, with whitish yellow hairs.

Male: frons about ¼ width of the head width; abdominal tergite 5 with dense; terminalia (abdominal segment 6-8) concealed in abdominal tergite 5.

Female: frons wider than ½ width of the head width; abdominal tergite 5 with yellow hairs; terminalia (segment 6-8) black or brown, with sparse hairs or bare, elongated and tubular, extended from abdominal tergite 5.

Fig. 67: Anterior view of male *Gasterophilus haemorrhoidalis* (specimen code: CNC-3037).

Fig. 68: Dorsal view of male *Gasterophilus haemorrhoidalis* (specimen code: CNC-3037).

Fig. 69: Lateral view of male *Gasterophilus haemorrhoidalis* (specimen code: CNC-3037).

Host:

The primary hosts of G. *intestinalis* include domestic donkey (*E. africanus asinus*), domestic horse (*E. ferus caballus*), Mongolia wild ass (*E. hemionus hemionus*) and wild horse (*E. przewalskii*) (Colwell et al. 2006, Li et al. 2019). In rare cases, predators have been recorded with infestations, presumably by accidentally eating bot fly larvae while feeding on *Equus* prey (Ganjali and Keighobadi 2016).

Biology:

The female *Gasterophilus haemorrhoidalis* deposits 50-200 eggs on the hairs around the lips of the host, and the hatching of the egg is stimulated by the host's moisture and heat (Dove 1918, Colwell et al. 2006, Li et al. 2019). The 1st instar larvae penetrate the epidermis of the lip and migrate into the esophagus. The 2nd instar larvae move and develop in the stomach and duodenum. The 3rd instar larvae migrate to the rectum and leave the host from anal and pupate on the ground (Colwell et al. 2006, Li et al. 2019). The pupal period is from 15-26 days, and the adult longivity is about 1-7 days (Dove 1918, Colwell et al. 2006, Li et al. 2019).

Distribution:

See Map. 3. In Canada, specimens are collected in British Columbia: Aspen Grove, Chilcotin, Kamloops, Knutsford, Rolla, Savona, Vavenby; Alberta: Lacolme, Lethbridge, Olds, Wetaskiwin; Saskatchewan: Aberdeen, Earl Grey, Indian Head, Maple Creek, Last Mountain Lake; Manitoba: Aweme; Ontario: Dobbinton, Lyndhurst, Marmora; Quebec: Rigaud Mountain; Nova Scotia: Sable Isle.

Remarks

Gasterophilus haemorrhoidalis is similar to *Gasterphilus nasalis* in adult morphology. However, the larval morphology and biology indicates that they are two species (Colwell et al. 2006, Li et al. 2019). The key characteristic distinguishing it from *G. nasalis* is the connection of crossveins r-m and dm-m. Seven specimens have a vestigial crossvein dm-m. As an alternative character to differentiate these two species in cases where crossvein dm-m is vestigial, I use the colouration of gena (whitish yellow in *G. haemorrhoidalis,* orange in *G. nasalis*).

Material examined:

In total, I examined 96 specimens of *G. intestinalis* from the CNC collection, including 63 females and 33 males.

7.2 *Gasterophilus intestinalis* (De Geer, 1776): 584

Diagnosis:

Flagellum yellow or orange. Wing membrane with infuscate patches on the distal side of crossveins r-m, dm-m, and wing tip. Crossvein r-m join dm-m distally. Abdominal cuticle yellow to amber.

Description (figs. 70-72):

Body Length: 13-23 mm. **Wing Length:** 10-12mm.

Head: fronto-orbital plate predominantly amber and hollow, with whitish yellow or black frontal setae, cuticle whitish yellow close to the orbital edge; frontal vitta white and ridged; lunule whitish yellow or yellow, thick and bare; arista bare; flagellum red or brown, whitish pruinose; facial plate with whitish yellow hairs, ventrally tapered; gena cuticle white or white yellow, with sparse to medium dense whitish yellow hairs; labium and palpi atrophied, as small knobs behind facial plate ventrally.

Thorax: mesoscutum with dense yellow hairs, with black haired band between wing base; notopleural hair tuft whitish yellow; mesopleuron with dense golden yellow hairs; scutellum dark yellow, short and semicircular, dorsally with dense white or whitish yellow hairs, ventrally white microsetose; vein C and vein Sc with dense black hairs laterally; crossvein r-m join crossvein dm-m distally; cell r_{4+5}, dm and wing tip with infuscate patches;alula small and folded dorsal over 90° in relation to the rest of the wing membrane; lower calypter semi-transparent or white, with white hairs on the margin; femur dull yellow, basally with long whitish yellow hairs; tibia dull yellow, with black hairs.

Abdomen: cuticle yellow to amber; abdominal tergites 1-2 with long white or whitish yellow hairs; abdominal tergites 3-5 with sparse short black and yellow hairs; abdominal tergite 3 tapered and bent ventrally; abdominal sternites dull yellow to dark yellow, with short black hairs.

Male: Frons about ¼ width of the head width; abdominal tergite 5 with dense; terminalia (abdominal segment 6-8) concealed in abdominal tergite 5.

Female: Frons wider than ½ width of the head width; abdominal tergite 5 with yellow hairs; terminalia (segment 6-8) black or brown, with sparse hairs or bare, elongated and tubular, extended from abdominal tergite 5.

Fig. 70: Anterior view of male *Gasterophilus intestinalis* (specimen code: LEM0095514).

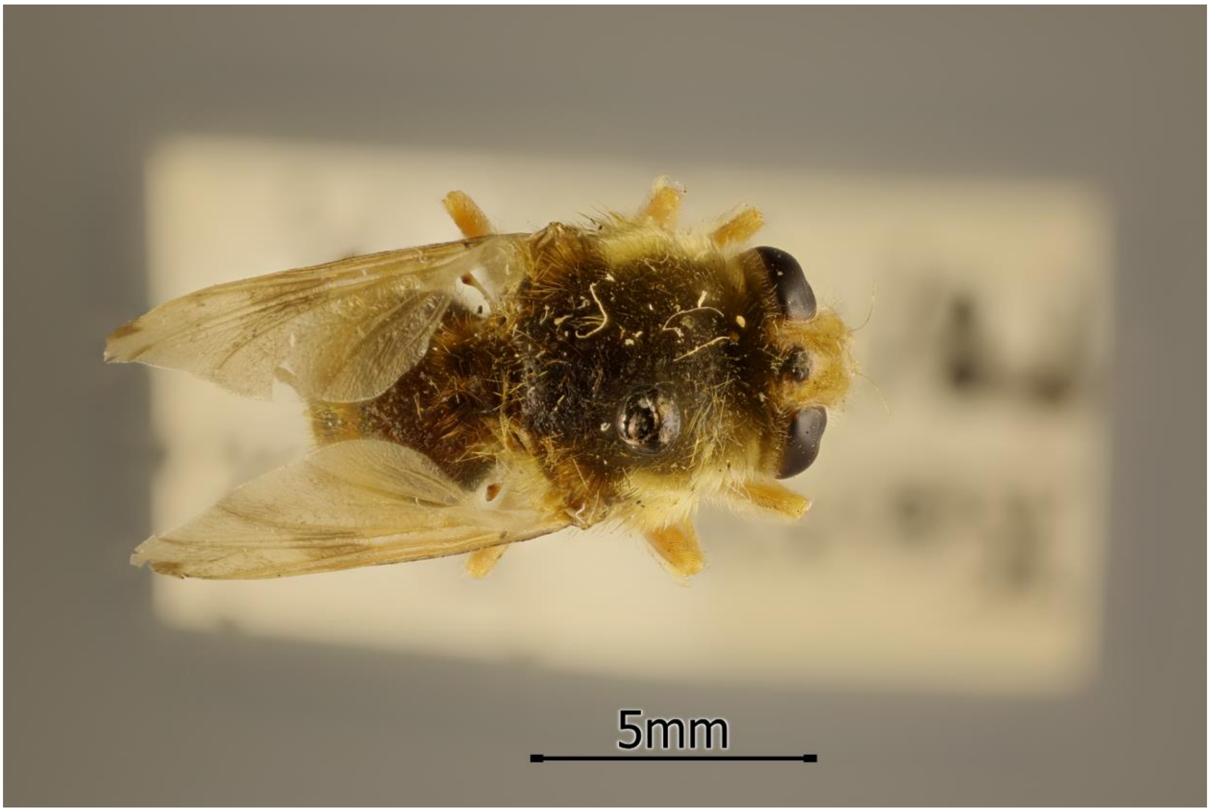


Fig. 71: Dorsal view of male *Gasterophilus intestinalis* (specimen code: LEM0095514).

Fig. 72: Lateral view of male *Gasterophilus intestinalis* (specimen code: LEM0095514).

Host:

The primary hosts of *G. intestinalis* include domestic donkey (*E. africanus asinus*), domestic horse (*E. ferus caballus*), Mongolia wild ass (*E. hemionus hemionus*) and wild horse (*E. przewalskii*) (Colwell et al. 2006, Li et al. 2019). Rarely, predators get infested by accidentally eating larvae with *Equu* as prey (Ganjali and Keighobadi 2016).

Biology:

Females of *Gasterophilus intestinalis* deposit 400-1000 eggs on the hairs of the forelegs and chest of the host (Cogley 1991, Colwell et al. 2006, Li et al. 2019). Egg hatching is stimulated by the moisture and heat of the host. The 1st instar larvae penetrate the skin at the hatching site and migrate subcutaneously. The 3rd larvae are usually found in rectum, and leave through anal (Colwell et al. 2006). Pupal duration is between 22-28 days and adult longivity is between 7-21 days (Dove 1918, Colwell et al. 2006, Li et al. 2019).

Distribution:

See Map. 3. In Canada, specimens are collected in British Columbia: Aspen Grove, Chilcotin, Kamloops, Knutsford, Rolla, Savona, Vavenby; Alberta: Lacolme, Lethbridge, Olds, Wetaskiwin; Saskatchewan: Aberdeen, Earl Grey, Indian Head, Maple Creek, Last Mountain Lake; Manitoba: Aweme; Ontario: Dobbinton, Lyndhurst, Marmora; Quebec: Rigaud Mountain; Nova Scotia: Sable Isle.

Remarks

Gasterophilus intestinalis obviously larger than the other 2 species of Canadian *Gasterophilus*. It can also be easily recognized by the uniquely patched wings and dull yellow patterns on abdomen. The black band on the postsutural scutum is not obvious; in many individuals, it is a patch with mixed yellow and black hairs on the postsutural scutum.

Material examined:

In total, I examined 96 specimens of *G. intestinalis* from the CNC collection, including 63 females and 33 males.

7.3 *Gasterophilus nasalis* (Linnaeus, 1758): 584

Diagnosis:

Flagellum yellow or orange. Wing membrane completely transparent. Crossvein r-m join dm-m distally. Abdominal cuticle black.

Description (figs. 73-75):

Body Length: 11-16 mm. **Wing Length:** 9-11 mm.

Head: fronto-obital plate yellow to dark yellow, with yellow or black frontal setae; frontal vitta dark yellow, ridged; lunule white to whitish yellow, thick, and bare; arista bare; flagellum yellow or orange; facial plate with whitish yellow hairs, ventrally tapered; gena cuticle yellow to orange, with sparse to medium dense whitish yellow hairs; labium and palpi atrophied, as small knobs behind facial plate ventrally.

Thorax: mesoscutum with dense yellow or amber hairs, with or without black haired band between wing base; notopleural hair tuft whitish yellow; mesopleuron with dense yellow or amber hairs; scutellum dark yellow, short and semicircular, dorsally with dense yellow or amber hairs, ventrally white microsetose; vein C and vein Sc with dense black hairs laterally;

crossvein r-m separate from crossvein dm-m distally; alula small and folded dorsal over 90° in relation to the rest of the wing membrane; lower calypter semi-transparent or white, with white hairs on the margin; femur dark yellow, basally with long white hairs; tibia dull yellow, with white hairs.

Abdomen: abdominal tergites 1-2 with long white or whitish yellow hairs; abdominal tergites 3-4 brown or black, with sparse hairs or with dense yellow hairs, tapered and bent ventrally; abdominal sternites yellow, with whitish yellow hairs.

Male: frons about ¼ width of the head width; abdominal tergite 5 with dense; terminalia (abdominal segment 6-8) concealed in abdominal tergite 5.

Female: frons wider than ½ width of the head width; abdominal tergite 5 with yellow hairs; terminalia (segment 6-8) black or brown, with sparse hairs or bare, elongated and tubular, extended from abdominal tergite 5.

Fig. 73: Anterior view of male *Gasterophilus nasalis* (specimen code: CNC-3188).

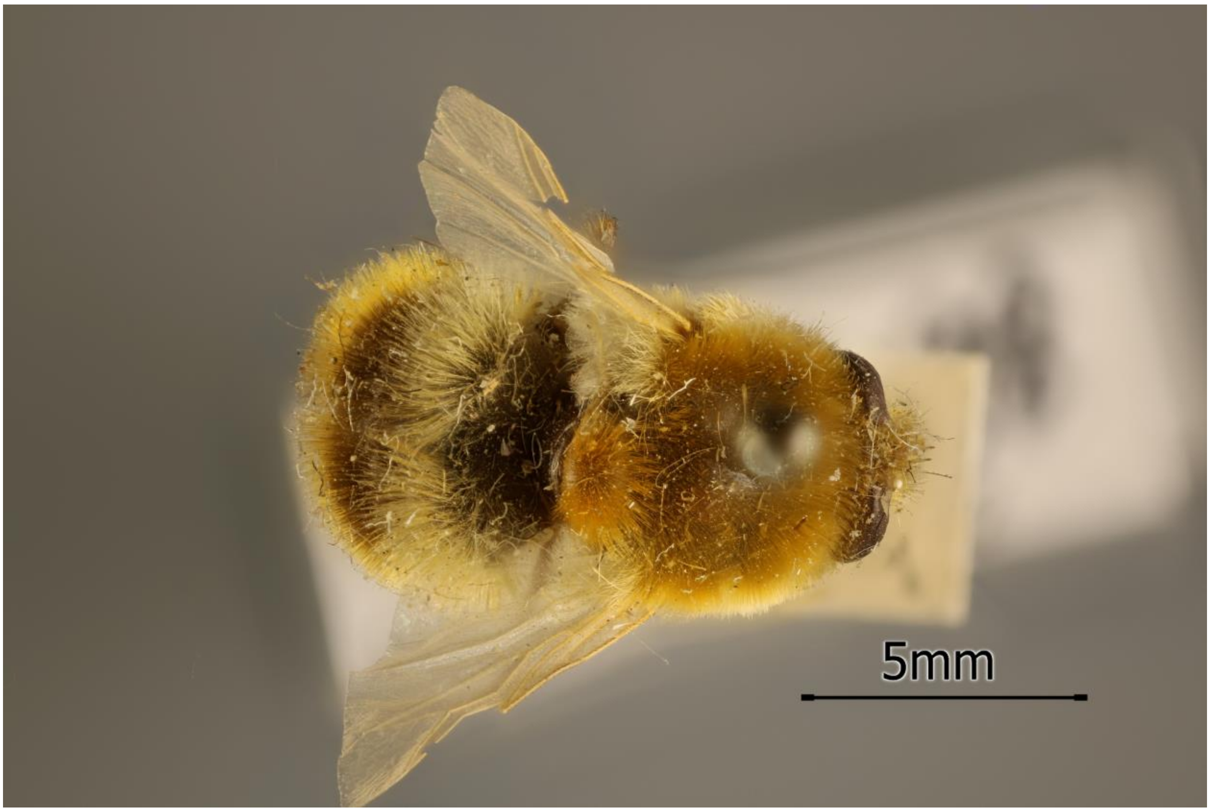


Fig. 74: Dorsal view of male *Gasterophilus nasalis* (specimen code: CNC-3188).

Fig. 75: Lateral view of male *Gasterophilus nasalis* (specimen code: CNC-3188).

Host:

The primary hosts of *G. nasalis* include Burchell's zebra (*E.quagga burchellii*), domestic horse (*E.ferus caballus*), donkey (*E.africanus asinus*), Mongolian wild ass (*E.hemionus hemionus*) and wild horse (*E.przewalskii*) (Colwell et al. 2006, Li et al. 2019).

Biology:

Females of *Gasterphilus nasalis* deposit 300-500 eggs on the hairs under the chin of the host. The eggs hatch spontaneously (Cogley 1991, Colwell et al. 2006, Li et al. 2019). The 1st instar larvae migrate along the surface to interdental spaces of the host, and moult to 2nd instar in the interdental spaces (Colwell et al. 2006, Li et al. 2019). The 2nd instar larvae migrate and attach to duodenum. The 3rd instar larvae leave the host via the anus and pupate on the ground. Pupal duration is between 16-24 days, and adult longevity is between 1-12 days (Dove 1918, Colwell et al. 2006, Li et al. 2019).

Distributions:

See Map. 3. In Canada, specimens are collected in British Columbia: Chilcotin, Oliver; Saskatchewan: Indian Head; Manitoba: Aweme; Ontario: Marmora; Nova Scotia: Sable Isle.

Remarks:

Gasterophilus nasalis is similar to *G. haemorrhoidalis*. Hair colouration is varied between individuals. There are 11 specimens (8 males and 3 females) without black bands on the mesonotum (fig. 76). Darker colour are more effective in absorbing solar heat, thus insect in colder environments or high latitude regions tent to present more melanism, which known as thermal melanin hypothesis (Fedrka et al. 2013). However, the distribution of the black banded individual and non-banded are irregular in Canada, can not be simply explain with thermal melanin hypothesis.

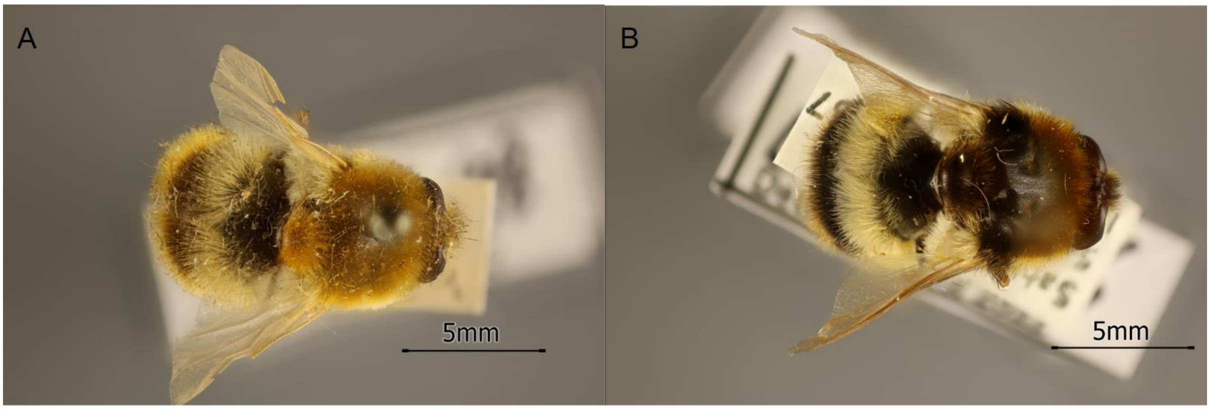


Fig. 76: Two *G. nasalis* male. A. black-haired bands on mesonotum; B: with black-haired bands on mesonotum.

Material examined:

In total, I examined 42 specimens of *G. nasalis* from the CNC collection, including 12 females and 30 males.

8. ***Hypoderma*** Latreille, 1818: 272

Current global taxonomy:

Eleven species are recognized worldwide:

Hypoderma actaeon Brauer 1858: 396
Hypoderma bovis (Linnaeus, 1758): 584
Hypoderma capreola Rubtsov 1940: 118
Hypoderma desertorum Brauer 1897: 377
Hypoderma diana Brauer 1858: 397
Hypoderma lineatum (Villers, 1789): 349
Hypoderma moschiferi Brauer 1863a: 281
Hypoderma qinghaiensis Fan 1982: 197
Hypoderma sinense Pleske 1926: 220
Hypoderma tarandi (Linnaeus, 1758): 584
Hypoderma wui Xue & Zhang 1996: 234

Diagnosis:

Arista bare. Facial plate margins parallel ventrally. Gena with dense yellow hairs. Scutellum short and semicircular, with dense hairs yellow dorsally. Wing membrane completely transparent. Vein M curved, ending before wing apex, and no extension crossing with crossvein dm-m. Abdomen conical, with dense black, yellow, or orange hairs. Female with a tubular ovipositor.

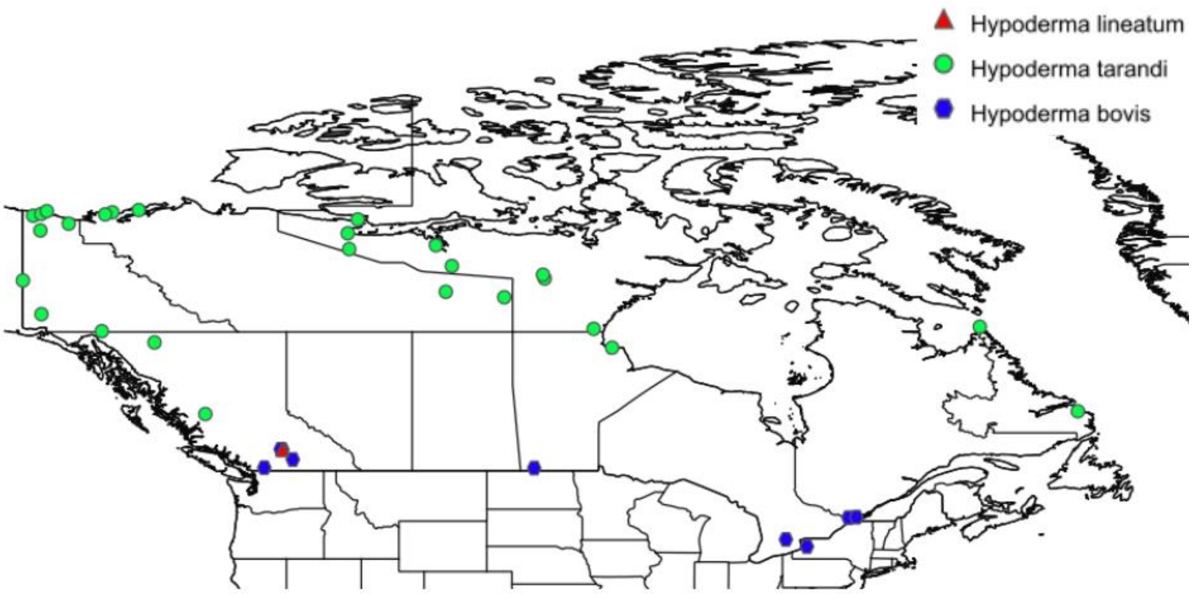
Biology:

Hypoderma are parasites of the infraorder Pecora. In Canada, they are parasites of deer (Cervidae) and cattle (Bovidae) (Wood 1987, Cortinas and Jones 2006). Females stick the eggs on the hairs of the host, chiefly on the flank, legs, or hip (Breevui and K. A 1940, Cortinas and Jones 2006). First instar larvae penetrate the skin and migrate inside the host. Second and third instar larvae eventually reach the subcutaneous tissue in the back

(Weintraub et al. 1959, Weintraub 1961). Mature larvae emerge through the breathing holes and pupate in the soil (Weintraub et al. 1959, Weintraub 1961). Adult life is less than one week (Zumpt 1965, Colwell 2001). The whole lifecycle completes in 1 year (Weintraub et al. 1959, Cortinas and Jones 2006).

Distribution:

Hypoderma are primarily found in Eurasia, with two cosmopolitan species, *Hypoderma bovis* and *Hypoderma lineatum*, and one Holarctic species, *Hypoderma tarandi* being found in Canada.



Map. 4: Distribution of *Hypoderma* spp. in Canada.

Remarks:

Latreille considered *Hypoderma* as two genera, *Hypoderma* and *Oedemagena* (Latreille 1818). Genus *Oedemagena* was a monotypic genus, with only *O. tarandi* (Zumpt 1965). The only diagnostic character that differentiates these two genera is the presence (in

Hypoderma) or absence (in *Oedemagena*) of palpi (Zumpt 1965, Wood 1987). They were later combined in the genus *Hypoderma*, as two subgenera, *Hypoderma* and *Oedemagena.*

Except *Hypoderma bovis*, *Hypoderma lineatum* and *Hypoderma tarandi*, *Hypoderma* spp. have not been categorized into any subgenera. I do not have enough morphological and phylogenetic information on these species to review the concept of subgenera. Thus, for this taxonomy review, I am not treating three Canadian *Hypoderma* spp. separately, and consider *Oedemagena* a junior synonym of *Hypoderma*.

Identification Key to Adult *Hypoderma* of Canada:

1) Palpi as a pair of conspicuous oranges knobs (fig. 77 C & F); scutellum with a thin and haired posterior margin (fig. 78 B); abdomen without black hair band (figs. 86 and 87) ………………………….………………………… ***Hypoderma tarandi*** (Linnaeus, 1758)

1') Palpi concealed behind labium (fig. 77 A, B, E & D); scutellum with a thick and polished posterior margin (fig. 78 A); abdominal tergite 3 covered with black hairs …………..…..2).

2) Labium monocuspid (fig. 77 A & D); notopleural hair tuft whitish yellow (fig. 81); mesopleural hairs yellow (fig. 81) ……………………… ***Hypoderma bovis*** (Linnaeus, 1758)

2') Labium bicuspid (fig. 77 B & E); notopleural hair tuft black (fig. 84); mesopleural hairs white (fig. 84) ………………...………………………. ***Hypoderma lineatum*** (Villers, 1789)

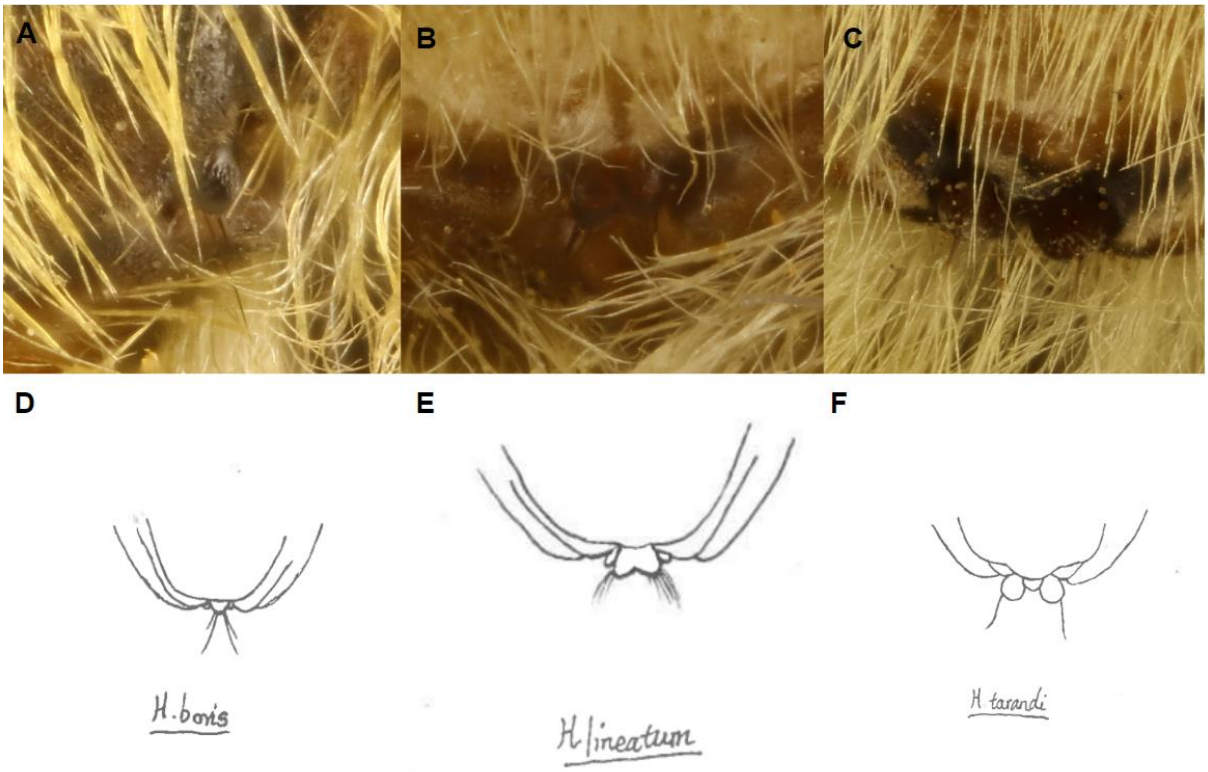


Fig. 77: Photos (A-C) and sketches (D-F) of mouthpart structures of Canadian *Hypoderma: H. bovis* (A and D), *H. lineatum* (B and E) and *H. tarandi* (G and F).

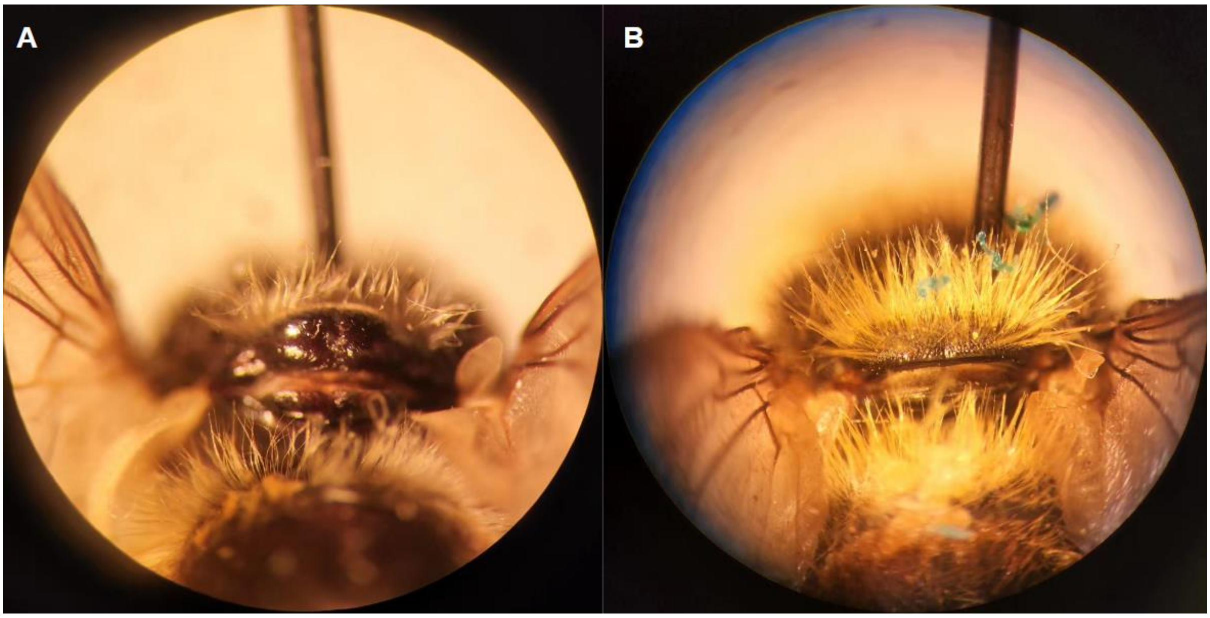


Fig. 78: Posterior scutellum of *H. bovis* (A) and *H. tarandi* (B).

8.1 ***Hypoderma bovis*** (Linnaeus, 1758): 584

Diagnosis:

Labium atrophied and monocuspid. Palpus smaller than labium and concealed behind. Presutural scutum densely black microsetose, with four longitudinal glossy black cuticular stripes. Notopleural hair tuft yellow. Mesopleuron with dense yellow hairs. Abdomen concealed in dense long hairs, with a black cross band on abdominal tergite 3. Abdominal tergite 5 with yellow to yellowish orange hairs.

Description (figs. 79-81):

Body Length: 12-15 mm. **Wing Length**: ~10 mm.

Head: fronto-orbital plate board and punctate, with golden yellow frontal setae; frontal vitta concealed in frontal setae; lunule black, thin and bare; arista bare; flagellum glossy brown, round; pedice glossy brown, bare; facial plate subquadrate, light brown, ventrally covered with dense whitish yellow hairs and margin parallel; gena narrow, with dense whitish yellow hairs; labium atrophied and monocuspid apically, with two pairs of hairs; palpi concealed behind labium.

Thorax: presutural and postsutural scutum densely black microsetose, with four longitudinal glossy black cuticular stripes; notopleural hair tuft yellow; mesopleuron with dense yellow hairs; scutellum short and semicircular, dorsally yellow haired, with a thick and polished posterior margin; wing membrane completely transparent; wing veins dull yellow to brown; vein C with black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula small and folded dorsal over 90° in relation to the rest of the wing membrane; upper calypters crumpled, with white hairs on margin; lower calypters round, white or semi-transparent, with short white on margin; femur black, ventrally with dense black hairs; tibia dark yellow, with black hairs; tarsomeres with pairs of bristles posterolaterally.

Abdomen: abdominal tergite 2 with dense whitish yellow hairs dorsally; abdominal tergite 3 with dense black hairs; abdominal tergite 4 and 5 with dense yellow hairs; abdominal sternites with little white pruinosity, and dense dark yellow hairs.

Male: frons apparently narrower than the width of one compound eye; terminalia bunt.

Female: frons apparently wider than the width of one compound eye; terminalia extended, abdominal segments 6, 7 and 8 forming a tubular ovipositor.

Fig. 79: Anterior view of male *Hypoderma bovis* (specimen code: CNC-4123).

Fig. 80: Dorsal view of male *Hypoderma bovis* (specimen code: CNC-4123).

Fig. 81: Lateral view of male *Hypoderma bovis* (specimen code: CNC-4123).

Host:

The primary host of *Hypoderma bovis* is domestic cattle (*Bos taurus*) (Zumpt 1965, Cortinas and Jones 2006). Occasionally, *Hypoderma bovis* have been found to infest humans and other mammals, almost certainly by accident (Kalelioğlu et al. 1989, Erol et al. 2000, Zygutiene et al. 2006).

Biology:

Females of *H. bovis* deposit a single egg at the base of a hair by flicking out its ovipositor (Weintraub 1961). Newly hatched larvae penetrate the skin and enter the host body. During the winter, larvae migrate through the spinal canal, and third-stage larvae arrive beneath the skin of the back (Patton 1936, Wood 1987, Cortinas and Jones 2006). In the spring, mature larvae emerge from the breathing hole on the skin, drop to the ground and pupate. The pupal period lasts from 24 to 70 days, and adults only last for 3-15 days (Zumpt 1965, Breyev 1971).

Distribution:

See Map. 4. In Canada, specimens are collected from: British Columbia: Kamloops; Agassiz; Kelowna; Mission Flats. Manitoba: Whitewater. Ontario: Embrun; Guelph; Glengarry. Nova Scotia: Clarence.

Remarks:

Hypoderma bovis and *Hypoderma lineatum* are highly similar in adult morphology. *Hypoderma bovis* have a monocuspid labium, are slightly larger, and the prescutum has yellow hairs; *Hypoderma lineatum* have a bicuspid labim, and it is smaller and has dark yellow to black on the presutural scutum. Based on larval morphology, genetic analysis, and biology, *Hypoderma bovis* and *Hypoderma lineatum* are definitively two separate species despite the similarity of adult morphology (Colwell et al. 1998, Otranto et al. 2003, Weigl et al. 2010).

Linnaeus confused *Hypoderma bovis* and *Gasterophilus intestinalis.* Four specimens (one of them may be the type specimen of *H. ovis*) of the Linnean Collection (LINN 3011-3014), which were identified as *Oestrus bovis,* are *G. intestinalis*. The identification of specimens needs to be corrected.

Material examined:

See Supplementary Material, I examined 62 Canadian specimens from CNC (33 female and 29 male) and 2 specimens form LEM (2 females).

8.2 *Hypoderma lineatum* (Villers, 1789): 349

Diagnosis:

Labium atrophied and bicuspid apically. Palpus smaller than labium and concealed behind. Presutural scutum densely black microsetose, with four longitudinal glossy black cuticular stripes. Notopleural hair tuft black. Mesopleuron with dense white hairs. Abdomen concealed in dense long hairs, with a black cross band on abdominal tergite 3. Abdominal tergite 5 with whitish yellow hairs.

Description (figs. 82-84):

Body Length: 10-12 mm. **Wing Length**: ~9mm.

Head: fronto-orbital plate board and punctate, dorsally dark brown and amber to yellow on lunule portion, with sparse whitish yellow frontal setae; frontal vitta narrow, bare and brown; lunule yellow to amber, thin and bare; arista bare; flagellum glossy brown, round; pedice glossy brown, bare; facial plate subquadrate, light brown, ventrally covered with dense whitish yellow hairs and margin parallel; gena narrow, with dense whitish yellow hairs; labium atrophied and bicuspid apically, with hair tuft on each cusp; palpi concealed behind labium.

Thorax: presutural and postsutural scutum densely black microsetose, with four longitudinal glossy black cuticular stripes; notopleural hair tuft black; mesopleuron with dense white to whitish yellow hairs; scutellum short and semicircular, dorsally white haired, with a thick and polished posterior margin; vein C with black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula small and folded dorsal over 90° in relation to the rest of the wing membrane; upper calypters crumpled, with white hairs on margin; lower calypters round, white or semi-transparent, with short white on margin; femur black, ventrally with dense black hairs; tibia dull yellow to dark yellow, with black hairs; tibia and tarsomeres with pairs of bristles posterolaterally.

Abdomen: abdominal tergite 2 with dense white hairs dorsally; abdominal tergite 3 with dense black hairs; abdominal tergite 4 and 5 with dense whitish yellow hairs; abdominal sternites slightly white pruinose, with dense dark yellow hairs.

Male: frons apparently narrower than the width of one compound eye; terminalia bunt.

Female: frons apparently wider than the width of one compound eye; terminalia extended, abdominal segments 6, 7 and 8 forming a tubular ovipositor.

Fig. 82: Anterior view of female *Hypoderma lineatum* (specimen code: CNC-4540).

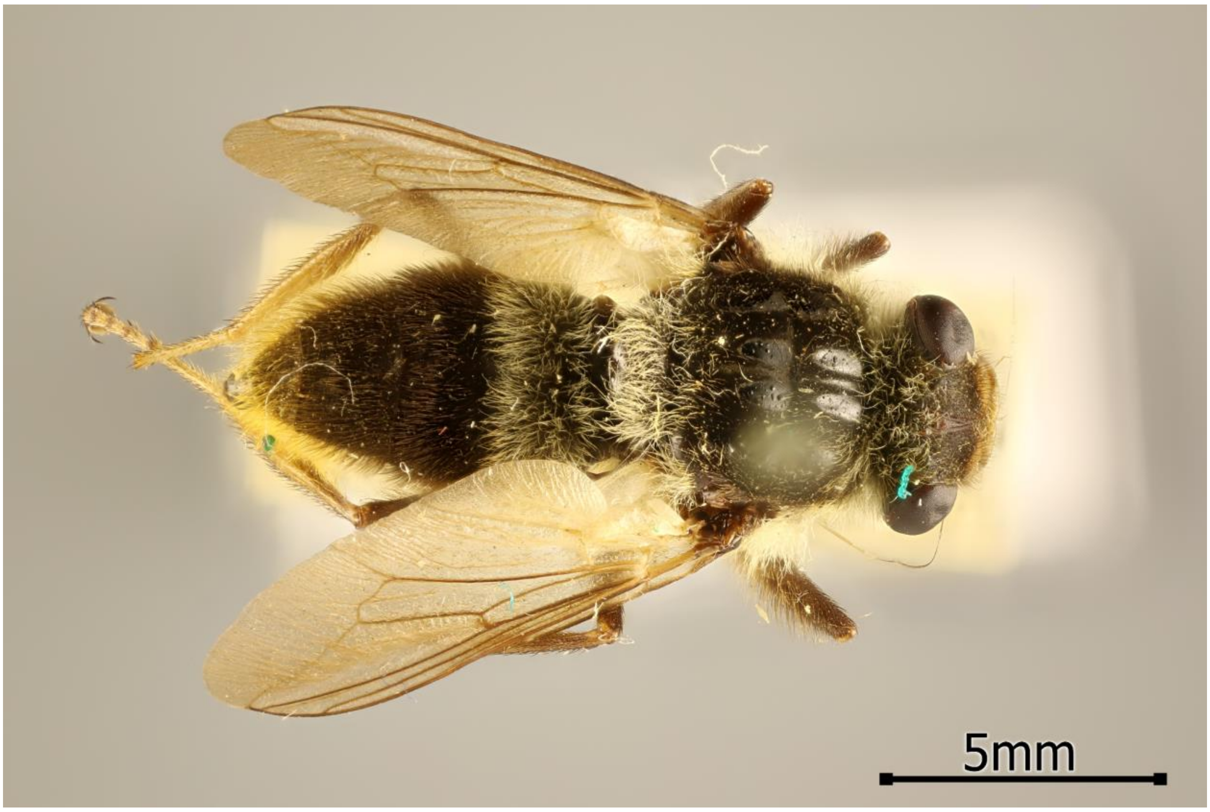


Fig. 83: Dorsal view of female *Hypoderma lineatum* (specimen code: CNC-4540).

Fig. 84: Lateral view of female *Hypoderma lineatum* (specimen code: CNC-4540).

Host:

The primary host of *Hypoderma lineatum* is domestic cattle, but they also occasionally infest horses and other mammals (Zumpt 1965, Olander 1967, Rappelli et al. 2018).

Biology:

The female *Hypoderma lineatum* grasps a hair with her ovipositor and attaches a row of eggs to it (Weintraub 1961). Newly hatched larvae penetrate the skin and eventually travel through the oesophagus to reach the back of the cattle during winter and emerge in the spring (Wood 1987, Cortinas and Jones 2006). The pupal stage lasts from 11 to 44 days, depending on the temperature (Colwell 2001). The low temperature extends the pupal stage. Adult longevity is between 1 and 25 days (Bishopp 1926, Breyev 1971).

Distribution:

See Map. 4. All 441 specimens were reared and collected from Kamloops Livestock Lab in British Columbia between the 1940s and 1960s, as a series of research on *Hypoderma*. The sample size is huge but biased, *H. lineatum* is unlikely restricted in Kamloops. Based on previous literature and records, and the host range, the predicted distribution of *H. lineatum* is like *H. bovis*.

The chance of misidentification of *Hypoderma bovi*s and *H. lineatum* in case report is high, because of identification difficulty, overlapping distribution, specimen damage during extracting larvae, etc, Thus, distribution of *Hypoderma bovis* is the potential range of *H. lineatum*, and vice versa.

Remark:

The Livestock Lab in Kamloops in British Columbia accomplished a series of research projects involving the rearing of *Hypoderma*, which resulted in 433 specimens of *H. lineatum* being deposited in both the Lyman Entomological Museum and the Canadian National Collection. There is a series of North American research on parasitology of *Hypoderma lineatum*. that are infesting livestock (Weintraub et al. 1959, Gooding and Weintraub 1960, Weintraub 1961). However, *Hypoderma lineatum* has not been observed or collected from anywhere else in Canada. I can not determine whether this species was ever fully established in Canada, nor what this species' current status is in Canada. *Hypoderma lineatum* and *Hypoderma bovis* compete for the same niche (both are dermal parasites of cattle), which lead to my hypothesis: *Hypoderma lineatum* has been outcompleted by *Hypoderma bovis* in Canada.

Material examined:

See Supplementary Material; I examined 433 Canadian specimens from CNC (239 female and 194 male) and 18 specimens from LEM (14 females and 4 males).

8.3 *Hypoderma tarandi* (Linnaeus, 1758): 584

Diagnosis:

Labium atrophied and bump-like. Palpi obvious orange knobs, twice larger than labium. Presutural scutum with four longitudinal glossy black bands of cuticle, concealed in dense yellow hairs. Notopleural hair tuft yellow. Mesopleuron with dense whitish yellow hairs. Abdomen concealed in dense long orange hairs, without a black cross band on abdominal tergite 3. Abdominal tergite 5 with whitish yellow hairs.

Description (figs. 85-87):

Body Length: 15 -18 mm. **Wing Length**: ~ 13 mm.

Head: fronto-orbital plate board and punctate, black, with sparse black hairs; frontal vitta narrow and bare, black; lunule thick and bare, black; arista bare; flagellum round and bare, glossy brown; facial plate subquadrate, light brown, ventrally covered with dense whitish yellow hairs and margin parallel; gena narrow, with dense whitish yellow hairs; labium bump-like atrophied, with two pairs of hairs; palpi as a pair of conspicuous oranges knobs.

Thorax: presutural scutum with four longitudinal glossy black cuticular stripes, concealed in dense whitish yellow hairs; postsutural scutum with four longitudinal glossy black cuticular stripes, concealed in dense black hairs; notopleural hair tufts yellow; mesopleuron with dense yellow hairs; scutellum short and semicircular, dorsally yellow haired, with a thick and polished posterior margin; wing membrane completely transparent; wing veins brown; vein C with black hair tuft before humeral break; remained vein C and vein Sc with two rows of black hairs laterally; alula small and folded dorsal over 90° in relation to the rest of the wing membrane; upper calypters crumpled, with white hairs on margin; lower calypters round, white or semi-transparent, with short white on margin; femur black, ventrally with dense black hairs; tibia dark yellow, with black hairs; tibia and tarsomeres with pairs of bristles posterolaterally.

Abdomen: abdominal tergite 2 with dense whitish yellow hairs dorsally; abdominal tergites 3 to 5 with dense yellow to orange hairs; abdominal sternites with little white pruinosity and dense dark yellow hairs.

Male: frons apparently narrower than the width of one compound eye; terminalia bunt.

Female: frons apparently wider than the width of one compound eye; terminalia extended, abdominal segments 6, 7 and 8 forming a tubular ovipositor.

Fig. 85: Anterior view of female *Hypoderma tarandi* (specimen code: CNC-4473).

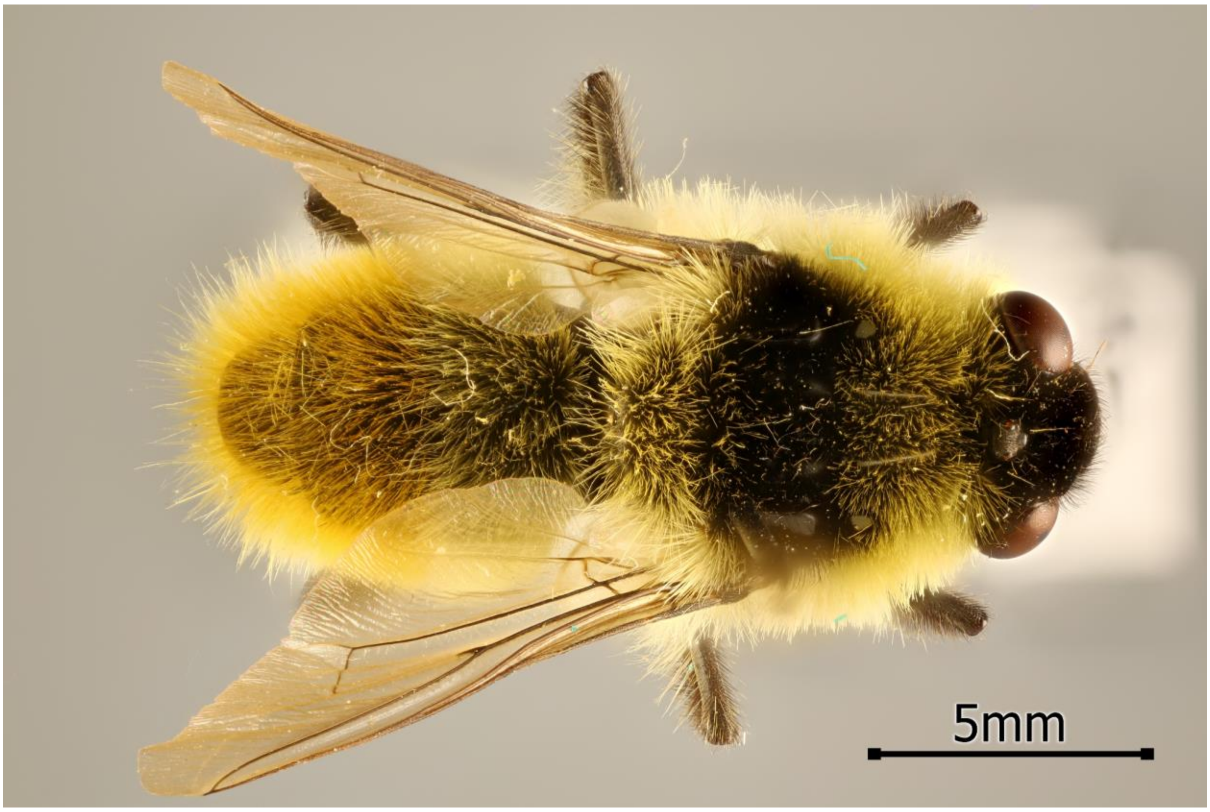


Fig. 86: Dorsal view of female *Hypoderma tarandi* (specimen code: CNC-4473).

Fig. 87: Lateral view of female *Hypoderma tarandi* (specimen code: CNC-4473).

Host:

The only known host of *Hypoderma tarandi* is reindeer (Rangifer tarandus) (Colwell 2001). Occasionally, *Hypoderma tarandi* accidentally infests humans (Lagacé-Wiens et al. 2008, Landehag et al. 2017).

Biology:

Adult females follow the odour of reindeer urine (Breevui 1940). Each female deposits about 650 eggs in batches on lower body parts in June (Breyev 1971). Newly hatched larvae penetrate the skin and migrate underskin. Sometimes they borrow deep into the muscle in the winter (Breevui 1940). After 80-90 days, larvae form warble on the hind part of reindeer (Breevui 1940). After leaving the host, larvae pupariation time varied from less than 1 day to 432 hours (at 8°C) (Nilssen 1997b). Pupal duration is from 10 hours to 105 hours, longer in the low temperature (Nilssen 1997b). Adult longevity from 3 days to 35 days (Breyev 1971, Nilssen 1997a).

Distribution:

See Map. 4. In Canada, they are distributed in the Northern area. Specimens are collected from: British Columbia: Fenton Lake; Tweedsmuir Park. Yukon: British Mountain; Firth River; Herschells; Burwash Flats; Carcross; Black Fox Creek; Yukon Delta. Northwest Territories: Bathurst Inlet; Canot Casse; Coppermine; Geillini Lake; Kidluit; Muskox Lake; Nr Beechey; Richards Island; Keewatin; Tuktoyaktuk. Labrador; Cartwright. Manitoba: Churchill.

Remarks:

Hypoderma tarandi is the outlier of Canadian *Hypoderma*, infesting reindeer rather than cattle. The body size of *Hypoderma tarandi* is significantly larger than the other two Canadian *Hypoderma*, and the abdomen is concealed dense orange hairs, without the black cross band on the abdominal tergite 3. Specimens in collections are heavily biased in the number of males versus female specimens; there are 155 females and only 3 males in the Canadian National Collection. This may be due to the short life of males after mating, or by biological traits such as females following reindeer urine, making them more commonly trapped by researchers (Anderson and Nilssen 1996).

Material examined:

See Supplementary Material; I examined 158 Canadian specimens from CNC (155 females, 3 males).

9. *Oestrus* Linnaeus, 1758: 584

Current global taxonomy:

Six species are recognized worldwide.

Oestrus aureoargentatus Rodhain & Bequaert, 1912: 381
Oestrus bassoni Zumpt, 1961: 5
Oestrus caucasicus Grunin, 1948: 1125
Oestrus macdonaldi Gedoelst, 1912: 430
Oestrus ovis Linnaeus, 1758: 584
Oestrus variolosus (Loew, 1863: 15)

Diagnosis:

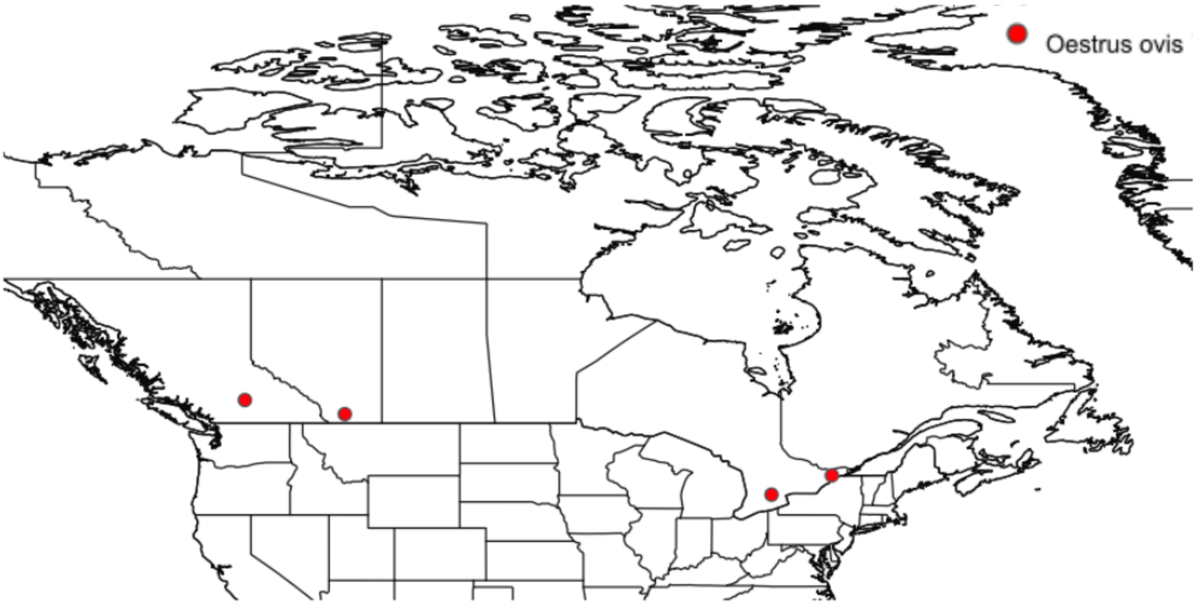
Arista bare. Facial plate margins converge ventrally. Gena cuticle yellow, with whitish yellow microsetae. Scutellum short, semicircular and yellow, with black punctuations. Wing membrane completely transparent. Vein M curved, ending before wing apex, and no extension crossing with crossvein dm-m. Abdomen oval, with cuticular grey and brown checkered pattern and grey microsetose sparsely. Female without external ovipositor.

Biology:

The primary hosts of *Oestrus* are Bovidae. Only *O. ovis* has become globally distributed with its host, domestic sheep (*Ovis aries* Linnaeus, 1758).

Distribution:

Species of *Oestrus* are mostly distributed in Africa and Europe (Evenhuis and Pape 2023). The only cosmopolitan species of *Oestrus* is *Oestrus ovis*. The distribution of *Oestrus ovis* in Canada is shown below (Map. 5).



Map. 5: Distribution of *Oestrus ovis* in Canada.

9.1 *Oestrus ovis* Linnaeus, 1758: 585

Diagnosis:

Since *Oestrus ovis* is the only *Oestrus* species in Canada, no diagnosis is required beyond the generic diagnosis provided above.

Description (figs. 88-91):

Body Length: 10 - 12mm. **Wing Length:** 7-8mm.

Head: fronto-orbital plate with punctated pits and frontal seta white to brown; frontal vitta without convex spots or pits; lunule yellow, thick, and bare; arista bare; flagellum reddish brown, white pruinose; facial plate bare, ventral margin converge but not attached, forming a vertical hollow; gena dull yellow, with sparse white or whitish yellow hairs; atrophied labium as small knobs on ventral facial plate.

Thorax: mesoscutum densely punctate with black convex spots, and each convex spots with fine white or whitish yellow hairs; scutellum with sparser black convex spots, similar to scutum; mesopleuron with long fine white hairs; wing membrane completely transparent; wing veins predominantly dull yellow; veins C and Sc with two row of short black bristles; r-m crossvein, bm-m crossvein and apical portion of stem vein brown to black; alula small and folded dorsal over 90° in relative to the rest of the wing membrane; lower calypter semi-transparent or white; legs dull yellow; femur with sparse white hairs; tibia and tarsomeres with pairs of bristles posterolaterally.

Abdomen: oval, brown or black, with cuticle checkered pattern and small convex black spots posterior margins of abdominal tergite yellow; abdominal sternites black, with white hairs.

Male: Frons about ¼ of the head width.

Female: Frons subequal or greater than ½ of the head width.

Fig. 88: Anterior view of male *Oestrus ovis* (specimen code: LEM-0095571).

Fig. 89: Dorsal view of male *Oestrus ovis* (specimen code: LEM-0095571).

Fig. 90: Lateral view of male *Oestrus ovis* (specimen code: LEM-0095571).

Fig. 91 Wing structure of *Oestrus ovis*.

Host:

The primary host of *O. ovis* is domestic sheep (*Ovis aries*), and secondary hosts are other *Ovis* and *Capra* Linnaeus species (Capelle 1966, Colwell et al. 2006). In some rare cases, *O. ovis* has been recorded infesting dogs, cats and even humans, causing external ophthalmomyiasis (Webb and Grillo 2010, McGarry et al. 2012, Pupić-Bakrač et al. 2020, Tamponi et al. 2022). As a common economic pest, the biology and lifecycle of *O. ovis* have been well explored (Whitworth 1880, Fallis 1940, Abul-hab 1970, Tabouret et al. 2001).

Distribution:

See Map. 5. In Canada, specimens of *Oestrus ovis* are recorded in British Columbia, Alberta, and Ontario.

Remarks:

As the only Canadian species of *Oestrus*, *O. ovis* can be easily recognized by the small size and dense black spots on the mesonotum, differentiating it from its hairy, robust relatives. *Oestrus ovis* have unique, checkered patterns among Canadian Oestridae, while many Canadian oestrids have bright yellow and black bands.

Material examined:

See Supplementary Material, I examined 45 specimens, including 25 females and 20 males.

10. Discussion:

The specimens I examined are borrowed from major entomological collections in Canada (CNCO; LEMQ; ROMQ, and IMQC). A large portion of these specimens were collected over 20 years ago. I have three hypotheses about this result:

Several research projects on the biology and behaviour of bot flies have been done by mass-rearing *Hypoderma*, *Gasterophilus* and *Cuterebra* between the 1940s and 1970s; and in Canada, the rearing experiment was accomplished by Kamloops Livestock Insect Lab in British Columbia during this period (Weintraub et al. 1959, Gooding and Weintraub 1960, Baird 1972, 1975, 1979, Nelson and Weintraub 1972, Baird and Graham 1973).

Bot fly larvae are endoparasites within mammal hosts and are hard to identify. Their adults are seasonal, short-lived, and rarely attracted to traps. There are two methods to collect bot flies: either by rearing the larvae within the living host until they pupate, or collecting the adult while they are aggregating. Aggregation, known as hilltopping, is the behaviour that males assemble on a specific site (usually the highest point of an area) and attract females (Catts et al. 1965, Catts 1979, Downes et al. 1985). Both collecting methods, rearing larva and collecting by aggregation site, are limited and highly target a specific species of bot fly. Thus, species of bot flies are rarely collected during general collecting or biodiversity surveys.

Compared with other insects (such as butterflies and moths), bot flies receive less attention from the public. Amateur collectors may fail to recognize a bee or wasp mimic bot fly and miss the chance of collecting it.

Insects are frequently introduced to or extinct in a region, without being noticed (Causton et al. 2006, Régnier et al. 2009). Due to the lack of surveys and accurate identifications, species in a region may not have been collected or observed over the last few decades. The absence of recent specimens leaves blanks in assessing the current status of an insect species. And that leads to consequences in taxonomic studies. For example, extinct species may be included, or newly introduced species may be absent in a regional checklist or identification key. To improve these studies, I need more collections, which will require more new taxonomists, more funding, and more permission for collecting insects. Unfortunately, traditional taxonomy is in decline because academic interest in traditional taxonomy has faded out in the last 20 years, and subsequently, projects, funding and training are running out (Wheeler 2004, Tewksbury et al. 2014, Britz et al. 2020). As a consequence, a 55% decline in the total amount of taxonomic research funding by the Natural Sciences and Engineering Research Council of Canada (NSERC) between 1997-2007 (Packer et al. 2009). Similarly, in the Canadian National Collection, entomological employees had decreased by half from 1980 to 2000 (Packer et al. 2009). As the modern trend of biology research, taxonomy is inevitably declining.

An updated taxonomy of Canadian Oestridae

Coquillett described *Cuterebra grisea* and *Cuterebra fontinella* as two species, distinguished by the colour of the scutum setae (Coquillett 1904). However, Sabrosky found intermediate forms with a mix in many of his specimens (Sabrosky 1986). Besides the coloration of the setae in the scutum, there are no characters (including male genitalia) to separate them into two different species consistently. Thus, I considered *Cuterebra grisea* to be a junior synonym of *Cuterebra fontinella*.

Cuterebra buccata is suggested to be a Canadian species, but only one Nova Scotia specimen was collected in 1849, and Austen identified it as *Cuterebra buccata* in 1895 (Austen 1895). Later, Sabrosky confirmed the specimen is *Cuterebra buccata*. Still, he doubted the corrective of the locality on label, since Eastern cottontails, the primary host of

Cuterebra buccata, are not distributed in Nova Scotia (Sabrosky 1986). I was not able to examine the specimen Sabrosky referred to nor find any Canadian *Cuterebra buccata* in collections. Nevertheless, Vlaine observed and photographed a *Cuterebra buccata* in Notre-Dame-de-l'Île-Perrot, Quebec, in August 2022, thus solidifying this species in the Canadian fauna (Vlaine 2022). Later, in August 2023, Ouellette provided another observation of *Cuterebra buccata* in Blainville, Quebec (Ouellette 2023). I was not able to access or examine either of these species, but the photos are clear enough to validate the species.

Citizen science is the cooperation between public volunteers and professional scientists, in which volunteers help in collecting and classifying data. During my research, I found many data that are provided by public volunteers (Farley 2019, Corden 2022, Deblan 2022, Vlaine 2022, Ouellette 2023). Some observations, such as Vlaine`s observation on *Cuterebra buccata* are critical for this taxonomic research. As I outlined above, taxonomy research is facing many issues, including the decline in funding, staff, training and all related resources (Wheeler 2004, Tewksbury et al. 2014, Britz et al. 2020). Compared with traditional collections, citizen science involves more naturalists (including public volunteers and professional scientists), which bridges the researchers in the 'ivory tower' and the general public (von Konrat et al. 2018). Since funding is declining and obtaining permits is becoming a burden for collecting specimens, updating the collection will not be much harder than in the last decades (Britz et al. 2020). The citizen scientists came in and filled the gap of updating taxonomy by gathering a large number of observation records (Mesaglio et al. 2021, Unger et al. 2021, Callaghan et al. 2022, Campbell et al. 2023). Benefiting from portable electric devices, observations in online databases (such as iNaturalist and BugGuide) are recorded with precise collectors, identifiers, dates and localities. In my research, this critical information is sometimes incomplete on the label of old specimens.

Though there are many advantages to online naturalist forums, the collections of specimens are irreplaceable. Without collecting and preserving, researchers will be unable to examine the specimen under the microscope, not to mention performing genitalia dissections or DNA extraction. I believe it is still necessary to maintain and expand the natural history collection. However, as the trend continues, funding is decreasing for collections, and citizen science has been brought into play in the last decade (Mesaglio et al. 2021, Callaghan et al. 2022, Campbell et al. 2023). Integrating the specimens from collections and observation records from citizen scientists has been normal (Mesaglio and Callaghan 2021, Unger et al. 2021, De Groot et al. 2023, Johnston et al. 2023).

Colouration in Insect Identification

In the earlier identification keys, colouration (especially setae colouration) was often used as a character to distinguish species (Fabricius 1787, Clark 1797, Sabrosky 1986). However, it is only sometimes reliable, such as in the case of *Cuterebra fontinella* (see above). I have also found that colour variation is common in other genera of Oestridae, such as *Gasterophilus* and *Cephenemyia* (figs. 36 and 76). Variations of coloration are also commonly found in other flies or other insects, which are usually considered the result of individual ontogenesis, chronological, and/or environmental influence (Adler 1946, Horber 1955, Merritt 1970, Sasakawa 1974). The thermal melanin hypothesis assumes that the cuticle of insects is darker in colder environments due to dark colours being more effective in absorbing solar radiation, and it is supported by the comparison of ground crickets from different regions (Fedorka et al. 2013). This hypothesis may explain the melanism in *Gasterophilus*, in which the ones collected from Nova Scotia are generally darker than the ones collected from Southern provinces. However, this same pattern does not apply in *Cephenemyia trompe; Cephenemyia trompe* collected from Quebec have reddish-orange hairs, which are undoubtedly darker than the ones from Northwest Territory and Yukon (with light yellow hairs). The reason behind this variation in the two regional populations is still unknown.

However, I do not exclude colouration as distinguishing characters. In insect identification, for example, in many butterflies (such as in the genus *Pieris*), colouration is the most straightforward diagnostic character to use (Ge et al. 2023). In my identification key, colouration is used as supplemental characters to distinguish species, in which structural characters are prioritized.

Some papers described the specimens with different coloration as subspecies or variants (Ebach and Williams 2009, Patten 2009). The boundaries of subspecies and variants are blurred, and the concepts are still debatable. The definition and concept of subspecies have no compelling justification and remain debatable (Reeves 2004, Burbrink et al. 2022).

Many researchers, such as Mayr and Inger, believe that subspecies fulfilled the most important role by contributing a further understanding of the geographic variation of taxa in nature and undermining the concept of species (Inger and Marx 1962, Mayr 1982). Thus, some scientists suggest that ‘subspecies’ and ‘race’ should not be used as synonyms (Ebach and Williams 2009, Patten 2009). Burbrink et al. have a profound discussion of the rank subspecies, both philosophical and empirical approaches. Philosophically, it is impossible to state an ontologically meaningful definition of subspecies, and in many empirical circumstances, subspecies would be indistinguishable from species (Burbrink et al. 2022). Thus, it is a convenient term to refer to a collection of population or a regional population, but it is neither clear nor logical.

Limited by the capacity of this project, I do not have enough information to discuss any subspecies-rank taxonomy. Thus, for the purpose of my thesis, I treat all subspecies-rank names as synonyms.

Introduced Species or Local Biota

Dematobia hominis, the human bot fly, is endemic to Central and South America (Sancho 1988). As global transport has developed, travelling between continents has become more convenient. In Canada, cases of human bot fly infestations on travellers returning from Central and South America are more often reported (Maier and Hönigsmann 2004). However, adult *Dermatobia hominis* has never been observed or collected in Canada. All larvae brought back by travellers are removed prior to eclosion, and the climate in Canada will not allow the larvae to develop into adults (Sancho 1988). Climatic change has modified the distribution of *Dermatobia hominis*, and made them expand northward (Safdar et al. 2003). An indigenous infestation case is recorded in Florida (Price et al. 2007). They may have invaded some southern states of the USA, but there is no evidence that they have been established in Canada yet.

However, there is no clear answer for whether a non-established species should be included in discussions of local biota: they are listed in some critical checklists, but they are unable to provide a long-term contribution or effect to biodiversity (Worner and Gevrey 2006, Ojaveer et al. 2017, Borg et al. 2023). A well-known example is the greenhouse camel cricket (*Tachycines asynamorus* Adelung, 1902), an introduced species from Southeastern China to Poland via exotic botany shipment but limited to greenhouses, botanical gardens and human houses (Epps et al. 2014, Rozwałka et al. 2022).

My thesis reviewed the taxonomy of Canadian Oestridae, delimited a species (or subspecies), confirmed that *Cuterebra buccata* has expanded into Canada and determined the distribution based on both localities of specimens and observations. This result indicates the species of *Cuterebra* expanded northward in the last few years. The review also explores the neglected taxa and notices the inadequate in previous studies, including misidentified type specimens in *Hypoderma bovis* and under-reviewed groups in *Cuterebra.* These remaining questions will be the direction for further research in Oestridae taxonomy.

11. Conclusion and Future Work

This thesis extensively reviewed Canadian Oestridae specimens, revealing 18 species of Oestridae found in Canada. An integrated and updated catalogue of Canadian Oestridae is presented with valid names of genera and species and synonyms. I have produced an identification key with explicit diagnosis characters and clear illustrations. I reviewed and summarised the natural history, biology and described the detailed morphology of all 18 Canadian Oestridae. All examined Canadian Oestridae specimens have been databased with collection codes, species-level identification, and digitized information for all labels. The map of the distribution of each genus and species are performed based on the Canadian Oestridae specimen database and iNaturalist.

Though, there are a few questions are remained unanswered in our research:

i) During the type specimens search, I discovered that the type specimens of *Hypoderma bovis* in the Linnean Society of London is a *Gasterophilus intestinalis*. Since *Hypoderma bovis* does not have a correct type specimens, I will need to establish a neotype specimen . ii) The distribution map of *Gasterophilus* spp. is biased due to the huge number of specimens reared from the lab. The actual incidence and distribution are uncertain yet. iii) Subgenera of *Hypoderma* are not able to be examined in this thesis because of the limited species in Canada. And *Hypoderma* are significant pests in global, but neglected in taxonomic study. I need to accomplish a taxonomic revision of global *Hypoderma*, in order to further discuss the subgenera of *Hypoderma* iv) Any taxon below the species level is treated as species. Limited by adult specimens' information, evidence of different species is inadequate. The variances in morphology are described under the species morphology.

To answer these remaining questions, a further taxonomic revision on species-level determination will be needed from a global range, further biological, ecological, and phylogenetic studies.

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