



Biology, Ecology and Diversity

Biology and management of the masked chafer *Cyclocephala distincta* Burmeister (Melolonthidae, Dynastinae, Cyclocephalini)

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ABSTRACT

Adults of *Cyclocephala distincta* are flower visitors of Neotropical palms (Arecaceae) and commonly found in the Atlantic Forest of Pernambuco, Brazil. Males and females were collected in the wild and subjected to captive rearing and breeding. The egg hatching rate, the life cycle, longevity of immatures and adults, and oviposition parameters in captivity were analyzed. The average duration of the life cycle of *C. distincta* was 108.2 days ($n = 45$). The egg stage lasted on average 10.9 days, and the egg-hatching rate was 73.9%. The immature stage lasted on average 93.4 days. The larvae stage exhibited negative phototaxis, and the size of their head capsules increased at a constant rate of 1.6 between instars, following Dyar's rule. The average duration of the first instar was 24.8 days ($n = 88$), whereas the second and third instars lasted for 17.2 ($n = 76$) and 40.4 ($n = 74$) days respectively, and survival rates were 21.6%, 86.4% and 97.4%. The pre-pupal stage was recorded, and pupal chambers were built before pupation. The average number of eggs laid per female was 15.5, the total reproductive period lasted for 3.3 days, and the total fertility was 81.2%. Adults that emerged in captivity exhibited an average longevity of 18.9 days. Adult *C. distincta* exhibited thanatosis behavior upon manipulation, a strategy observed for the first time in *Cyclocephala*.

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Introduction

One group of insects which stands out for including highly specialized pollinators are the scarab beetles of the tribe Cyclocephalini, often associated with attractive floral scent volatiles produced by their host plants during episodes of floral thermogenesis (Bernhardt, 2000; Gottsberger, 1990, 1999; Gottsberger and Amaral, 1984; Gottsberger and Silberbauer-Gottsberger, 1991). *Cyclocephala* Dejean contributes with over 85% of the richness of cyclocephaline scarabs, with about 500 described species (Ratcliffe et al., 2013). Little is known about the biology of *Cyclocephala*, but it is generally observed that the adults of many species exhibit crepuscular/nocturnal habits (Ratcliffe, 2008; Riehs, 2006) and feed on pollen, flower parts and nutritious exudates produced by the flowers they visit (Gibernau et al., 1999; Gottsberger, 1986).

Females of *Cyclocephala* lay their eggs directly on soil (Mondino et al., 1997; Santos and Ávila, 2007). The larvae dwell underground, where they feed on grass roots, decaying organic matter or on the petioles of plants (Grebennikov and Scholtz, 2004; Ponchel, 2006;

Ratcliffe, 2003; Ratcliffe and Cave, 2006; Stechauner-Rohringer and Pardo-Locarno, 2010). Depending on the feeding substrate, the larvae can either be treated as contributors to the environmental balance (Gassen, 2000) or destructive agricultural pests (Potter et al., 1996; Ritcher, 1966). The biological cycle of *Cyclocephala* is considered univoltine (it was described as bivoltine only for *C. lunulata* Burmeister, 1847), however, it has only been studied in about 1% of the currently described species (Cherry, 1985; Gavotto, 1964; Nogueira et al., 2013; Rodrigues et al., 2010; Santos and Ávila, 2007; Souza et al., 2014; Stechauner-Rohringer and Pardo-Locarno, 2010).

Cyclocephala distincta Burmeister, 1847 is native to the Guianas, Colombia and Brazil. Adults of the species are known flower visitors of palms, and even assumed as likely pollinators of some species (Arecaceae) (Endrödi, 1985; Voeks, 2002). However, interactions of the larvae with plants are currently unknown. Larvae of several other congeners have been historically documented as pests (Bran et al., 2006; Potter et al., 1996). Nonetheless, most of these species have only been poorly studied regarding their biology, including *C. distincta*, thus hindering the development of strategies for the conservation of native pollinators and efficient pest management. This work aims to evaluate the biological aspects of *Cyclocephala distincta* through the analysis of egg-hatching rates, the life cycle and oviposition parameters.

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Material and methods

Adult *C. distincta* ($n = 227$) were collected in the wild at the Campo de Instrução Marechal Newton Cavalcante (07°50' S; 35°06' W, Abreu e Lima, Pernambuco, Brazil). The CIMNC fragment is considered one of the largest continuous patches of the Atlantic Forest north of the São Francisco River, with lowland dense rainforest (IBGE, 1992). Sampling was carried for three months (December 2010, January and February 2011), between 6:00 p.m. and 5:00 a.m., using light traps. The trap consisted of a vertical white cloth illuminated by a black light 250W, during the new, growing or waning moon stages, when most nocturnal insects exhibit a lower discernment between natural and artificial light sources (Almeida et al., 2012; Nowinszky, 2004). The breeding in captivity was reared under natural environmental conditions of temperature (29.3 ± 0.7 °C) and relative humidity ($56 \pm 1.9\%$), and a fixed photoperiod of 12:12h.

Egg-hatching rate and life cycle. A total of 127 adults were kept in plastic terraria (4 dm³) filled with circa 3 dm³ of potting soil (Gnúmus Ltda). On average, 25 individuals of *C. distincta* (2 ♀: 1 ♂) were allocated per terrarium. A diet of fresh sliced apples and plantains was offered to the beetles (roughly 3.0 g per individual) and replenished every three days (Lai and Shin-ping, 2008; McMonigle, 2006; Souza et al., 2014). Egg-hatching rate, size, viability, coloration, duration, longevity, and behavior of each stage of life cycle were observed. The total duration of life cycle and longevity of adults emerged in captivity were compared between the sexes through Student's t test.

The immature stages were maintained as following:

Egg: On a daily basis, freshly oviposited eggs were removed from the terraria and placed in smaller plastic containers (250 cm³) also filled with c. 167cm³ of potting soil (Gnúmus Ltda).

Larvae: Immediately after hatching, the larvae were transferred to individual plastic containers (250 cm³) also filled with c. 167 cm³ of potting soil (Gnúmus Ltda). To feed the larvae, we prepared an even mix of fresh humus (Gnúmus LTDA) and finely pulverized dead wood and crushed leaf-litter (c. 50 g) that was collected at the site where the adults were captured. This feeding substrate was replenished every three days.

Pre-pupa and pupa: The larvae that reached the pre-pupal stage, and then pupated, were kept in the same containers. Food supply was interrupted.

Females of *C. distincta* captured in the wild ($n = 100$) were individually placed in plastic containers (250 cm³) filled with 167 cm³ of potting soil (Gnúmus LTDA) and fed with a diet of sliced apples and plantains (roughly 3.0 g per individual), replenished every three days (Lai and Shin-ping, 2008; McMonigle, 2006; Souza et al., 2014). To estimate the oviposition parameters, we recorded the pre-oviposition period (time interval between the day of capture to the first posture); number of postures per female; number of eggs per posture; inter-posture period; total reproductive period (interval between the first and last posture in captivity), and overall fertility (ratio of the total number of larvae and total number of eggs).

Results and discussion

During sunlight hours, adult beetles kept in the terraria buried themselves in the substrate and displayed no other activities that could be visualized. Copulation and feeding occurred during nighttime (between 6:00 p.m. and 8:00 p.m.), but independently of each other. In other species of the genus, mating activities were not restricted to any period of the day (Rodrigues et al. [2010] for *C. verticalis* Burmeister, 1847; and Souza et al. [2014] for *C. celata* Dechambre, 1980). Adult *C. distincta* exhibited negative phototaxis, and when handled exhibited thanatosis (Fig. 1). This behavior was characterized by the retraction of all legs and lack of movement from the antennae and maxillary palps. This is the first record of thanatosis for the genus.



Figure 1. Male *Cyclocephala distincta* exhibiting thanatosis behavior. Adult mean size: 10 mm.

Larvae hatching rate and life cycle

Egg

Each egg was accommodated inside an individual cell built by the female out of the soil substrate of the terraria. About 80% of these egg cells were entirely closed, while the remainder exhibited a small opening (approx. 3 mm diameter). The construction of egg cells had been previously described for *C. verticalis*, *C. signaticollis* Burmeister, 1847, *C. melanocephala* (Fabricius, 1755), *C. tucumana* Brethes, 1904, *C. paraguayensis* Arrow, 1913 and *C. celata* (Albuquerque et al., 2014; Morelli, 1991; Nogueira et al., 2013; Rodrigues et al., 2010; Souza et al., 2014) and it is assumed to be a strategy of parental care, since it offers extra protection to the fragile, recently oviposited eggs (Triplehorn and Jonsson, 2011). According to Potter and Gordon (1984), the shell of freshly oviposited eggs of *C. lurida* Bland, 1863 is thin and highly susceptible to desiccation. The same authors also observed that larvae of this species that hatched from eggs subjected to water stress were significantly smaller in size and were sometimes unable to disengage from the chorion membrane.

Freshly oviposited eggs of *C. distincta* were in average 1.2 mm long and 1.0 mm wide ($n = 30$), elliptically shaped, and exhibited a whitish color. During embryonic development, the eggs gradually increased in size and assumed a spherical shape, as previously observed for *C. signaticollis*, *C. parallela* Casey, 1915, *C. paraguayensis* and *C. celata* (Albuquerque et al., 2014; Cherry, 1985; Gavotto, 1964; Souza et al., 2014). The increase in egg size is due to the absorption of water during growth and is made possible by the serosal layer of the egg membrane (Hinton, 1981). The egg stage lasted 10.9 ± 0.2 days ($n = 408$). Egg-hatching rate was 73.9% (Table 1).

Larvae

Both the head and body of newly hatched larvae exhibited a whitish-transparent coloration. One day after hatching, the head assumed an orange coloration, and the body became transparent. The larvae exhibited negative phototaxis and defecated when handled (Fig. 2A). Although no distinguishable odor was detected in the feces of *C. distincta*, the release of fecal material is a widely recognized defense mechanism developed by various animal taxa (Alpert and Ritcher, 1975). The released odor may repel possible predators and increase the chances of survival of the prey (Alpert and Ritcher, 1975). The behavior of defecation when handled was similar to that of *C. verticalis* (Coutinho et al., 2011).

Table 1.Duration (mean \pm DP), interval variation, viability (%), and number of specimens (N) of development stages of *Cyclocephala distincta* in captivity.

Stage	Duration (days)	Interval variation	Viability (%)	N
Egg	10.9 \pm 0.2	9-14	73.9	408
1 st instar	24.8 \pm 5.6	17-42	21.6	88
2 nd instar	17.2 \pm 1.9	9-26	86.4	76
3 rd instar	40.4 \pm 2.3	28-55	97.4	74
Pre-pupa	3.9 \pm 1.5	2-10	90	67
Pupa	11 \pm 0.6	7-15	67.2	45
Adult ♀	20.2 \pm 8.4	4-36	–	24
Adult ♂	17.4 \pm 8.2	4-29	–	21
Egg to adult	108.2 \pm 11	90-137	8.2	45

Three larval instars were recorded in *C. distincta*, easily distinguishable from one another by abrupt changes of the maximum width of the head capsule (Fig. 2B), which increased at a constant rate of 1.6 (1.0–1.6–2.6 mm), following the Dyar's rule (1890). The same rate of increase was found in *C. fosteri* Endrödi, 1963 and *C. paraguayensis* (Albuquerque et al., 2014; Santos and Ávila, 2007). The intervals between successive larval instars (1st–2nd, 2nd–3rd, 3rd–pre-pupal) were respectively 24.8 \pm 5.6 (n = 88), 17.2 \pm 1.9 (n = 76) and 40.4 \pm 2.3 days (n = 74), and survival rates were 21.6%, 86.4% and 97.4%.

As a general rule, the longest interval of the life cycle of holometabolous insects is spent during the larval stage, a period during which they must secure nutritional resources that may be allocated to support growth and/or reproduction in the adult stage (Chapman, 1998). During the larval stage of *C. distincta*, the 3rd instar was the longest, a feature shared with other congeners (Albuquerque et al., 2014; Cherry, 1985; Mondino et al., 1997; Rodrigues et al., 2010; Santos and Ávila, 2007; Souza et al., 2014) and even with other pest species of scarabs (Ávila and Santos, 2009). Because it is the longest, individuals at the 3rd instar exhibit a more pronounced food intake than at the previous instars, and consequently this stage is considered the most damaging to crops (Ávila and Santos, 2009; Oliveira, 2007; Pereira and Salvadori, 2006).

Pre-pupa and pupa

At the end of the 3rd instar, the larvae of *C. distincta* constructed a pupal cell with soil from the rearing substrate. They remained inside it without food, with consequent weight loss (Mondino et al., 1997), until their emergence as imagoes. The silk and other secretions that cement the particles used to build the pupal cells are generally produced by the Malpighian tubules, peritrophic membrane or glands

that open on the last abdominal tergite and are connected to the anus (Costa et al., 1988). During 3.9 \pm 1.5 days (n = 67) prior to pupation, individuals of *C. distincta* remained in the pre-pupal stage, characterized by a milky-white colored tegument, which is thinner and transparent in the abdominal segments VIII, XI and X (Fig. 2C). When handled, the pre-pupae reacted by stretching their bodies, which were previously curved in a characteristic “C” shape.

Ninety percent of the pre-pupae reached the pupal stage. The pupae possessed a yellowish tegument and presented circular mobility of the terminal portion of the abdomen. The stage lasted for 11 \pm 0.6 days and was similar only to what had been previously observed for *C. paraguayensis* (Albuquerque et al., 2014; Cherry, 1985; Mondino et al., 1997; Nogueira et al., 2013; Rodrigues et al., 2010; Santos and Ávila, 2007; Souza et al., 2014). We recorded an emergence rate of 67.2% (n = 45), 21 males and 24 females. We noticed that light-trappings of *C. distincta* yielded more female than male captures, a fact also observed for other congeners, such as *C. clarae* Höhne, 1923, *C. paraguayensis*, *C. suturalis* Ohaus, 1911, and *C. variolosa* Burmeister, 1847 (Riehs, 2006).

According to Fisher (1930), a population will only reach stability when its sex ratio is 1:1. A deviating sex ratio shift is not evolutionarily stable, because gradual increases of individuals belonging to the less abundant sex will occur in future generations. Typically, these deviations are explained by theories involving (1) demographic factors (Otsuka and Koshio, 1999; Yanega, 1996, 1997), (2) local competition for mating and/or inbreeding (Cowan, 1991; Hamilton, 1967), and (3) differential availability of resources in terms of quantity and/or quality (Charnov, 1982; Schwarz, 1988). Nonetheless, specific studies are in order because it is plausible that the putative unbalanced sex ratio observed for *C. distincta* is merely the result of a higher attractiveness of females to artificial light sources (Kober, 1982).



Figure 2. Larval stage of *Cyclocephala distincta* bred in captivity. A, Larva of the 2nd instar defecating (mean size: 1.3 mm); B, Cephalic capsule of the 1st, 2nd and 3rd instars, respectively; C, Transition between the 3rd instar (below) and pre-pupa (above).



Figure 3. Adult *Cyclocephala distincta* bred in captivity. A, Newly hatched male; B, Male one day after hatching; C, Liquid-releasing behavior. Adult mean size: 10 mm.

Adult

The newly emerged adults (Fig. 3A) exhibited pale beige-colored elytra, membranous wings not folded under the elytra, defined stains on the pronotum, and poorly-defined stains on the elytra, as well as limited mobility. One day after emergence (Fig. 3B), the elytra of the beetles assumed a dark beige coloration, hind wings folded under the elytra, stains on the elytra became defined, the insects showed improved mobility, and when handled they presented thanatosis behavior and released a transparent liquid from the anus (Fig. 3C). The discharge of liquids from the anus generally has a defensive function (Chapman, 1998).

Life cycle

The complete life cycle of *C. distincta*, from an egg to a new adult, lasted on average 108.2 ± 11 days; 112.3 ± 11.6 [range: 90, 137] for females and 103.9 ± 8.5 [92, 116] for males, with a significant difference of the duration of the cycle between the sexes ($p < 0.05$; 0.0091). In many insects, males complete the sexual development before their female siblings. This hastier sexual maturation of the males can sometimes be sexually selected (Thornhill and Alcock, 1983). Among species in which the emergence of both sexes is synchronized, the most precocious males will potentially have more chances of finding mates (e.g. Gwynne, 1980), whereas in species with less obvious synchrony, the development may reflect sexually dimorphic patterns of growth and nutritional needs (e.g. Cicero, 1988).

The adults emerged in captivity had an average longevity of 18.9 ± 8.3 days; 20.2 ± 8.4 [4, 36] for females and 17.4 ± 8.2 [4, 29] for males, with no significant difference in longevity between sexes ($p > 0.05$; 0.1055). Virgin females emerged in captivity did not lay eggs. The *C. tucumana* and *C. melanocephala* adults emerged in captivity had an average longevity of 13.3 and 26.0 days respectively (Nogueira et al., 2013).

The complete life cycle of *C. distincta* in captivity is the shortest among all known species of *Cyclocephala*. A rough analysis of the environmental conditions in captivity shows that ambient temperatures throughout the duration of the experiment with *C. distincta* were higher than those under which other congenics were reared (Mondino et al., 1997; Rodrigues et al., 2010; Santos and Ávila, 2007; Souza et al., 2014). Because cyclocephaline scarabs are endothermic, environmental temperatures strongly influence their metabolism (Seymour et al., 2009). Thus, under higher temperatures, the life cycles of these insects are completed faster than they would be at lower temperatures (Duarte and Polanía, 2009; Galvão et al., 1999; Triplehorn and Jonsson, 2011).

Our results show that the larvae of *C. distincta* grow well and healthy when fed an exclusively saprophagous diet. A comparison of the survival rate of *C. distincta* (egg to adult) observed in the current study with that of *C. verticalis*, whose larvae were fed with living roots of grasses (Rodrigues et al., 2010), evidenced a difference of

only 0.9%. Captivity rearing and breeding of beetles of the genus *Cyclocephala* are usually performed using living roots of grasses for larval feeding (Miner, 1948; Rodrigues et al., 2010). However, there are records of some species (*C. amazona* (Linnaeus, 1767), *C. lunulata*, *C. fulgurata* Burmeister, 1847, *C. stictica* Burmeister, 1847, *C. paraguayensis* and *C. celata*) that are identified as facultative saprophages, thus capable of undergoing their entire life cycle without feeding on living plant tissue (Albuquerque et al., 2014; Pardo-Locarno et al., 2005; Souza et al., 2014).

Oviposition parameters

Of the 171 females collected in the field, 57% laid eggs, and the pre-oviposition period was in average 3.7 ± 1.6 days [1, 7] long. We recorded one to three postures per female. The number of postures per female and the corresponding average number of eggs laid per female were: one posture ($n = 24$), 16.7 ± 5.9 eggs; two postures ($n = 22$), 13.5 ± 6.9 eggs, and three postures ($n = 11$), 16.4 ± 5.4 eggs. Female *C. signaticollis* laid in average 17 eggs, and *C. tucumana* laid 6.5 to 10.8 eggs, but the number of postures per individual was not recorded (Gavotto, 1964; Nogueira et al., 2013). Our results show

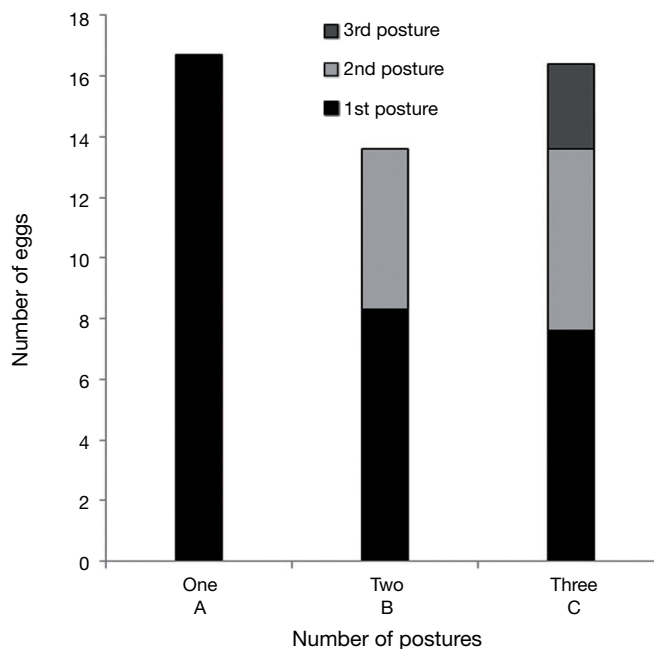


Figure 4. Average number of eggs laid by female *Cyclocephala distincta* in the 1st, 2nd and 3rd postures. A, females that made one posture; B, females that made two postures; C, females that made three postures.

that the number of eggs laid per female tends to be similar, regardless of the number of postures. Distributing the eggs in more than one posture could be a strategy to minimize the pressure of predation and/or parasitism under natural conditions (Zanuncio et al., 1992).

Females that made two postures laid an average of 8.3 ± 6.6 and 5.3 ± 6.1 eggs in the first and second postures, respectively, and those that laid their eggs in three postures had an average of 7.6 ± 6.9 , 6.0 ± 4.4 , and 2.8 ± 1.7 eggs in the consecutive events (Fig 4). These results show a tendency of decrease in the number of eggs per posture. This may be a strategy to preserve oocytes until a new copulation occurs, since the females are under conditions of nutritional stress and the males assist them with nutritional contribution during copulation, as has been observed in many insects (Ganho and Marinoni, 2000; Wheller, 1996).

Gravid females of *C. distincta* who made only two postures exhibited a longer interval between them, in average 2.4 ± 0.9 days. On the other hand, females that made three postures did so in an interval of 1.3 ± 0.5 days between the first and second postures, and of 1.7 ± 2.1 days between the second and the third postures. The total reproductive period lasted for 3.3 ± 2.3 days [1, 12], and the total fertility was 81.2% ($n = 879$).

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Conflicts of interest

The authors declare no conflicts of interest.

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