Monomorium sahlbergi Emery, 1898 (Formicidae, Hymenoptera): a cryptic globally introduced species

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Abstract
The discovery in the Netherlands in a shipping container of the ant Monomorium sahlbergi Emery, 1898, a species similar to the invasive pharaoh ant M. pharaonis (Linnaeus, 1758), led to a quest to better define the distribution of this species, which was initially obscure due to uncertain specimen identifications. Here it is shown that M. sahlbergi, like M. pharaonis, is found worldwide, almost certainly as a result of introductions. Including quarantine interceptions, this species is recorded from seven global biogeographic regions, but its established outdoor distribution is currently limited to the tropics and subtropics. Monomorium dichroum Forel, 1902 is here presented as a junior synonym of M. sahlbergi syn. nov. based on morphometric and CO1 analyses.

Keywords
CO1, invasive species, Monomorium dichroum, Monomorium pharaonis

Introduction
Broadening transport networks and rising demand for commodities have led to increases in alien species worldwide (Hulme 2009), including ants (Suarez et al. 2001; Bertelsmeier et al. 2017). In the Netherlands, for example, a relatively large number
of non-native ant species are being recorded owing in part to the shipments of plant material imported into the country (Boer and Vierbergen 2008).

A concerted effort is underway to identify ant species introduced into the Netherlands, whether they are established or found during import inspections. Thus far 120 species have been identified (Boer et al. 2018). Many of these introduced species are poor colonisers and have not been able to establish and/or spread after arriving (Boer and Vierbergen 2008). The actual number of introduced species is almost certainly greater; some specimens are impossible to identify due to a lack of suitable identification keys and uncertainty about the origin of the ants. Limited identification tools and training increase the chances that species names are ascribed incorrectly, especially in the case of closely related species. In this work we describe an example of one invasive species remaining hidden in the guise of another, more common species. The case concerns two closely related species of the genus *Monomorium*, of which one, *M. pharaonis* (Linnaeus, 1758), is considered the most notorious pest ant species in the world (Wetterer 2010). In the Netherlands, *M. pharaonis* is the first recorded tramp ant species; the oldest specimen is dated 1877 (Boer and Vierbergen 2008).

On 2 June 2014, the pest controller A.J.A. Heetman intercepted ants found in a shipping container at a distribution company in the Netherlands and sent them to the first author. The shipping container, filled with glycine for the food industry, came from a chemical plant in Wuyi, Hengshui, Hebei, China. The intercepted ants appeared similar to the well-known and globally common tramp species *M. pharaonis*, but differed in their black gaster. While trying to identify the specimens, we came across images of identical specimens on AntWeb (http://www.antweb.org), where they were recorded under the provisional name *M. pharaonis* _nr* (CASENT0173275, CASENT0246074) and *M. bicolor* complex (CASENT0178876).

Further comparison of our specimens with the images from AntWeb convinced us that the ants discovered in the Hebei shipping container were a previously described species, *M. dichroum* Forel, 1902 (Figs 1–3). *Monomorium dichroum* was reported as only known from India (type locality) (Imai et al. 1984, Bharti 2015) and China (Guénard and Dunn 2012).

Further exploration of similar species on AntWeb, however, suggested our specimens, and *M. dichroum* for that matter, were identical to *M. sahlbergi* Emery, 1898, a little-known species described from Israel. We set out to ascertain the true identity of our specimens and determine whether *dichroum* and *sahlbergi* are two distinct species.

**Materials and methods**

Available descriptions of all *Monomorium* species occurring in the area between Saudi Arabia in the west and China in the east were consulted. Syntype material of *M. dichroum* and *M. sahlbergi* were requested and investigated. *Monomorium pharaonis*, *M. cf. pharaonis*, *M. nr. pharaonis*, and *M. bicolor*-complex ants identified from the
collection of CASC and RMNH were investigated. In total, we examined hundreds of specimens from the Netherlands, France, Germany, Israel, Saudi Arabia, United Arab Emirates, Oman, Yemen, Seychelles, Papua, Nepal, New Zealand, Western Australia, Myanmar, Taiwan, China, Ivory Coast, Cameroon, Madagascar, Indonesia, Panama, Mexico, Trinidad, Netherlands Antilles, and the United States of America.

For morphometrical comparisons, 16 workers of *M. pharaonis* were examined (all in the collection of Naturalis Biodiversity Center, RMNH). The size and shape characters of these workers were quantified (Table 1) and reported as lengths or indices. All measurements are in millimetres. The numeric characters and abbreviations are defined below.

- **CI**: Cephalic Index (CW/CL) ×100.
- **CL**: Maximum cephalic length in median line.
- **CW**: Maximum cephalic width, across eyes.
- **EYI**: Eye Index (maximum eye length / CW) ×100.
- **Omm**: Number of ommatidia across the widest diameter of the eye.
- **PI**: Petiole Index (Maximum width of petiole / maximum width postpetiole) ×100.
- **PrI**: Promesonotal Index (Promesonotal width / CW) ×100.
- **SI**: Scape Index (Maximum straight line scape length excluding articular condyle / CW) ×100.

The examined specimens in this study are deposited in the following institutions:

- **CASC**: California Academy of Sciences, USA
- **MHNG**: Museum d’Histoire Naturelle, Geneva, Switzerland
- **MSNG**: Museo Civico di Storia Naturale ‘Giacomo Doria’, Genova, Italy
- **RMNH**: Naturalis Biodiversity Center, Leiden, the Netherlands (the former Rijksmuseum van Natuurlijke Historie)
- **TAMU**: Texas A & M University, Texas, USA
- **UCDC**: R.M. Bohart Museum of Entomology, University of California, Davis, USA
- **NZAC**: New Zealand Arthropod Collection, D.S.I.R., Auckland, New Zealand

**DNA sampling**

We sequenced 654 base pairs (bp) of mitochondrial cytochrome oxidase I (COI) gene from 39 *Monomorium* specimens previously identified as *M. pharaonis*, *M. dichromum*, or *M. sahlbergi*. DNA extraction and COI sequencing were performed at University of Guelph (Ontario, Canada) and Naturalis Biodiversity Center (Leiden, the Netherlands), following the protocol described in Fisher and Smith (2008). All sequences are available at GenBank and Appendix 1. Phylogenetic analyses also included 20 *Monomorium* sequences from GenBank and two sequences as outgroup (*Huberia striata* and *Podomyrma* sp.), see Appendix 1 for sequence details.
Molecular phylogenetic inference. Sequences were aligned using Geneious 11.1.5 (Biomatters Ltd.). The phylogenetic tree was inferred in MEGA7 using maximum likelihood and 100 bootstrap replicates. Nucleotide substitution model selection and genetic p-distance calculation were also performed using MEGA7 (Kumar and Tamura, 2016). The best fit model selected under the corrected Akaike Information Criteria (AICc) was GTR+G+I.

Results

CO1

The phylogenetic tree recovered sequences of *M. dichroum* and *M. sahlbergi* in the same clade (Fig. 5), showing low within-clade genetic distance (1.0%). Genetic distance among sequences previously identified as *M. dichroum* and *M. sahlbergi* was also low (1.3%). All *M. pharaonis* sequences clustered together, showing 0.3% within genetic distance and 16.5% genetic distance between this and the *M. dichroum + M. sahlbergi* clade.

Morphological comparisons

*Monomorium dichroum* and *M. sahlbergi* show similar colouration, especially with regard to the infuscate genae and the light spot on the posterior side of the gaster. Morphometrically, these ants are identical. None of the regression analyses of various morphometrical data, such as cephalic width versus cephalic length, scape length, maximum width of postpetiole, width of postpetiole versus width of petioles, comparisons between the cephalic index versus eye index, versus petiole index, versus scape index, and versus promesonotal index, showed any difference. The number of ommatidia across the widest diameter of the eye was the same. Nor could we find any differences in pilosity and pubescence. The surface sculpturing of the head, mesosoma, nodes, and gaster were the same.

### Table 1. Morphometric data of workers of *Monomorium dichroum*, *M. sahlbergi*, and *M. pharaonis*. Arithmetical mean in parentheses.

|                | *M. dichroum* (n = 48) | *M. sahlbergi* (n = 32) | *M. pharaonis* (n = 16) | *M. pharaonis* (n = 50) from Bolton, 1987 |
|----------------|------------------------|-------------------------|-------------------------|------------------------------------------|
| CW             | 0.41–0.54 (0.44)       | 0.40–0.44 (0.42)        | 0.41–0.48 (0.44)        | 0.40–0.48                                |
| CL             | 0.49–0.66 (0.54)       | 0.49–0.54 (0.51)        | 0.52–0.59 (0.56)        | 0.52–0.60                                |
| CI             | 79–85 (82)             | 79–85 (81)              | 75–84 (80)              | 73–80                                    |
| EYI            | 19–24 (21)             | 19–26 (22)              | 18–20 (19)              | 18–21                                    |
| Omm            | 7–10 (9)               | 7–11 (9)                | 7–9 (8)                 | 5–7                                     |
| PI             | 67–86 (74)             | 64–73 (69)              | 71–82 (78)              | –                                       |
| SI             | 102–110 (103)          | 103–110 (106)           | 105–117 (109)           | 105–117                                  |
Figure 1. *Monomorium sahlbergi* from Sacramento, USA, imported from Thailand. Worker, CASENT0005783 A frontal view B lateral view C dorsal habitus.

Figure 2. *Monomorium dichroum*, syntype from Mumbai, India. Worker, CASENT0908718 A frontal view B lateral view C dorsal habitus.

Figure 3. *Monomorium sahlbergi*, syntype from Jericho, Palestine. Worker, CASENT0904576 A frontal view B lateral view C dorsal habitus.

Figure 4. *Monomorium pharaonis* from Nampar Macing, Indonesia. Worker, CASENT0171086 A frontal view B lateral view C dorsal habitus.
Figure 5. Maximum likelihood phylogeny of Monomorium COI sequences. Blue clade corresponds to *M. sahlbergi* and green clade to *M. pharaonis*. Values associated to nodes correspond to bootstrap values.
Both *Monomorium sahlbergi* and *M. pharaonis* belong to the *salomonis* group, as defined by Bolton (1987). For a detailed description of *M. pharaonis* see Heterick (2006). Morphometrically *M. sahlbergi* is similar to *M. pharaonis* (Table 1). Compared to the workers of *M. pharaonis*, 1/4 instead of 2/3 of the first gastral tergite (abdominal segment 4) is light-coloured; the structure of the frontal side of the head is strigulate rather than reticulate; the mesonotal groove is shallower; the pronotum and metanotum are higher than the propodeum in *M. pharaonis* as opposed to equally high in *M. sahlbergi* and promesonotal setae are missing on the mesosoma, in *M. pharaonis* two to six (Figs 1–4). Note that in *Monomorium* specimens the setae are quite stiff and break easily, thus reducing utility of this character in some specimens.

**Taxonomic implications**

*Monomorium sahlbergi* Emery

*Monomorium sahlbergi* Emery, 1898: 131. Syntype worker, ergatoid queen: [Jericho] Jericho, Palestine (J. Sahlberg) (MSNG; worker, unique specimen code CASENT0904576; ergatoid queen, CASENT0904577) [examined].

*Monomorium dichroum* Forel, 1902: 212. Syntype workers: Poona, India (Wroughton) (BMNH, CASENT0902222) [examined]; Bombay, India (Wroughton) (MHNG, CASENT0908718) [examined] syn. nov.

**Distribution.** All records of *M. sahlbergi* originate from desert-like, urban, industrial, and military areas ranging from sea level to an elevation of 1800 m. It is not clear from our research what the original geographic region of *M. sahlbergi* was. Based on the distribution of other species in the *salomonis* group, the native distribution would include specimens from the Indomalaya region (Nepal, India, Thailand). Our data came from the following main geographic regions: Palearctic (China, Israel, Netherlands (interception)), Australian (New Zealand, from likely interceptions), Nearctic (USA, in part interceptions), Neotropical (Panama, Galapagos), Afrotropical (Reunion, Madagascar) and Oceania (Hawaii) (Fig. 6).

**Discussion**

The global distribution of *Monomorium sahlbergi* suggests a history of introductions. Although the native distribution requires further evaluation, specimen records from disturbed habitats suggest that, like the introduction in the Netherlands, this species has already been introduced to other regions. Some distribution records suggest that *M. sahlbergi* could indeed be a successful invasive species, and is already successfully established in areas such as disturbed areas on the islands of the Galapagos (Ecuador) and urban areas in Texas, USA, Panama-City, Hawaii, Madagascar, and Reunion.

It is easy to confuse *M. sahlbergi* with the well-known pharaoh ant *M. pharaonis*, because the former also lives near or in human settlements and looks very similar to
Therefore, we suspect that *M. sahlbergi* has more than once been misidentified as *M. pharaonis*, a view supported by the misidentifications encountered in this study. These findings suggest that *M. sahlbergi* is likely more common than we realise.

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## Appendix I

Monomorium and outgroups COI sequences information. Asterisks (*) in the final column indicate duplicated haplotypes not included in the phylogeny.

| Species                   | Specimen ID number | Geographical region | GenBank accession number | BOLD process ID number |
|---------------------------|--------------------|---------------------|--------------------------|------------------------|
| *Monomorium aithoderum*   |                    | Australia           | KJ847507                 |                        |
|                           |                    | Australia           | KJ847472                 |                        |
| *Monomorium emarginatum*  |                    | USA                 | KJ847473                 |                        |
| *Monomorium exiguum*      | CASENT0135941-D01  | Madagascar          | MT887664                 | ASNAU286-09            |
|                           | CASENT0145058-D01  | Madagascar          | MT887665                 | ASNAU751-09            |
|                           | CASENT0147596-D01  | Madagascar          | MT887669                 | ASNAU850-09            |
| *Monomorium fieldi*       | Australia          |                      | JQ846291                 |                        |
| *Monomorium floricola*    | CASENT0136664-D01  | Comoros             | GU709847                 | ASANO792-09            |
|                           | Costa Rica         |                      | KC418239                 | ACGAJ207-11            |
| *Monomorium minimum*      | USA                |                      | KX687942                 |                        |
|                           | USA                |                      | KX687943                 |                        |
| *Monomorium pharaonis*    | Africa             |                      | KJ847499                 |                        |
|                           | Costa Rica         |                      | KC419188                 | ACGAJ043-11            |
|                           | Korea              |                      | KC407745                 |                        |
|                           | CASENT007802-D01   | Madagascar          | GU710435                 | ASANP639-09            |
|                           | CASENT0120402-D01  | Madagascar          | GU710434                 | ASANP651-09            |
|                           | CASENT0120437-D01  | Madagascar          | GU710437                 | ASANP653-09            |
|                           | CASENT0120835-D01  | Madagascar          | GU710436                 | ASANP657-09            |
|                           | CASENT0122487-D01  | Madagascar          | GU710439                 | ASANP666-09            |
|                           | CASENT0122499-D01  | Madagascar          | GU710438                 | ASANP667-09            |
|                           | CASENT0123480-D01  | Madagascar          | GU710441                 | ASANP673-09            |
|                           | CASENT0125050-D01  | Madagascar          | GU710440                 | ASANP679-09            |
|                           | CASENT0159459-D01  | Seychelles          | HQ546097                 | ASAND352-10            |
|                           | CASENT0159472-D01  | Seychelles          | HQ546095                 | ASAND355-10            |
|                           | CASENT0160217-D01  | Seychelles          | HQ546997                 | ASAND421-10            |
|                           | CASENT0160424-D01  | Seychelles          | HQ547018                 | ASAND445-10            |
|                           | CASENT0161400-D01  | Seychelles          | HQ547092                 | ASAND546-10            |
|                           | CASENT0162033-D01  | Seychelles          | HQ547099                 | ASAND557-10            |
|                           | CASENT0162075-D01  | Seychelles          | HQ547102                 | ASAND560-10            |
|                           | USA                |                      | JX402725                 |                        |
|                           | USA                |                      | KC617835                 | DIRTT037-11            |
| *Monomorium rothsteini*   | Australia          |                      | KC572958                 |                        |
|                           | Australia          |                      | KC572978                 |                        |
| *Monomorium salibergi*    | RMNH.5082323       | Israel              | MT943758                 | MONOM001-20            |
|                           | CASENT0118484-D01  | Madagascar          | MT887671                 | ASAMY032-07            |
|                           | CASENT0121143-D01  | Madagascar          | GU709866                 | ASANO669-09            |
|                           | CASENT0122926-D01  | Madagascar          | GU709869                 | ASANO683-09            |
|                           | CASENT0122935-D01  | Madagascar          | GU709868                 | ASANO684-09            |
|                           | CASENT0122940-D01  | Madagascar          | GU709871                 | ASANO685-09            |
|                           | CASENT0122947-D01  | Madagascar          | GU709870                 | ASANO686-09            |
|                           | CASENT0122966-D01  | Madagascar          | GU709873                 | ASANO687-09            |
|                           | CASENT0122991-D01  | Madagascar          | GU709872                 | ASANO688-09            |
|                           | CASENT0124847-D01  | Madagascar          | GU709875                 | ASANO692-09            |
|                           | CASENT0009847-D01  | New Zealand         | MT887667                 | ASAM1149-07            |
|                           | CASENT0125184-D01  | Reunion             | MT887663                 | ASAMY578-07            |
### Appendix 2

Distribution details of the mapped specimens of *Monomorium sahlbergi*.

| Map ID number | Locality            | Country  | Latitude | Longitude |
|---------------|---------------------|----------|----------|-----------|
| 1             | Maui                | USA      | 20.63    | -156.1    |
| 2             | Kawaihae            | USA      | 20.04    | -155.8    |
| 3             | Elk Grove           | USA      | 38.41    | -121.3    |
| 4             | El Paso             | USA      | 31.76    | -106.4    |
| 5             | College Station     | USA      | 30.63    | -96.33    |
| 6             | Panama City         | Panama   | 8.98     | -79.52    |
| 7             | Galapagos           | Ecuador  | -0.59    | -90.32    |
| 8             | Rijen               | Netherlands | 51.59 | 4.92    |
| 9             | Jericho             | Israel   | 31.86    | 35.46     |
| 10            | Riyadh              | Saudi Arabia | 24.71 | 46.68    |
| 11            | Um-al-Quwain        | UAE      | 25.52    | 55.71     |
| 12            | Wadi Maidaq         | UAE      | 25.35    | 56.09     |
| 13            | Muscat              | Oman     | 23.59    | 58.41     |
| 14            | Socotra             | Yemen    | 12.46    | 53.82     |
| 15            | Mumbai              | India    | 19.08    | 72.88     |
| 16            | Pune                | India    | 18.4     | 73.85     |
| 17            | Belgaum             | India    | 15.85    | 74.5      |
| 18            | Coonoor             | India    | 11.35    | 76.8      |
| 19            | Odisha              | India    | 20.95    | 85.1      |
| 20            | Hetauda             | Nepal    | 27.44    | 85        |
| 21            | Fujian              | China    | 26.48    | 117.92    |
| 22            | Mahajanga           | Madagascar | -15.69 | 46.33    |
| 23            | Toamasina           | Madagascar | -18.14 | 49.4      |
| 24            | Toliara             | Madagascar | -23.35 | 43.69    |
| 25            | Grotte des Premiers Français | Reunion | -21.02 | 55.26 |
| 26            | Le Port             | Reunion  | -20.94   | 55.3      |
| 27            | Napier Port         | New Zealand | -39.48 | 176.91 |
| 28            | Port Nelson         | New Zealand | -41.26 | 173.28 |