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OBSERVATIONS ON MASS EMERGENCE OF CHIRONOMIDS (DIPTERA: CHIRONOMIDAE) IN BEDOK, SINGAPORE WITH NOTES ON HUMAN–CHIRONOMID INTERACTIONS

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ABSTRACT. **—** The dipteran family Chironomidae is one of the most ubiquitous groups of freshwater invertebrates that occupy a wide range of ecological niches. As each member of the Chironomidae (chironomid) reaches the final stage of its life cycle, it emerges from a water body, sometimes in mass swarms, to reproduce and lay eggs. When occurring near human settlements, these mass emergence events can cause a nuisance to residents and present problems associated with allergens. In Jan.2011, a mass emergence of chironomids was observed at Bedok Reservoir. This article represents the first known documentation of a chironomid mass emergence event in Singapore. The identity of the chironomid responsible was narrowed down to a member of the sub-family Chironominae. However, further identification to species level was not possible owing to the lack of available region-specific identification keys. Despite the problems associated with chironomids, they form an integral part of the ecosystem as a major food source for many organisms, and they are also used widely as pollution indicators. Control of chironomid populations has mainly focused on chemical methods, but understanding the biology of nuisance species and identifying the underlying causes of population booms are essential basics for a more economical and holistic control treatment.

KEY WORDS. **—** Chironomidae, chironomids, mass emergence

INTRODUCTION

The Chironomidae (Order: Diptera), or 'non-biting midges' (derived from the weak development of the adult's mandibles), are one of the most abundant insect families found within freshwater systems. It is the most widespread of all aquatic families, with individual species occurring from Antarctica at 68°S (*Belgica antarctica* Jacobs) and sub-antarctic islands (*Parochlus steinenii* Gercke) (Usher & Edwards, 1984; Edwards & Usher, 1985), to Lake Hazen at 81°N on Ellesmere Island (Oliver & Corbet, 1966). They also exhibit extreme elevational ranges, occurring in a glacial-melt stream at 5,600 m in the Himalayan Mountains (Koshima, 1984) to more than 60-m depths in Lake Hovsgol (Hayford & Ferrington, 2006) and >1,000 m deep in Lake Baikal (Linevich, 1971). They are among the most tolerant of aquatic insects to extreme of water quality and air temperatures, with larvae of *Paratendipes thermophiles* occurring in hot springs at temperatures of 38.8°C (Hayford et al., 1995), and adults of *Diamesa mendotae* Muttkowski able to depress their freezing point and survive air temperatures less than –20°C (Carrillo et al., 2004; Bouchard et al., 2006). In waters affected by organic pollution and heavy metal contamination, the Chironomidae are usually one of the few invertebrates present (Pinder, 1986). *Chironomus riparius* Meigen is one notable example as it is frequently exceedingly abundant in organically rich waters (Gower & Buckland, 1978).

The Chironomidae is a speciose family, with over 5,000 described species worldwide. They are divided into 11 subfamilies and nominally into 22 tribes (not including five additional provisional tribes resulting from a division within Orthocladiini as proposed by Sæther [1979]). Of the 10 subfamilies of Chironomidae, only four are known from Southeast Asia: the Tanypodinae, Orthocladiinae, and Chironominae are widespread, with one species of Diamesinae recorded from high elevations (above 3,000 m) on Mount Kinabalu in Sabah (Willassen, 1988). According to Karunakarn (1969), subfamilies Tanypodinae, Orthocladiinae, and Chironominae are recorded from Singapore. At present, less than 100 species in 32 genera are documented within the region (Sublette & Sublette, 1973). However, this is likely to represent only a minor portion of the faunal diversity, due to a lack of investigations. For example, Ashe (1990) listed an additional 31 genera from Sulawesi, while the fauna of New Guinea has hardly been investigated.

Although Chironomidae larvae are largely inconspicuous even in large numbers, the aerial swarming behaviour of adult Chironomidae when they emerge from their pupal stages makes them visually distinctive. The swarming behaviour in Chironomids, like those of many aquatic insects such as the mayflies and caddisflies, serves a reproductive purpose. It increases the likelihood of females to be inseminated, while providing the numbers necessary for sexual selection. This behaviour, coupled with mass emergence events, can lead to potential nuisance problems especially in areas close to human habitation.

In Jan.2011, a mass emergence of chironomids was observed close to Bedok Reservoir in eastern Singapore Island. This article is the first to document the mass emergence event, which has been a severe nuisance to the surrounding residential areas. We will then explore human-chironomid interactions around the world and the different control measures employed.

SITE DESCRIPTION

Bedok Reservoir, located within the eastern catchment of Singapore Island, is one of the 17 reservoirs created in Singapore. Formerly a sand quarry, it was constructed in 1981 to meet the nation's demand for water (National Parks Board, 2009). It is surrounded primarily by Housing Development Board (HDB) residential areas to the south, and the Temasek Polytechnic campus to the north. Water sports such as wakeboarding and kayaking have been allowed since 2004, as part of the ABC (Active, Beautiful, Clean) Waters Programme of the Public Utilities Board (PUB) and that aims to transform Singapore into a 'City of Gardens and Waters' through the promotion of recreational activities and public ownership of its 'blue' spaces (Public Utilities Board, 2009).

OBSERVATIONS

Anecdotal reports of 'mosquito-like' insects entering the homes of residents of Bedok surfaced around 2 Jan.2011. The number of these insects, which we later confirmed to be non-biting midges of the family Chironomidae, increased substantially over the subsequent week and started to cause disturbance to the lives of the residents (Cai, 2011a). Chironomids were reported to swarm around household lights and fly into the mouths, eyes, or ears of the residents; causing extreme discomfort (Cai, 2011a; Tan, 2011). Unsightly accumulation of dead adult midges also necessitated an increase in the frequency of cleaning of the housing blocks.

On 20 Jan.2011 at 1000 hours, a trip was made to Bedok Reservoir to document and collect specimens of the problematic chironomids. We did not observe the huge swarms of chironomids as reported in the newspapers (Cai, 2011a, 2011b; Tan, 2011) but individuals were observed flying. Upon further inspection at the grass patch beside the reservoir near Apartment Block 742, adult chironomids were observed to be hiding in the grass and damp soil. A mass of adult chironomids emerged from their hiding areas when the grass patch was disturbed. The adults were small (less than 5 mm long) and yellowish green (Fig. 1). Adult males were differentiated from females by their more slender abdomen, paired reproductive claspers, and prominent, generally plumose antennae (Figs. 2, 3). Using available identification keys, this Chironomidae species was identified to be a member of the sub-family Chironominae (Armitage et al., 1995; Dudgeon, 1999; Yule & Yong, 2004). Further identification to species level proved difficult owing to lack of available regional and Singapore-specific species identification keys for adults.

Chironomid pupal exuviae (cast skins left behind as the pupae undergo eclosion) were observed along the southern and south-eastern shores of the reservoir, indicating a high possibility of mass emergence (Fig. 4). A strong prevailing north-east wind was also observed which could explain the aggregation of pupal exuviae at the southern and south-eastern shores of the reservoir. Spider webs with copious amounts of dead adult midges lining the entire length of the webs were also observed along the recreational floating pontoons (Fig. 5). In addition, large flocks of birds, possibly swifts and swiftlets, were observed circling the open sky between Blocks 745 and 715, likely feeding on the large numbers of emerging chironomids (Fig. 6).

Fig. 1. Resting chironomid adults that emerged from their hiding places in the grass after being disturbed.

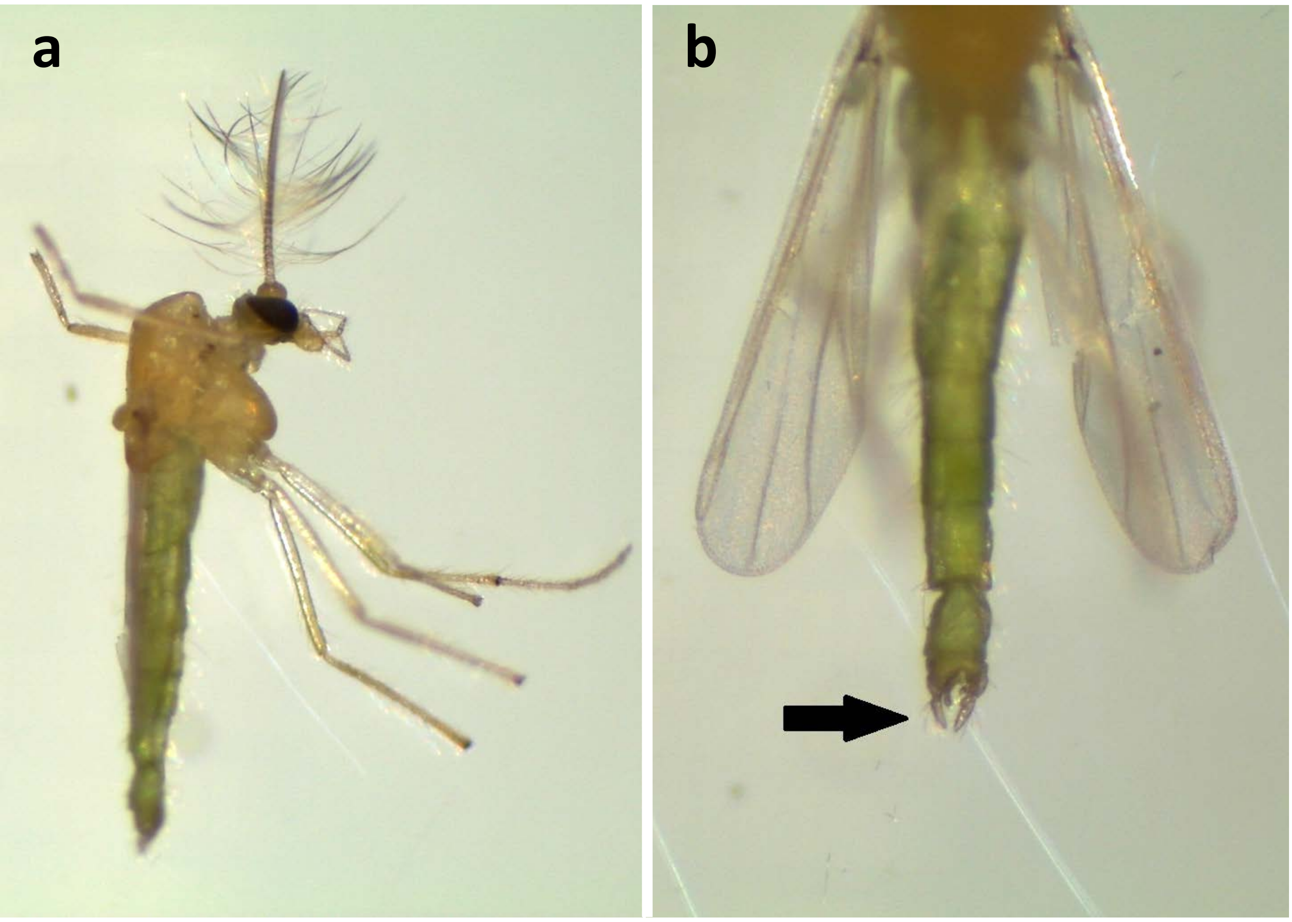

Fig. 2. Adult male Chironominae: a, lateral view. Length from tip of antennae to tip of abdomen = 2.4 mm. Note the plumose antennae and slender abdomen. The lack of biting or piercing mouthparts gives them the name 'non-biting midges'. b, close up ventral view of the abdomen. Width of abdomen (at the widest) = 0.2 mm. The arrow points towards the pair of claspers used for reproduction.

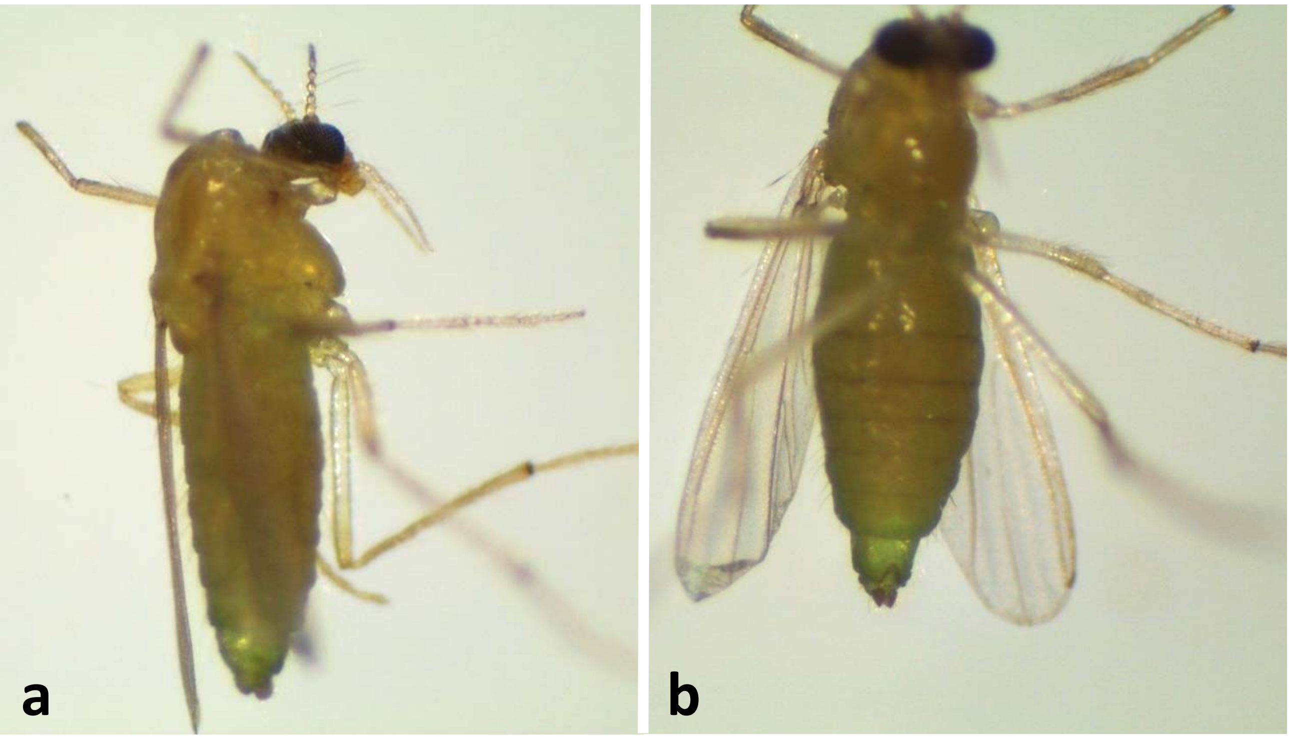

Fig 3. Female Chironominae: a, lateral view. Length from tip of antennae to tip of abdomen = 2.54 mm. Note the lack of plumose antennae, and a rounder abdomen. b, close up ventral view of the abdomen. Width of abdomen (at the widest) = 0.6 mm. Note the lack of paired claspers.

Fig. 4. Pupal excuviae found at the southern and southeastern shores of Bedok Reservoir.

Fig. 5. Spider webs at a floating pontoon covered with dead adult chironomids.

Fig 6. Birds, possibly swifts and swiftlets, circling the open sky to feed on emerging chironomids.

DISCUSSION

Emergence is a necessary process in the life cycle of the Chironomidae where the adult emerges from its pupal stage underwater. Synchronous or mass emergence among chironomids is usually a natural phenomenon to maximise reproductive success by preventing interference from other insects and by reducing losses due to predator 'saturation' (Davies, 1984). The timing of this phenomenon varies greatly among different species and at different latitudes, and may be influenced by seasonal cues (Armitage et al., 1995). This current mass emergence of chironomids observed at Bedok Reservoir is most likely to be a natural phenomenon. However, there may be some unknown underlying emergence cue that resulted in the magnitude of emergence seen. Such a magnitude has never, to date, been recorded before. Future studies into the ecology of the nuisance species will be required to investigate emergence cues for better prediction of emergence patterns.

The extremely large chironomid numbers could have been a result of alien fish species in Bedok Reservoir. In a study of 15 Singaporean reservoirs, 54 alien fish species were recorded from 14 of the 15 studied reservoirs, and 31of these alien fish species were found to be established and breeding (Chua, 2010; Ng & Tan, 2010). Alien fish species may displace and out-compete native fish species, and disrupt natural ecosystems (Britton et al., 2010). It could be possible that small chironomid-feeding fishes that formed part of the Bedok Reservoir freshwater ecosystem fell prey to the mainly predatory alien species there, such as the toman and the Asian arowana (Ng & Tan, 2010), creating a decrease in their numbers. As a result, the chironomid larvae numbers could be left unchecked, resulting in the magnitude of chironomids seen during the mass emergence event.

The swarming behaviour in some species of Chironomidae makes them nuisance species (Ali, 1995), whilst other species are suspected of being sources of environmental allergens (Cranston, 1995) or hosts of pathogenic bacteria (Broza & Halpern, 2001). Much of the nuisance problems associated with chironomids stem from the fact that property developers favour areas near water bodies for development into residential or commercial areas, mainly for their aesthetic value. However, these are also areas where chironomids are naturally occur in large numbers and will exhibit the mass emergence behaviour (Armitage et al., 1995). In the case of Bedok Reservoir, there have been many past and recent housing estates that have developed along the southern fringes since the creation of the reservoir in the 1980s. The close proximity of these residential buildings to the reservoir is bound to bring 'conflicts' between residents and the naturally-occurring chironomids.

The problems caused from the synchronised emergence of dense populations of chironomid species can be quite extant in highly urbanised landscapes. Adult chironomids are attracted to light sources from shops, restaurants, homes, or other places where people congregate, and can stain buildings when meconium is produced and deposited. Dead individuals in large numbers can also clog up screened air intakes to furnaces (Ferrington Jr., 2008), air conditioner cooling systems and compressors, or indoor building environmental systems. These may result in negative economic impacts owing to maintenance costs and business losses. In Florida, these costs have amounted to millions of dollars annually

(Anonymous, 1977) and control efforts were estimated at approximately one million US dollars in Venice in the late 1980s or early 1990s (Ali et al., 1992).

The ecologically diverse Chironominae is the Chironomidae sub-family that is the most likely to be a nuisance. Chironominae species have a relatively high tolerance for environmental conditions, and therefore possess the ability to occupy a wide range of habitats (Oliver, 1971). However, the greatest numbers of individuals typically occur in lakes and lowland streams (Ferrington, 2008), feeding on, for the most part, tubicolous plankton or Aufwuchs (Oliver, 1971). There is evidence that Chironominae emerges in such large numbers that “pest swarms” are produced (Sublette & Sublette, 1973) in many localities, including temperate regions such as the Char Lake in Canada (Welch, 1973), Illinois in the USA (Polls et al., 1975), and Japan (Tabaru et al., 1987), and in tropical regions such as the Wekiva River in Florida (Lobinske et al., 1996), and Khartoum and Omdurman in Sudan (Brown et al., 1961).

Despite the many problems associated with chironomids, they are important in the functioning of ecosystems. Both adults and benthic larvae play essential roles in ecosystem processes such as nutrient cycling and energy flow (Covich et al., 1999). The ecosystem goods and services provided include forming an important part of the food web, being a crucial trophic level for which many fishes depend on (Moss, 2010). Mating swarms of adults attract swifts and swallows as well (Lack & Owen, 1955; St Louis et al., 1990), and at least some species of bats intermittently consume large quantities of adults (Griffith & Gates, 1985). The larvae can also be important in diets of migratory waterfowl during breeding seasons (e.g. Austin et al., 1990). Chironomids also act as ecosystem engineers through accumulation of their faecal pellets in lake sediments, which may change the physical properties and alter living conditions, thus providing a habitat for other benthic organisms (Frouz et al., 2004).

Larval chironomids track environmental conditions: their presence and abundance in freshwaters have long been used to assess water quality (Johnson, 1995; Cranston, 1998) and to classify water bodies (Wiederholm, 1980). Haemoglobin in many larval species allows them to extract oxygen from the oxygen-depleted environments which are indicative of organic pollution, hence enabling them to be good indicator species of eutrophication. In addition, the high tolerance of certain species to extreme environmental conditions, such as acidification, heavy metal contamination, sedimentation, and elevated water temperatures (Pettigrove, 1989; Armitage et al., 1995), makes them ideal aquatic organisms for environmental monitoring.

There is also substantial commercial value to chironomids. It is a food source for freshwater commercial and sport fisheries (Mackay, 1979; Rasmusen, 1990), as food for other species of invertebrates and amphibians (Avery, 1968; Johnson, 1985), and as ingredients in production of insect flour (Bergeron et al., 1988). Chironomids are also a major component of some live and freeze-dried commercial tropical fish food (Armitage, 1995).

Many different control strategies have been employed to combat chironomid pest problems worldwide. In places frequently affected by mass adult chironomid swarms such as the state of Florida in the Unites States, local authorities have experimented with different chemical, biological, and physical methods to curb outbreaks of mass emergence (Lobinske & Ali, 2006; Ali, 1991). Of all the control measures employed, focus has been placed on chemical controls, with physical methods being investigated. The chemical control of midges primarily by larviciding has been attempted mostly in the USA and Japan (Ali, 1991; Tabaru et al., 1987). Lab- and field-based chemical control studies have also been conducted in Europe (Edwards et al., 1964; Ali & Majori, 1984; Ali et al., 1985, 1992), Africa (Abdul-Nasr et al., 1970; Brown et al., 1961), and Australia (Stevens, 1992; Trayler et al., 1994). While chemical methods have shown to be effective in some cases, the high costs of using chemical controls may not be economic should the affected area spread over hundreds of hectares. Understanding the physical and chemical composition of overlying waters as population drivers in relation to chironomid spatial and seasonal distribution may be more effective in curbing their proliferation (Ali, 1991). With this knowledge, manipulation of the environment and even chemical and biological controls can be integrated together in a timely manner to curb this problem more economically and efficiently. Unfortunately, there is still a dearth of knowledge in the ecology, biology, and behaviour of many pestiferous species, especially in tropical Asia (Ali, 1991).

CONCLUSIONS

This particular chironomid mass emergence incident has highlighted the problems that people will be faced with when developments are built close to water bodies where large numbers of chironomids naturally reside. With an increasing number of waterfront developments for their aesthetic value and marketability, there is a need for long-term chironomid control measures to be implemented in these areas. As current knowledge of the ecology and behaviour of Southeast Asian and Singaporean midges is largely lacking, future research can be directed at bridging this knowledge gap, and hopefully help mitigate future problems.

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