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New austral records of massive swarming by a chloropid fly, *Chloromerus striatifrons* (Diptera: Chloropidae)

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Abstract Mass aggregations, including aerial swarms, of a yellow swarming chloropid fly are reported from Australia. The species, *Chloromerus striatifrons* (Becker), is endemic to south-eastern Australia and has been reported swarming only once previously, 40 years ago.

Key words Chloropidae, *Chloromerus striatifrons*, swarming.

INTRODUCTION

Aerial swarming is a characteristic and perhaps fundamental behaviour in insects, seen in many orders including mayflies, odonates, caddisflies, many social insects, and especially true flies (Diptera). Most dipteran swarming is associated with mating in which females are attracted to nuptial swarms of males (Downes 1969, 1991). Swarms usually are located with respect to a landmark, either terrestrial or at the horizon, termed a swarm marker. Such markers include hilltops, tall buildings or tree tops (Sullivan 1980), and these swarms are termed 'station-dependent'. In nuptial swarms, females gather by response to the same cues as the males (Gibson 1985), and mating takes place in or proximate to the swarm. Although a 'swarm of one' is possible, being a precursor to other individuals arriving using the same cues (Gibson 1985; Gullan & Cranston 2014), the term is applied best to assemblies of airborne insects numerous and conspicuous enough to be noticed by human observers (Downes 1969). Among the Diptera, such conspicuous ('mass') swarms are well documented among biting flies (especially Culicidae, Ceratopogonidae and Simuliidae) (e.g. Downes 1969; Sullivan 1980; Gibson 1985) and non-biting midges (Chironomidae) in which swarms have been studied in relation to human nuisance and allergenicity (Cranston 1994).

Displays located with respect to a marker (station) have been reported in other families of Diptera, although outside of the 'Nematocera' (a paraphyletic grouping of 'lower flies') reports are rarer, with more frequent reporting of resource-based mating aggregations, including among blood-sucking 'higher' flies (Yuval 2006). A major exception in a 'higher' fly is seen in the 'frit' or 'grass' fly, the chloropid *Thaumatomyia notata* (Meigen) commonly termed the 'yellow swarming fly', which makes massive aggregations. Early records of swarms that resembled clouds of smoke date from 1736 in England, 1807 in Germany and 1812 in Poland (Narchuk 2000), associated usually with high buildings in parks with grass lawns. Reports continue from locations predominantly throughout the Palaearctic, but also from an extended Afrotropical and Oriental range (Nartshuk & Andersson 2013).

Here we provide new records for Australia of the formation of massive plumes of flying insects identified as a different chloropid, *Chloromerus striatifrons* (Becker), as well as details from additional locations elsewhere in south-east Australia of non-aerial massed aggregations of this fly forming lower in the vegetation.

MATERIALS AND METHODS

Visual observations assisted with binoculars were made in response to reports of large clouds of insects flying above treetops at several locations in the Southern Tablelands of New South Wales, eastern Australia, between January and March 2015. Observations were made in late afternoon to around dusk as swarms developed, and were filmed by camera in still and movie mode. Adult flies were collected by sweeping from vegetation, including immediately beneath swarms, and from the lower swarms using a long-handled net. Sweep samples were taken once from grassland surrounding pine trees where aerial swarms were seen. Adult flies of both sexes were retained separately from different sampling events and preserved in 70% ethanol. Specimens were sent to Australian Museum for identification. Specimens of each sex were soaked in KOH and dissected, and subsequently slide prepared in Euparal mountant (by PSC). Photographs of whole flies (preserved in ethanol) were taken by PJ Gullan with a Nikon

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Coolpix P4, and those of slide-mounted specimens were taken (by PSC) using Nomarski phase contrast optics on a Leica® DMRX compound microscope with Automontage™ image-stacking software. All images were manipulated subsequently with Adobe Photoshop™. Specimens are deposited in BMNH – the Natural History Museum, Cromwell Road, London, UK; ANIC – Australian National Insect Collection, CSIRO, Canberra; and AM(SA) – the Australian Museum (Sydney, Australia).

RESULTS

Aerial swarming

Large, smoke-like plumes of flying insects, reported first to RF in mid-January (austral summer) 2015, formed above mature Monterey (radiata) pines (*Pinus radiata*) and natural and planted eucalypts in Wamboin (35°237381 S 149°333509 E) and Carwoola (35.406408 S 149.358989 E), east of Canberra, in the Southern Tablelands of NSW (Fig. 1a). At Carwoola, large aggregations persisted for over 2 months until the end of March, in a cluster of trees adjacent to a substantial creek (observed by MB). Nearby 'smoke plumes' also turned out to be clouds of insects, and 'tiny yellow flies' were found clustered on a wattle (*Acacia* sp.). Reports of two large swarms aggregating over pines in early February came from Urila (35°568600 S 149°291836 E), south of Canberra (Fig. 1a), where RF undertook the first detailed observations of swarm behaviour and took samples to identify the insects involved. Soon afterwards a billowing swarm above a pine tree of RF's nearby property was seen: subsequent swarms were observed intermittently for several weeks. Swarming ceased by late February at Urila, but persisted for some weeks at Carwoola.

Swarming at Carwoola sometimes started as early as 3 h before sunset, but in general commenced between 17:30 h and 18:00 h (1–2 h prior to sunset) and ceased between 18:30 h and 19:00 h, with swarm activity declining rapidly in fading light after sunset (c. 19:00 h). All swarming started with flies streaming from the tops of the same marker pine trees at 20–30 m above the ground in a coherent plume (Fig. 1c–f). Accompanied by a distinctive humming sound, swarms exhibited a complex pattern of aerial behaviour best described as billowing, with extraordinary cohesive aerial gymnastics not previously reported. Usually this was a plume of variable and continuously changing shape, but sometimes with a strong ascending plume and very rarely descending streams moved down the side of the marker pine trees.

At Carwoola, up to four separate plumes were observed at the same time above four different marker pine trees in a cluster of trees about 50 m apart, as well as a single tree about 800 m distant and well above a creek. In late March, new swarms billowed from several other pine trees close to this distant one. Two plumes originated from above each of two pines situated about 50 m apart in shelter belts at Urila, but nearby a single plume originated from the same pine top in a group of equal-sized pines (RF's property).

Swarms did not occur daily: for example at Carwoola in February, swarms were noted on 10 of 26 days, whereas in March they were observed on 15 of 25 days. Weather conditions at swarm times ranged from clear to overcast, windy to calm, and warm to cool. Temperature data showed no relationship between air temperature at 18:00 h and the incidence and size of swarming.

Observations on the behaviour of swarms made using binoculars trained on marker trees started prior to aerial swarm formation when flies were clustered in the foliage of the tree (Fig. 2a). As horizontal plumes moved away from the pine tops, the insects dispersed and were lost to sight at 20–50 m from the source trees. Flies must have been returning to the swarm source undetected and then re-aggregating into the plumes as continuing recruitment of such vast numbers of flies for the >1 h duration of the activity is extremely unlikely. Estimation of the volume of the plumes is inexact but derived from images some measured up to 60 m long and 1–2 m across and would have contained millions of flies. This order of magnitude for the number of flies is consistent with the numbers cited for swarms of *Thaumatomyia notata* in the Northern Hemisphere (Narchuk 2000).

The sex ratios based on morphology of flies in the two samples showed significant differences. The sample swept from settled flies in low foliage of the marker pine in Urila was 2 : 1 female to male, whereas in the airborne flies from a swarm at Carwoola it was 15 : 1 male to female (n >100 for each).

Aggregations of *Chloromerus striatifrons* in low vegetation

In addition to the observations on aerial swarms reported above, between 2013 and 2015, huge sedentary concentrations of yellow swarming flies were photographed (RF) on understory shrubs in regional eucalypt forests (Fig. 1b). These comprised (1) Victoria, Mt Buffalo National Park, Long Plain, 36°64813 S 146°752649 E, 13.ii.2013, on *Daviesia latifolia* (Fig. 2b); (2) New South Wales, Tinderry Nature Reserve, Round Flat, 35°729174 S 149°286853 E, 30.xii.2014, on *Pomaderris phylicifolia*; and (3) Australian Capital Territory, Namadgi National Park, Mt Corin, Smokers Flat, 35°518815 S 148°921933 E, 25.iii.2015, on diverse shrubs and lower foliage of *Eucalyptus viminalis*. An environmental feature in common between the three sites is the presence of a nearby fen dominated by sedges, *Carex* spp. The flies in the first two aggregations covered an area of about 50 m^2, and contained millions of flies of such high density that shrubs appeared grey. No interactions between settled flies were seen, but all behaved similarly when approached, flying in dense clouds to settle quickly on more distant foliage. Provisionally identification of the Mt Buffalo flies (RF) and of flies clustering on an *Acacia prominens* at Carwoola in late February 2015 was as a chloropid resembling the Palaearctic *Thaumatomyia notata* Meigen, the well-studied yellow swarming fly (Narchuk 2000).

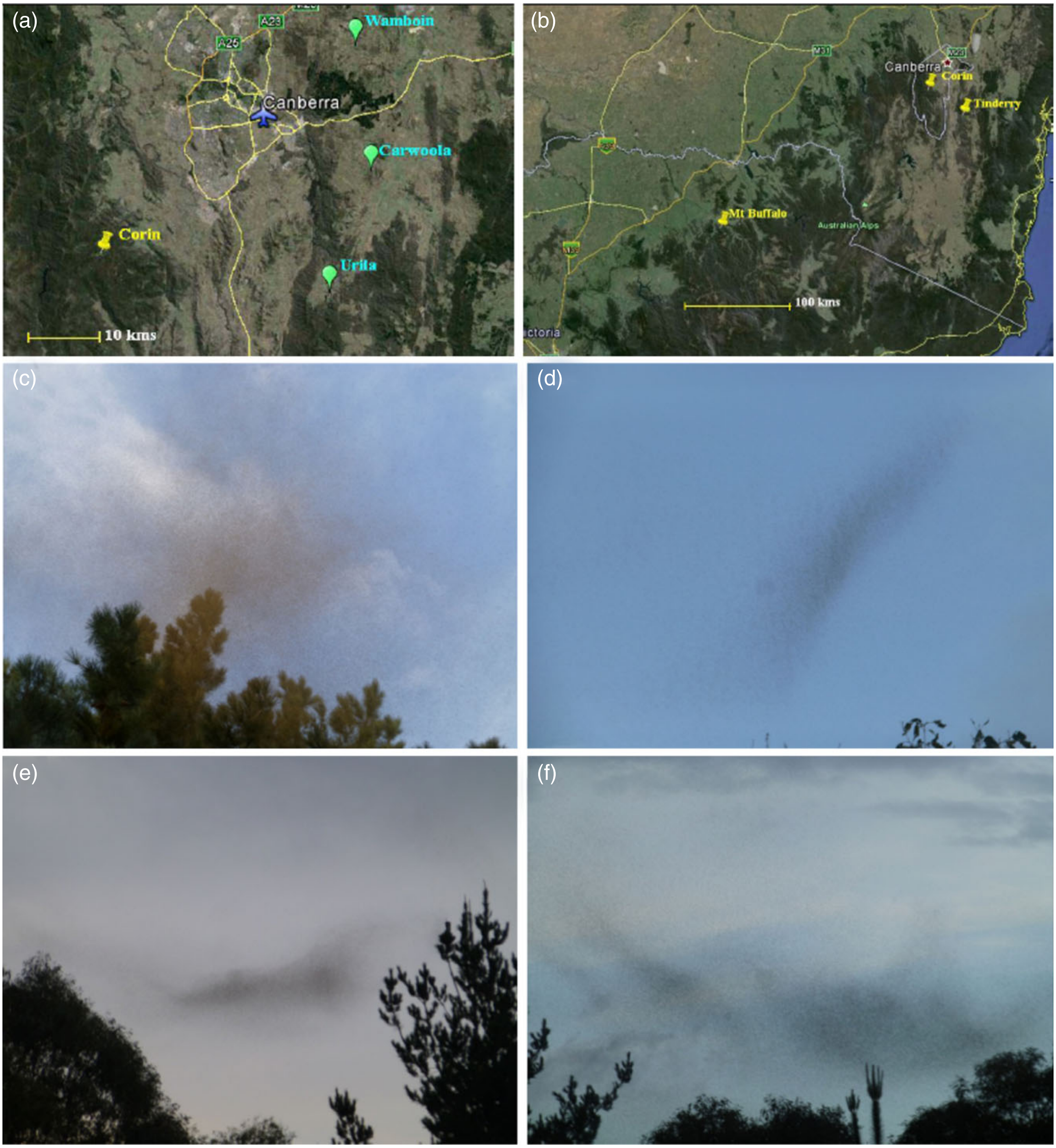

Fig. 1. (a) Aerial swarming locations, south-east Australia; and (b) static (non-aerial) aggregation locations, south-east Australia. Swarms of *Chloromerus striatifrons*. (c) Lifting off over pine tree, Urila, 18:22 h, 13.ii.2015 – golden colour due to reflection of the flies in the setting sun; (d) ascending plume above pine tree, Urila, 18:47 h, 7.ii.2015 – eucalypt tree (lower right) is not a marker; (e) horizontal billowing plume at a distance of 70 m, marker pine tree to right, Urila, 18:47 h, 10.ii.2015; (f) complex large billowing swarm at a distance of 20 m, Urila, 18:37 h, 10.ii.2015.

Identity of the swarming fly

Given that the behaviour of this Australian swarming chloropid fly is very similar to that reported for Northern Hemisphere *Thaumatomyia* species, an initial identification was of the sole Australian species *Thaumatomyia subnotata* (Malloch) and included comparison with the type (Australian Museum). Under advice from J Ismay, male genitalia were studied by soaking abdomens in cold 10% KOH for a lengthy period (days), and the abdomen was then probed, teased and dissected using fine forceps, seeking characteristic vesicles (Kotrba 2009). That none were visible, either

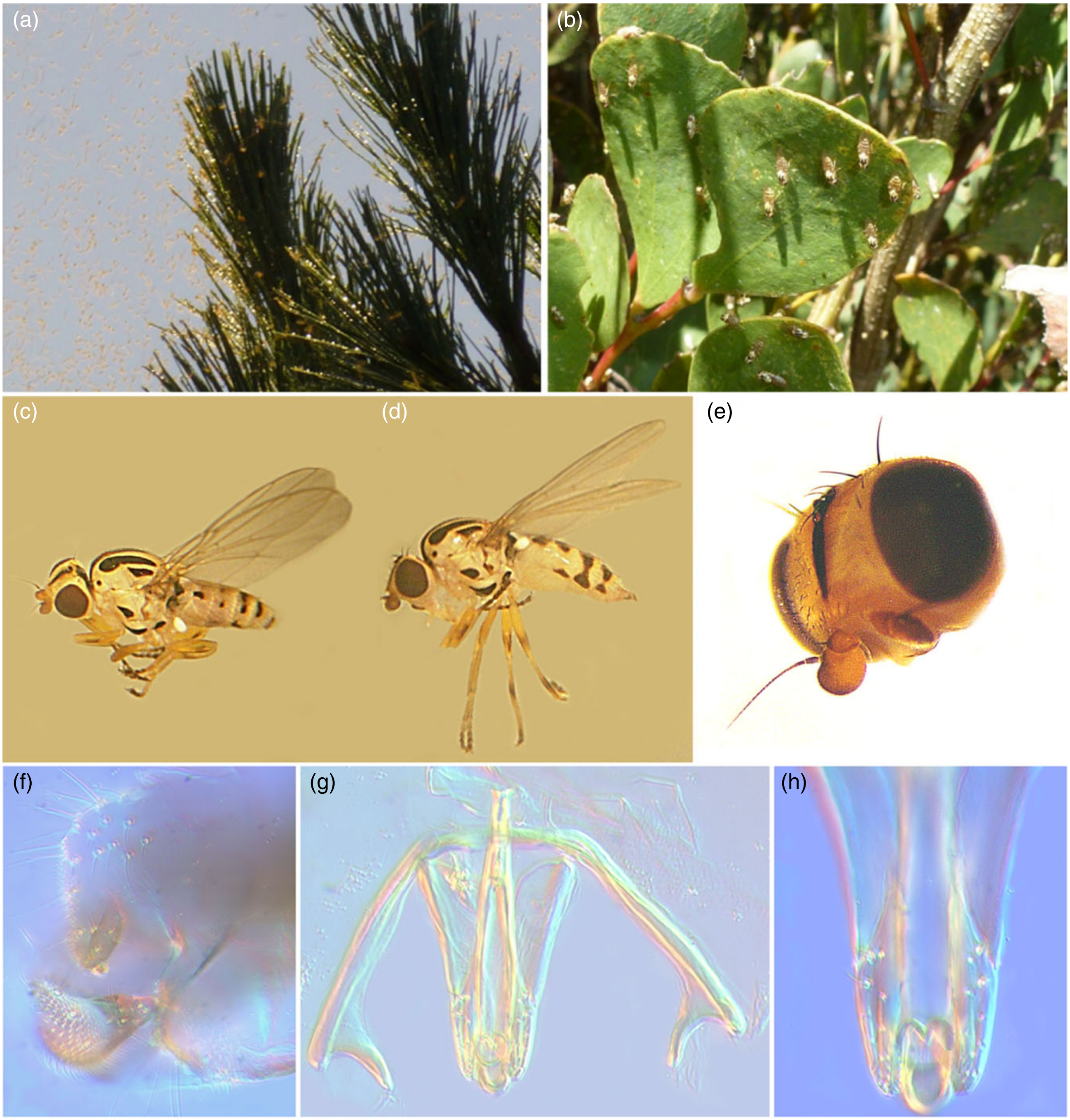

Fig. 2. 'Sedentary' aggregations. (a) Flies aggregating on foliage at top of pine tree, Urila, 18:27 h, 14.ii.2015 – glistening yellow colour due to reflectivity in the setting sun; (b) *Chloromerus striatifrons* on *Daviesia latifolia*, Victoria, Mt Buffalo, Long Plain, 13.ii.2013 – note parallel alignment of many flies. *Chloromerus striatifrons* (c) male habitus and (d) female habitus: (e) head, (f) surstyli (♂), (g) aedeagus/hypandrium (♂), and (h) apex of aedeagus, gonopod (♂).

exerted or retained internally, suggested re-examination of the identity. Discovery of a note by Moore (1976) and the use of Spencer's (1986) key led us to suspect *Chloromerus* with the following keyed features: without projection on lower face, arista slender, hair-like, with short pubescence, frons non-projecting and hind femora thickened. Within *Chloromerus*, the species keys to *C. striatifrons* (Becker 1911) based on the broadening of the hind femora and yellow frontal triangle with conspicuous dark median stripe running its full length (Fig. 2e). Comparison with specimens identified by Spencer and Ismay housed in the Australian National Insect Collection (ANIC, Canberra) revealed similarity also in the following: overall habitus and pigmentation (Fig. 2c,d); hind femora with elongate subapical brown band, subapical ventral dark area with pegs-like setae and maximum width 2× that of hind tarsomere 1 width;

mid-femora uniformly yellow-brown of maximum width 1.5 times that of mid-tarsomere 1; anterior femora as hind femora in colour and shape, but lacking pegs; with two pairs of submarginal scutellar setae, inner longer than outer; and scutellum gently curved/convex. The male post-abdomen and genitalia are illustrated for the first time as photographs (Fig. 2f–h), for future studies.

Additionally, specimens reported by Moore (1976), provisionally identified by Colless and Liepa and deposited in ANIC, confirmed as *C. striatifrons* by Ismay in 1994, are identical to ours. All photographs taken of these swarming flies appear to be *C. striatifrons*.

Sweep samples from the grassland adjacent to the pine tree at the Urila property, and identified by D. Bickel, contained no chloropids but were dominated by a common ephydrid fly, *Hydrellia tritici* Coquillet and other small acalyptrate flies.

DISCUSSION

Our observations supplement and extend those of Moore (1976) in recognising that swarming of the Australian *C. striatifrons* much resembles that described in Europe for *T. notata*, as summarised by Narchuk (2000), who integrated over a hundred records covering more than two centuries. The density and billowing nature of European swarms, especially when associated with tall buildings as swarm markers, have led to confusion with smoke and provoked reports of fire. Given that the Australian swarms similarly could be misinterpreted, it is surprising that observations date from such few reports, 40 years apart despite the distinctiveness of the phenomenon. The first author has lived on his property at Urila for 36 years and has never witnessed this phenomenon until 2015. Museum records of the species in the intervening period have been regular though sporadic, associated with standard trapping (e.g. malaise trapping, sweeping) widely in south-eastern Australia but none associated with mass swarming. We interpret the sedentary (non-aerial) aggregations of flies described above as pre-aerial swarming behaviour, although any ensuing aerial swarm was not seen perhaps due to the timing of observations.

A major difference from chloropid swarming reported in the Northern Hemisphere concerns over-wintering aggregations of adult flies in buildings. We have no reports of association with buildings (but the high points in our landscape are trees not churches), nor do we have any evidence of cyclical irruptive population fluctuations across decadal periods as reported for *T. notata* (Narchuk 2000).

Our data concerning sex ratios associated with near ground (female-dominated) and base of swarm (male-dominated) imply that at least the aerial swarms of *C. striatifrons* result from both sexes aggregating in response to the same site-specific environmental cues. As expected with nuptial swarming, typically the males form the swarms and females fly briefly into swarm where a mate is located. Only when conditions are favourable do massive swarms develop, otherwise both sexes remain aggregated in proximity to what we presume, but have not confirmed, to be their emergence sites.

A speculative question concerns why such impressively large numbers of adult *C. striatifrons* are available for swarms to develop. Although we know nothing of their larval habitat, some chloropid larvae are predatory and feed on 'root aphids' and show inter-year fluctuations (Nartshuk 2000), perhaps under the influence of climate cycles that also drive variation in adult fly abundance. However, assuming that the swarms reported here emanate from local larvae, then the habitat must be substantially pasture grassland understory and sedge fen swamps. If static aggregations and aerial swarms are part of the same phenomenon, the understory is near both native and non-native trees in both cleared land and native forest. It is noteworthy that in the (austral) summer of 2015, a dry spring was followed by very wet summer with abundant pasture growth.

Evidently this system provides scope for further study on larval biology, including feeding and synchronisation of emergence with prevailing weather, and on adult biology including the possibility of over-wintering in this stage, and if so where this occurs. In the longer term, it will be of interest to see if mass swarms return in subsequent years and if any cyclicity can be detected.

Movie pictures of the swarms are available on disk from the first author on request.

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