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Aphids (Hemiptera: Aphididae), ants (Hymenoptera: Formicidae) and associated flora of Palau with comparisons to other Pacific Islands

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Abstract— Aphids, aphid plant host, and ant associations in the major islands of Palau are reported from collections made during 2000-2001 and 2003-2004. Eleven aphid species and twenty three ant species were collected. None of the collected aphids and ants was indigenous to Palau. Earlier collectors' records are also presented. Aphid and ant distribution on Palau and throughout Micronesia is described. Identification species keys are provided for the aphids and ants from Palau reported in this study.

Introduction

Many exotic, invasive insect species have been accidentally introduced to the Pacific Islands (Nafus 1991, Pike et al. 2000, Daehler and Dudley 2002, Muniappan and Nandwani 2002). The islands of Palau have experienced invasions of alien insects in the past, including the coconut beetle, *Oryctes rhinoceros* L. (Bryan 1949, Muniappan 2002), oriental fruit flies, *Bactrocera dorsalis* (Hendel) and *Bactrocera umbrosa* F. (Allwood et al. 1999), and most recently, the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Anon. 2003).

The known aphids of Palau are all introduced species accidentally introduced over the years. Most are pests of varying importance that occur on crops including bean, guava, banana, citrus, cucumbers, and taro. Others are pests of ornamental plants or infest exotic weeds now widespread throughout the islands. No effective contol measures are employed against aphids on Palau, and

occasional outbreaks of aphids on certain crops such as beans and cucurbits sometimes cause severe yield loss.

The objectives of this study were to identify Palau's aphids and their associated plant hosts, to identify and assess the distribution of ants associated with aphids in Palau, and to provide taxonomic keys for use with the aphids and their attendant ants. Such knowledge provides baseline information with which future aphid and ant introductions may be compared.

Materials and Methods

The Republic of Palau is located in the tropical Western Pacific Ocean at 7° 30' N latitude and 134º 30' E longitude and consists of a cluster of small islets (Fig 1). Aphids were collected in both cultivated and uncultivated settings on the islands of Koror and Babeldaob using search and sample strategies described by Pike et al. (2000). Aphids were preserved in 70% ethanol in 1 ml Corning® cryogenic vials with internal screw tops. Latitude and longitude for each sample site were recorded using a Garmin eTrex® handheld GPS unit.

Ants associated with aphids on plants, as well as those in the immediate vicinity in leaf litter were collected with an aspirator or by direct hand sampling. Voucher specimens of aphids were deposited at the University of Guam and at Washington State University, IAREC, Prosser, Washington. Voucher specimens of ants were deposited at the University of Guam and at Spokane Falls Community College, Spokane, Washington.

Adult aphids to be identified were mounted on glass slides using clearing and preservations methods described by Hille Ris Lambers (1950) and modified by Foottit and Maw (1998). Mounted aphids were identified under a compound microscope using a variety of identification guides (Takahashi 1941; Essig 1956; Calilung 1968; Blackman and Eastop 1984, 1994; Stoetzel and Miller 1998, 2001; Pike et al. 2000).

Ants were identified in the laboratory using published references by Wilson and Taylor (1967) and Hölldobler and Wilson (1990).

The plants from which the aphids and ants were taken were identified on location where possible using identification guides by Moore and Krizman (1981), Stemmermann (1981), Raulerson and Rinehart (1991), and Smith (2002). Plants not identified in the field were photographed for later comparison with specimens preserved in the University of Guam Herbarium, with assistance from Dr. L. Raulerson, Division of Natural Sciences, University of Guam. Plant names used follow Fosberg et al. (1979, 1987).

A morphology-based key to Palauan aphids was generated from collected specimens using published descriptions by Essig (1956), Calilung (1968), Blackman and Eastop (1984), Pike et al. (1991, 2000), Blackman and Eastop (1994), Stoetzel et al. (1996), Stoetzel and Miller (1998, 2001). Scientific names for aphids follow Remaudière and Remaudière (1997).

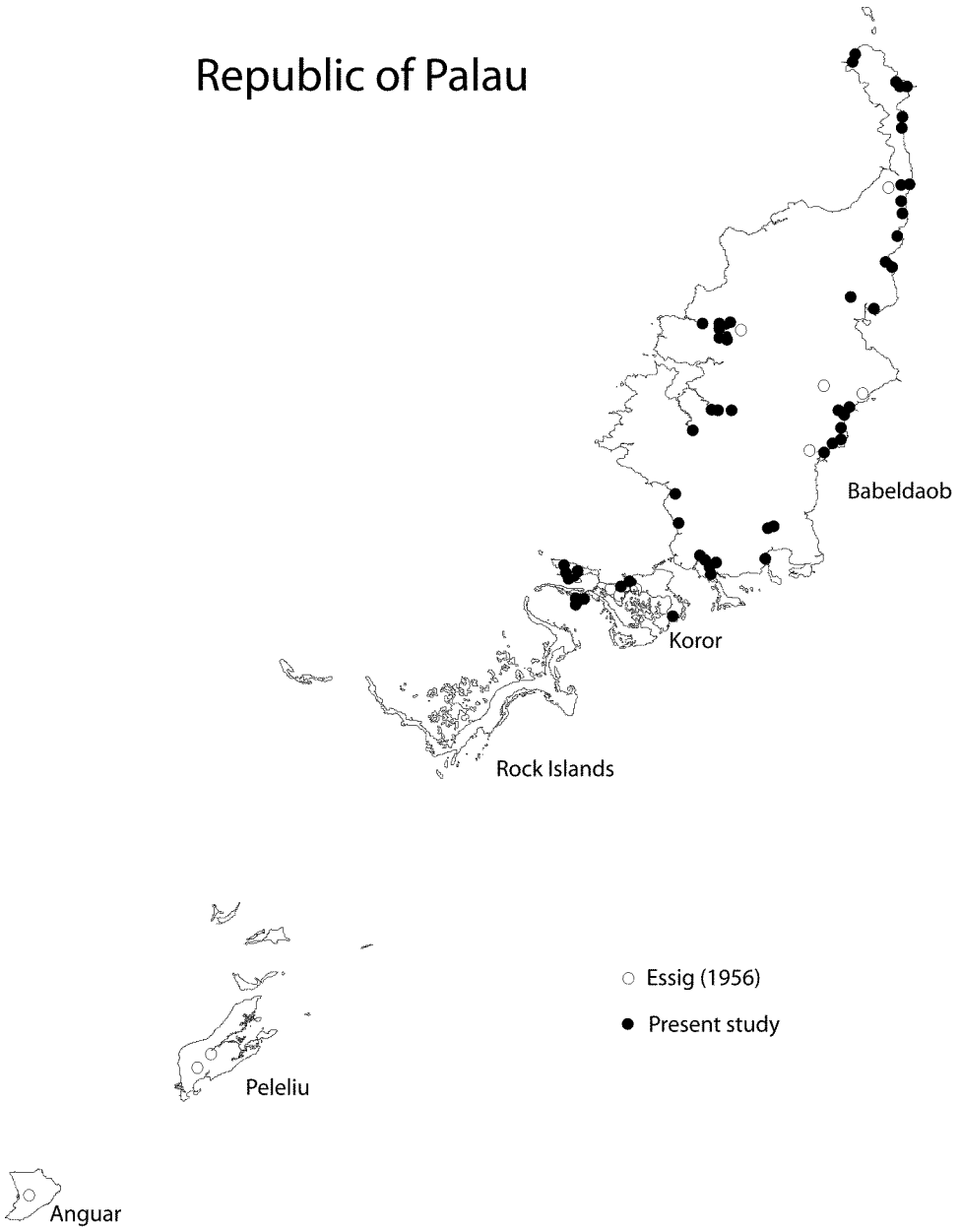

Fig. 1. Map of Palau showing collection sites reported in Essig (1956) and collection sites reported in the present study.

A morphological key to ants collected in this study was generated from collected specimens using published descriptions by Wilson and Taylor (1967) and Hölldobler and Wilson (1990).

Results

The present study combines newly obtained information on ants and aphids in Palau with information from previous studies. Essig (1956) summarized several previous aphid surveys from Micronesia. Similarly, Wilson and Taylor (1967) reviewed information on ants previously published by Wheeler (1932), Brown (1960, 1964), and Brown and Kempf (1960).

Table 1 summarizes aphid × plant associations, while Table 2 provides a restructured plant × aphid summary. Similarly, aphid-ant associations are summarized in Table 3 while ants collected but not associated with aphids are described in Table 4.

There were 14 ant species associated with *Aphis gossypii* Glover on various plant hosts, ten ant species associated with *Pentalonia nigronervosa* Coquerel on banana (Musaceae), heliconia (Heliconiaceae), and ginger (Zingiberaceae). Three ant species were associated with *Hysteroneura setariae* (Thomas) on several species of grasses (Poaceae). *Technomyrmex albipes* (Smith) was found with *A. gossypii* and a single *Tetraneura* sp. on okra (Malvaceae). There was no ant attendance observed with colonies of *Aphis craccivora* Koch or *Rhopalosiphum maidis* (Fitch).

Table 1. Aphid × plant index. Included are scientific name of aphid, scientific name of plant host, collection site, site coordinates (latitude and longitude in decimal degrees), collection date, and reference.

Genus *APHIS* L.

***Aphis craccivora* Koch**

Phaseolus vulgaris L.
Aimeliik, 7.3986N 134.5097E, 11-Apr-01
Ngeremlengui, 7.5294N 134.5611E, 10-Apr-01

Vigna unguiculata (L.)
Airai, 7.4000N 134.5561E, 15-Dec-00

Unidentified leguminose vine
Tobi, Sept 1952, coll. Krauss (Essig 1956)

***Aphis gossypii* Glover**

Abelmoschus esculentus (L.)
Aimeliik, 7.3967N 134.5106E, 11-Apr-01
Ngeremlengui, 7.5249N 134.5459E, 16-Apr-03

Acalypha hispida L.
Koror, 7.3542N 134.4450E, 09-Apr-01

Cassia fistula L.
Angaur, Jan 1953, coll. Beardsley (Essig 1956)

Table 1, continued

Chromolaena odorata (L.) King & H. Rob.
- Aimeliik, 7.3967N 134.5106E, 11-Apr-01
- Aimeliik, 7.4523N 134.5194E, 16-Apr-03
- Airai, 7.3642N 134.5339E, 11-Apr-01
- Airai, 7.3579N 134.5591E, 18-Apr-03
- Airai, 7.4000N 134.5561E, 11-Apr-01
- Airai, 7.3850N 134.5561E, 17-Apr-03
- Koror, 7.3293N 134.4550E, 18-Apr-03
- Koror, 7.3296N 134.4502E, 19-Apr-03
- Koror, 7.3542N 134.4450E, 09-Apr-01
- Koror, 7.5305N 134.4428E, 17-Apr-03
- Koror, 7.3387N 134.4979E, 18-Apr-03
- Koror, 7.3478N 134.4488E, 19-Apr-03
- Ngchesar, 7.4638N 134.5389E, 07-Jan-04
- Ngchesar, 7.4614N 134.6002E, 08-Jan-04
- Ngchesar, 7.4528N 134.6040E, 08-Jan-04
- Ngchesar, 7.4643N 134.5926E, 08-Jan-04
- Ngaraard, 7.5967N 134.6356E, 03-Jan-04

Citrus limon (L.) Burm. f.
- Koror, 7.3539N 134.4461E, 09-Apr-01

Colocasia esculenta (L.) Schott
- Babeldaob, July 1946, coll. Townes (Essig 1956)
- Angaur, Jan 1953, coll. Beardsley (Essig 1956)
- Airai, 7.3618N 134.5267E, 17-Apr-03
- Airai, 7.3579N 134.5591E, 18-Apr-03
- Koror, 7.3524N 134.4456E, 19-Apr-03
- Koror, 7.3296N 134.4502E, 19-Apr-03
- Koror, 7.3493N 134.4495E, 19-Apr-03
- Koror, 7.3387N 134.4979E, 18-Apr-03
- Ngeremlengui, 7.5294N 134.5611E, 14-Dec-00
- Ngeremlengui, 7.5294N 134.5606E, 10-Apr-01
- Ngeremlengui, 7.5250N 134.5460E, 16-Apr-03
- Ngeremlengui, 7.5294N 134.5606E, 16-Apr-03
- Ngchesar, 7.4718N 134.6116E, 08-Jan-04

Cucumis sativus L.
- Koror, Apr 1953, coll. Beardsley (Essig 1956)
- Aimeliik, 7.4523N 134.5194E, 16-Apr-03
- Airai, 7.3850N 134.5561E, 17-Apr-03
- Airai, 7.3826N 134.5545E, 17-Apr-03
- Ngeremlengui, 7.5269N 134.5478E, 14-Dec-00

Hyptis capitata Jacq.
- Koror, 7.3547N 134.4450E, 09-Apr-01

Ixora casei Hance
Aimeliik, 7.3967N 134.5106E, 11-Apr-01
Momordica charantia L.
Aimeliik, 7.3986N 134.5097E, 11-Apr-01
Osmoxylon oliveri Fosb. & Sachet
Airai, 7.3531N 134.4428E, 17-Apr-03
Koror, 7.3417N 134.4721E, 14-Apr-03
Koror, 7.3546N 134.4450E, 17-Apr-03
Koror, 7.3387N 134.4979E, 18-Apr-03
Ngaraard, 7.5967N 134.6356E, 03-Jan-04
Ngchesar, 7.4445N 134.5976E, 08-Jan-04
Premna obtusifolia R. Br.
Koror, 7.3553N 134.4439E, 09-Apr-01
Ngchesar, 7.4445N 134.5976E, 08-Jan-04
Pseuderanthemum carruthersii var. *atropurpureum* (Bull) Fosberg
Aimeliik, 7.3967N 134.5106E, 11-Apr-01
Airai, 7.3642N 134.5339E, 11-Apr-01
Unidentified Composite flower
Pulo Anna, Sept. 1952, coll. Krauss (Essig 1956)
Sonsorol, Sept 1952, coll. Krauss (Essig 1956)

Genus *ASTEGOPTERYX* Karsch

***Astegopteryx bambusae* (Buckton)** (not observed in present study)
Bambusa sp.
Ngermid, Feb 1936, coll. Esaki (Essig 1956)
Ngerkesoaol, Feb 1936, coll. Esaki (Essig 1956)
***Astegopteryx esakii* (Takahashi)** (not observed in present study)
Bambusa sp.
Ngchesar, Aug 1939, coll. Esaki (Essig 1956)
***Astegopteryx rhapidis* (van der Goot)** (not observed in present study)
Cocos nucifera L.
Peleliu (Ngerdelolk), Aug 1939, coll. Esaki (Essig 1956)

Genus *CERATAPHIS*

***Carataphis brasiliensis* (Hempel)**
Areca catechu L.
Airai, Lark Daniel Residence, 05-Oct-04

Genus *HYALOPTERUS* Koch

***Hyalopterus pruni* (Geoffroy)** (not observed in present study)
Unidentified host
Melekeok, Feb 1936, coll. Esaki (Essig 1956)

Table 1, continued

Genus *HYSTERONEURA* Davis

***Hysteroneura setariae* (Thomas)**

Digitaria violascens Link
Koror, 7.3542N 134.4450E, 09-Apr-01
Ngeremlengui, 7.5271N 134.5586E, 16-Apr-03
Ngchesar, 7.4653N 134.5318E, 08-Jan-04

Paspalum paniculatum L.
Airai, 7.3642N 134.5339E, 11-Apr-01
Ngeremlengui, 7.5269N 134.5478E, 10-Apr-01

Genus *PENTALONIA* Coquerel

***Pentalonia nigronervosa* Coquerel**

Alpinia pubiflora (Benth.) K. Schum.
Koror, 7.3550N 134.4461E, 09-Apr-01
Koror, 7.3531N 134.4428E, 17-Apr-03
Ngeremlengui, 7.4728N 134.5311E, 10-Apr-01

Alpinia purpurata (Vieill.) K. Schum.
Airai, 7.3406N 134.3422E, 19-Dec-00
Airai, 7.3619N 134.5267E, 18-Apr-03
Koror, 7.3533N 134.4442E, 22-Dec-00

Caladium sp.
Koror, Jan 1953, coll. Beardsley (Essig 1956)

Hedychium coronarium Koenig
Koror, Sept 1952, coll. Krauss (Essig 1956)
Koror, 7.2126N 134.2666E, 21-Dec-00
Koror, 7.3533N 134.4442E, 09-Apr-01

Heliconia psittacorum L. f.
Koror, 7.3553N 134.4439E, 09-Apr-01
Ngeremlengui, 7.5269N 134.5478E, 10-Apr-01

Hornstedtia scyphifera var *grantis* (Ridl.) Holttum
Airai, 7.3579N 134.5591E, 18-Apr-03
Ngetpang, 7.4536N 134.5294E, 10-Apr-01

Musa sp.
Babeldaob: Ngaraard to Ngerchelong, Feb 1936, coll. Esaki (Essig1956)
Ngeremlengui, Mar 1936, coll. Esaki (Essig 1956)
Ngaraard, Dec 1947, coll. Dybas (Essig 1956)
Koror, Oct 1947, coll. Dybas (Essig 1956)
Aimeliik, 7.4081N 134.5094E, 16-Apr-03
Airai, 7.3579N 134.5591E, 18-Apr-03
Koror, 7.3567N 134.4447E, 09-Apr-01
Koror, 7.3531N 134.4428E, 17-Apr-03

Costus speciocus (Koen.) Sm.
Airai, 7.3642N 134.5339E, 11-Apr-01
Koror, 7.3531N 134.4428E, 17-Apr-03

Genus *RHOPALOSIPHUM* Koch

***Rhopalosiphum maidis* (Fitch)**
Coix lacryma-jobi L.
Koror, July 1946, coll. Oakley (Essig 1956)
Zea mays L.
Koror, Nov & Dec 1953, coll. Beardsley (Essig 1956)
Digitaria violascens Link
Ngeremlengui, 7.5269N 134.5478E, 10-Apr-01
Unidentified grass
Koror, Mar., Nov., & Dec 1953, coll. Beardsley (Essig 1956)

Genus *TETRANEURA* Hartig

***Tetraneura* sp.**
Abelmoschus esculentus (L.)
Aimeliik, 7.4081N 134.5094E, 19-Apr-03

Discussion

Palau has the greatest species diversity of any of the Micronesian islands (Otobed and Maiava 1994). On Babeldaob, the largest of Palau's islands, there are 1,258 taxa (species and varieties) of plants recognized of which 839 are native (Raulerson et al. 1996), 141 species of birds of which eight are endemic (Engbring 1988), three bat species with one species endemic to Palau, and approximately 5,000 species of insects (Cassell et al. 1992). Some insect species in the Mantidae, Phyllinae, Rutelinae, Dynastinae, Glaucytini, Mutillidae, Scoliidae, and Crabronidae are unique to Palau (Gressitt 1954).

The earliest aphid collections on Palau were made by Esaki in 1936, with additional collections made by J. W. Beardsley, H. S. Dybas, T. Esaki, N. L. H. Krauss, R. G. Oakley, and H. K. Townes between May 1945 and February 1954 (Essig 1956, Table 5). Eight aphid species were reported from Palau by 1954. *A. gossypii*, *A. craccivora*, and *P. nigronervosa* were common and frequently abundant on ornamental plants, weeds, and crops, while *H. setariae* and *R. maidis* (Fitch) and an unidentified *Tetraneura* sp. were uncommon. *Astegopteryx bambusae* Buckton, *Astegopteryx esakii* (Takahashi), *Astegopteryx rhapidis* (van der Goot), and *Hyalopterus pruni* (Geoffroy) previously reported on Palau, were not found in the present study and may no longer be present.

The collections of *H. setariae* and *Tetraneura* sp. constitute new records for Palau. *Tetraneura* is a small group of aphids with about 20 species that alternate between hosts of *Ulmus* spp. and the roots of grasses (Poaceae) (Blackman and Eastop 1984). A single *Tetraneura* sp. in association with a colony of *A. gossypii* was collected in Palau from okra. This aphid was probably an errant transient as

Table 2. Plant × aphid index. Included are names of families and plant speices on which aphids were collected. ♠ indicates a plant indigenous to Palau. ♠♠ indicates a plant endemic to Palau (Fosberg et al. 1979, 1987).

Plant family	Host plant	Aphid species
Acanthaceae	*Pseuderanthemum atropurpureum*	*Aphis gossypii*
Aracaceae	*Areca catechu*	*Cerataphis brasiliensis*
Araceae	*Caladium* sp.	*Pentalonia nigronervosa*
	Colocasia esculenta	*Aphis gossypii*
	Osmoxylon oliveri ♠♠	*Aphis gossypii*
	Cocos nucifera ♠	*Astegopteryx rhapidis*
	Chromolaena odorata	*Aphis gossypii*
Compositae	Unidentified flower	*Aphis craccivora*
Cucurbitaceae	*Cucumis sativus*	*Aphis gossypii*
	Momordica charantia	*Aphis gossypii*
Euphorbiaceae	*Acalypha hispida*	*Aphis gossypii*
Fabaceae	*Cassia fistula*	*Aphis gossypii*
	Phaseolus vulgaris	*Aphis craccivora*
	Vigna unguiculata	*Aphis craccivora*
Heliconiaceae	*Heliconia psittacorum*	*Pentalonia nigronervosa*
Lamiaceae	*Hyptis capitata*	*Aphis gossypii*
Malvaceae	*Abelmoschus esculentus*	*Aphis gossypii*
	Abelmoschus esculentus	*Tetraneura* sp.
Musaceae	*Musa* sp.	*Pentalonia nigronervosa*
Poaceae	*Bambusa* sp.	*Astegopteryx esakii*
	Bambusa sp.	*Astegopteryx bambusae*
	Coix lacryma-jobi	*Rhopalosiphum maidis*
	Digitaria violascens	*Hysteroneura setariae*
	Paspalum paniculatum	*Hysteroneura setariae*
	Zea mays	*Rhopalosiphum maidis*
	Unidentified grass	*Rhopalosiphum maidis*
Rubiaceae	*Ixora casei* ♠	*Aphis gossypii*
Rutaceae	*Citrus limon*	*Aphis gossypii*
Verbenaceae	*Premna obtusifolia* ♠	*Aphis gossypii*
Zingiberaceae	*Alpinia pubiflora* ♠♠	*Pentalonia nigronervosa*
	Alpinia purpurata	*Pentalonia nigronervosa*
	Hedychium coronarium	*Pentalonia nigronervosa*
	Hornstedtia scyphifera	*Pentalonia nigronervosa*
	Costus speciocus	*Pentalonia nigronervosa*

Table 3. Ants associated with aphids on Palau.

Aphid	Ant
Aphis craccivora	none
Aphis gossypii	*Anoplolepis gracilipes* *Camponotus reticulatus* *Iridomyrmex anceps* *Monomorium floricola* *Monomorium monomorium* *Paratrechina bourbonica* *Paratrechina longicornis* *Pheidole fervens* *Pheidole* sp. *Solenopsis geminata* *Tapinoma melanocephalum* *Tapinoma* sp. *Technomyrmex albipes* *Tetramorium bicarinatum*
Hysteroneura setariae	*Camponotus navigator* *Tapinoma melanocephalum* *Technomyrmex albipes*
Pentalonia nigronervosa	*Anoplolepis gracilipes* *Camponotus reticulatus* *Cardiocondyla emeryi* *Cardiocondyla wroughtonii* *Paratrechina bourbonica* *Pheidole* sp. *Tapinoma melanocephalum* *Technomyrmex albipes* *Technomyrmex* sp. *Tetramorium bicarinatum*
Rhopalosiphum maidis	none
Tetraneura sp.	*Technomyrmex albipes*

Table 4. Collected ants that were not associated with aphids. Included are scientific name of ant, plant host, collection site, collection site coordinates (latitude and longitude in decimal degrees), and collection date or reference.

***Pachycondyla croceicornis* (Emery)**
Ground; Koror, 7.3546N 134.4450E, 17-Apr-03
***Camponotus chloroticus* Emery**
Trail on ground; Koror, 7.3546N 134.4450E, 17-Apr-03
Retaining wall; Airai, 7.3618N 134.5267E, 18-Apr-03
Ground; Koror, 7.3350N 134.4740E, 19-Apr-03
***Camponotus reticulatus* Roger**
Dead log on yard; Airai, 7.3847N 134.5586E, 15-Apr-03
Ground near lily pond; Koror, 7.3350N 134.4740E, 19-Apr-03
House floor; Airai, 7.3847N 134.5586E, 19-Apr-03
***Cardiocondyla wroughtonii* (Forel)**
Ground NW corner of dock; Koror, 7.3293N 134.4550E, 18-Apr-03
***Eurhopalothrix procera* (Emery)** (not observed in present study)
Unknown host; Palau, (Wilson & Taylor 1967)
***Monomorium monomorium* Bolton**
Ground, NW corner of dock; Koror, 7.3293N 134.4550E, 18-Apr-03
***Odontomachus simillimus* Smith**
Soil under house; Koror, 7.3472N 134.4814E, 05-Jan-04
Trail ground; Koror, 7.3546N 134.4450E, 17-Apr-03
***Paratrechina bourbonica* (Forel)**
Port pavement; Ngiwal, 7.5373N 134.6252E, 03-Jan-04
Ground; Airai, 7.3847N 134.5586E, 19-Apr-03
***Paratrechina longicornis* (Latreille)**
Debris/fallen leaves; Koror, 7.3553N 134.4439E, 09-Apr-01
Ground; Koror, 7.3539N 134.4461E, 09-Apr-01
Ground by cargo container; Koror, 7.3293N 134.4550E, 18-Apr-03
Edge of old building; Koror, 7.3293N 134.4550E, 18-Apr-03
Ground, NW corner of dock; Koror, 7.3293N 134.4550, 18-Apr-03
Ground, NW corner of dock; Koror, 7.3293N 134.4550E, 18-Apr-03
***Pheidole megacephala* (F.)**
Near cargo container; Koror, 7.3293N 134.4550E, 18-Apr-03
Ground, NW corner of dock; Koror, 7.3293N 134.4550E, 18-Apr-03
***Pheidole umbonata* Mayr**
Ground; Koror, 7.3539N 134.4461E, 09-Apr-01
Ground, NW corner of dock; Koror, 7.3293N 134.4550E, 18-Apr-03
House floor; Airai, 7.3847N 134.5586E, 19-Apr-03
***Polyrhachis dives* Smith**
PCC concrete walkway; Koror, 7.3414N 134.4716E, 19-Apr-03
***Pyramica karawajewi* (Brown)** (not observed in present study)
Unknown host; Peleliu (Brown 1953, in Wilson and Taylor, 1967)

***Solenopsis geminata* (F.)**
Edge of old building on dock; Koror, 7.3293N 134.4550E, 18-Apr-03
***Tapinoma melanocephalum* (F.)**
Ground; Koror, 7.3539N 134.4461E, 09-Apr-01
On retaining wall; Airai, 7.3618N 134.5267E, 18-Apr-03
House floor; Airai, 7.3847N 134.5586E, 19-Apr-03
Ground; Koror, 7.3546N 134.4450E, 17-Apr-03
***Technomyrmex albipes* (Smith)**
Dead log in yard; Airai, 7.3847N 134.5586E, 15-Apr-03
Ground; Airai, 7.3847N 134.5586E, 19-Apr-03
Ground; Koror, 7.3546N 134.4450E, 17-Apr-03
***Tetramorium bicarinatum* (Nylander)**
Dead log in yard; Airai, 7.3847N 134.5586E, 15-Apr-03

okra does not normally serve as a host for *Tetraneura* (Blackman and Eastop 1984).

The rusty plum aphid, *H. setariae*, is of North American origin and is widely distributed throughout the warmer parts of the world (Blackman and Eastop 1984). In Palau, *H. setariae* colonies were found on leaves and immature seeds of *Digitaria violascens* Link and *Paspalum paniculatum* L., both Poaceae.

Hyalopterus pruni was first found in Palau by Esaki in 1936 (Essig 1956) on an unidentified host, but was not detected during the present study. On Guam, *H. pruni* was reported on *Phragmites karka* (Retz.) by Swezey (1942) but was not found during recent collecting trips (Pike et al. 2000).

Because ant dispersal is often associated with humans (Wilson 2000), most of the common ants in the Indo-Pacific region are "tramp ants" moved from island to islands as a by-product of human commerce (Wilson and Taylor 1967). Tramp ant species are generally invasive and opportunistic foragers that dominate natural habitats by displacing native fauna. They may compete with other insects for food, driving some including rare, indigenous species, to extinction (Staples and Cowie 2001).

Brown (1960, 1964) and Brown and Kempf (1960) initially described 14 ant species from Micronesia: *Odontomachus simillimus* Smith, *Eurhopalothrix procera* (Emery), *Smithistruma dubia* Brown, *Pheidole fervens* Smith, *Monomomorium pharaonis* (L.), *Monomorium talpa* Emery, *Pheidole* (Pheidolacanthinus) *sexspinosa* Mayr, *Tetramorium pacificum* Mayr, *Iridomyrmex anceps* (Roger), *Tapinoma minutum* Mayr, *Technomyrmex albipes* (Smith), *Anoplolepis gracilipes* (Smith), *Cardiocondyla wroughtonii* (Forel), and *Camponotus reticulatus* Roger. Neither Brown (1960, 1964), and Brown and Kempf (1960) specified the islands from which these specimens were collected (Table 6). However, three of these ants were documented in more detail by Wilson and Taylor (1967) who reported *T. albipes* from Koror, *Pyramica karawajewi* (Brown) from Peleliu, and *E. procera* from an unspecified location in Palau.

Twenty three ant species were collected during the present study, belonging to 13 genera in 4 subfamilies (Tables 3, 4). Two species recorded by Brown (1960, 1964), *E. procera* and *P. karawajewi*, were not collected during this study which was centered on Palau's seaport, and urban and disturbed areas in Koror and Airai. Twelve of the 27 species of ants collected in this study are cosmopolitan known tramp species (Wilson and Taylor 1967). These include *A. gracilipes*, *P. bourbonica*, *P. longicornis*, *T. melanocephalum*, *C. emeryi*, *C. wroughtonii*, *M. monomorium*, *M. floricola*, *P. megacephala*, *S. geminata*, *T. bicarinatum*, and *T. lanuginosum*. A. Olsen (personal communication, Palau National Museum, Koror) has made numerous additional collections from throughout Palau and estimates the total number of ant species in Palau to be around 60 with some indigenous species present.

Six of the 27 ant species reported in this study, *C. chloroticus*, *I. anceps*, *T. albipes*, *E. procera*, *P. ferve*ns, *P. umbonata*, *P. karawajewi*, and *O. simillimus*, are indigenous to Indo-Australia and Asia with broad discontinuous distributions throughout Pacific islands (Wilson and Taylor 1967).

Ant attendance of aphids may result in larger than normal aphid colonies which feed more heavily (Way 1963). The presence of aphid-attending ants on Palau will likely allow aphids to colonize a wider area than in the absence of attending ants.

The recent development of the interior and coastal areas of Babeldaob spurred by the general economic upturn in the Asian tourism business, inflows of funds and resources from Asian rim nations, and the completion of a paved access road and national capital in Melekeok on Babeldaob that will open up the interior of that island to development, will pose particular challenges with regards to invasive species management. Palau's heavy dependence on imported food and goods, its high visitation rate from Guam, the Philippines, and increases in agriculture and commerce associated with increased development will accelerate the spread of aphids and associated ant species on Palau. Native plants and animals, unadapted for competing with these and other invaders, will likely suffer.

Introduced invasive insect species, including exotic aphids and ants described in this study, may interact with resident insects, vegetation, and wildlife in a range of different ways and may displace native species from their niches (Wilson 1988). Generally, ants are opportunistic. Some such as those in the genus *Solenopsis*, *Pheidole*, and *Polyrhachis* are predatory and attack humans, invade bird nests, and kill other insects and other ant species in their vicinity (Way et al. 1998). In a short time they may come to dominate insular ecosytems through competitive displacement of native fauna and alter ecosystem structure and function (Gordon 1999).

Aphids are mobile vectors of many crop diseases, as well as being crop pests themselves. In Palau, invading aphids are largely free of predators and

Table 5. Distribution of aphids in Micronesia sorted by aphid subfamily (after Essig 1956). The numbers and letter in columns indicate the source documenting the aphid's occurrence (see footnote).

	Micronesian Island Groups												
		Carolines							Mariana Islands				
Aphid	Palau	Yap	Caroline Atolls	Chuuk	Pohnpei	Kosrae	Marshall	Gilbert	Guam	Rota	Saipan	Tinian	Wordwide Distribution
Subfamily Aphidinae													
Aphis craccivora Koch	P	1,2	1	1,2	1	1,2	1,4		1,3	1	1		Pacific Is., Europe, Africa, N. & S. America
Aphis gossypii Glover	1,P	1,2	1	1,2	1,2	1,2	1,4	1	1,3	1	1	1	Cosmopolitan
Hyalopterus pruni (Geoffroy)	1								1				Pacific Is., Asia, Europe, Africa, N. America
Hysteroneura setariae (Thomas)	P								3				
Pentalonia nigronervosa Coquerel	1,P	1		1,2	1		1,4		1,3		1		Pacific Is., Asia, S. America, Africa
Rhopalosiphum maidis (Fitch)	1,P	1		1	1				3		1		Pacific Is., Asia, Africa, Australia, New Zealand, N. & S. America, Europe (greenhouse)
Subfamily Pemphiginae													
Tetraneura sp.	P												
Subfamily Hormaphidinae													
Astegopteryx bambusae Buckton	1												S. Asia
Astegopteryx esakii (Takahashi)	1												
Astegopteryx rhapidis (van der Goot)	1												Singapore, Java, Sumatra
Cerataphis brasiliensis (Hempel)	P												

1 = Essig (1956), 2 = Esguerra & Javier (1990), 3 = Pike et al. (2000), 4 = Muniappan & Nandwani (2002), P = Present study.

Table 6. Distribution of ants in Micronesia sorted by subfamily (after Terayama et al. (1994). Numbers and letters represents author's code for source reference and current status (see footnote).

Ant	Micronesian Island Groups															Status	Origin
		Carolines							Mariana Islands								
	Palau	Yap	Caroline Atolls	Chuuk	Pohnpei	Kosrae	Marshall	Gilbert	Guam	Rota	Saipan	Tinian	Northern Mariana				
Subfamily Formicinae																	
Anoplolepis gracilipes (Smith)	P								1,2		3,7		7			T	Africa
Camponotus chloroticus Emery	P								1,2				7			D	
Camponotus reticulatus Roger	P																
Camponotus navigator Wilson	P																
Paratrechina bourbonica (Forel)	P								1,2		3,7		7			T	
Paratrechina longicornis (Latreille)	P								1,2	7			7			T	SE Asia
Polyrhachis dives Smith	P																
Subfamily Dolichoderinae																	
Iridomyrmex anceps (Roger)	P										7		7			D	Indo-Australian
Tapinoma melanocephalum (F.)	P								1,2		3		7			T	
Tapinoma sp.	P																
Technomyrmex albipes (Smith)	P								1,2							D	Asia
Technomyrmex sp.	P																

Table 6, continued

Subfamily Myrmicinae											
Cardiocondyla emeryi Forel	P					1,2		3	7	T	
Cardiocondyla wroughtonii (Forel)	P					2			7	T	Tropical Asia
Eurhopalothrix procera (Emery)	4									D	
Monomorium monomorium Bolton	P									T	
Monomorium floricola (Jerdon)	P									T	Tropical Asia
Pheidole fervens Smith	P					1,2			7	D	
Pheidole megacephala (F.)	P					6				T	Africa
Pheidole umbonata Mayr	P					2			7	D	
Pheidole sp.	P							3			
Pyramica karawajewi (Brown)	5		5	5	5					D	Tropics, Warm Tropical Zone
Solenopsis geminata (F.)	P					1,2		3		T	
Tetramorium bicarinatum (Nylander)	P					1,2				T	Africa
Tetramorium lanuginosum Mayr	P					1,2	7	3	7	T	Tropical Asia
Subfamily Ponerinae											
Pachycondyla croceicornis (Emery)	P										
Odontomachus simillimus Smith	P					1,2	7	3	7	D	Indo-Australian

Modified after Terayama et al. (1994): 1 = Wheeler (1912), 2 = Swezey (1942), 3 = Weber (1950), 4 = Brown (1960), 5 = Brown (1964), 6 = Schreiner (1991), 7 = Terayama et al. (1994), P = Present study.
Status: T = tramp species, D = Distributed from Indo-Australia to Pacific Islands.

parasitoids, allowing them to colonize crops and ornamentals with few of the environmental constraints they face in areas with rich natural enemy complexes. Furthermore, some endemic plants on Palau appear well suited as aphid hosts. Some, such as *Premna obtusifolia* and *Osmoxylon oliveri* are widely distributed in Palau.

Biological invasions of exotic insects may lead to elevated extinction rates for island species. Extinction rates are higher on oceanic islands than on continental land masses, because island species generally have small populations, restricted genetic diversity, and narrow host ranges (Cox 1999).

Among the pestiferous aphids that are a threat to be introduced and established in Palau in the future is the brown citrus aphid, *Toxoptera citricida* (Kirkaldy). Originally from Asia, it is now widely spread in many Pacific islands (Blackman and Eastop 1984), and is a common pest of several citrus species on Guam (Pike et al. 2000). The ability of this aphid to vector citrus tristeza virus (CTV), the high volume of visitors to Palau from Guam, the Philippines and China and the imporation of nursery stock from these areas, increases the probability of its introduction.

The Compact road now under construction on Babeldaob (Stayman and Graves 1998) will increase the opportunity for biological invasion by aphids and ants, as well as other species. The relatively pristine habitats in the interior of Babeldaob may in the future be threatened by the impact of these and other alien, invasive species (Shugart 1998, Mooney and Hobbs 2000).

KEY TO APHIDS OF PALAU

1 Apterous (wingless) female 2
Alate (winged) female 10

2(1) Cornicle mere pore or slightly raised cone (Fig. 2a) 3
Cornicle elongated (Fig. 2b & 2c) 5

3(2) Head with frontal horns (Fig. 2d) 4
Head without frontal horns ..... *Tetraneura* sp.

4(3) Body margin entirely encircled with wax glands
..... *Cerataphis brasiliensis* (Russell)
Body margin without encircling wax glands ..... *Astegopteryx* spp.
[Three spp. reported from Palau (not seen by authors): *A. bambusae, A. esakii, A. rhapidis*]

5(2) Cornicle flanged (Fig. 4b) 6
Cornicle flangeless (Fig. 4a) ..... *Hyalopterus pruni* (Geoffroy)

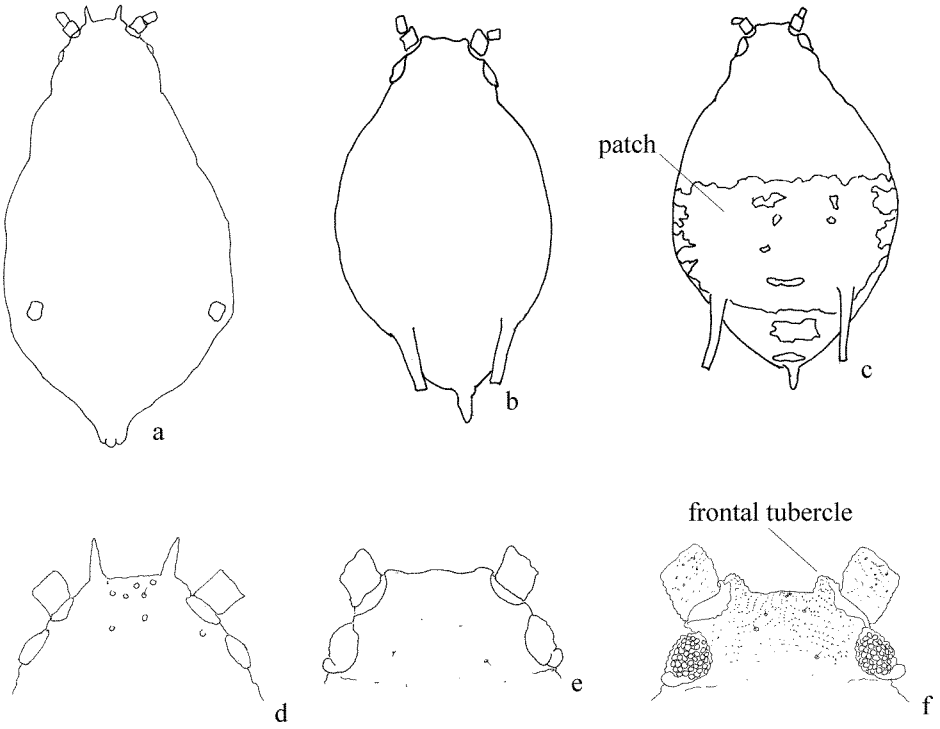

Fig. 2. Aphid features (illustrations not to scale): a) *Astegopteryx* sp., cornicle mere pores [after Blackman and Eastop 1984]; b, *Aphis gossypii*, abdomen without patch; c, *Aphis craccivora*, abdomen with large pigmented patch; d, *Astegopteryx* spp., head with hornlike processes [after Takahashi 1941]; e, *Aphis* sp., frontal tubercles weakly developed; f, *Pentalonia nigronervosa*, frontal tubercles developed.

6(5) Frontal tubercles distinctly developed and protuberant (Fig. 2f); cornicle swollen ..... *Pentalonia nigronervosa* Coquerel
Frontal tubercles only weakly developed (Fig. 2e); cornicle not swollen 7

7(6) Abdominal dorsum with large pigmented patch (Fig. 2c) .... *Aphis craccivora* Koch
Abdominal dorsum without pigmented patch (Fig. 2b) 8

8(7) Cauda and cornicles equally dark; legs dark . *Rhopalosiphum maidis* (Fitch)
Cauda pale or at least paler than cornicles; legs pale or with pale areas 9

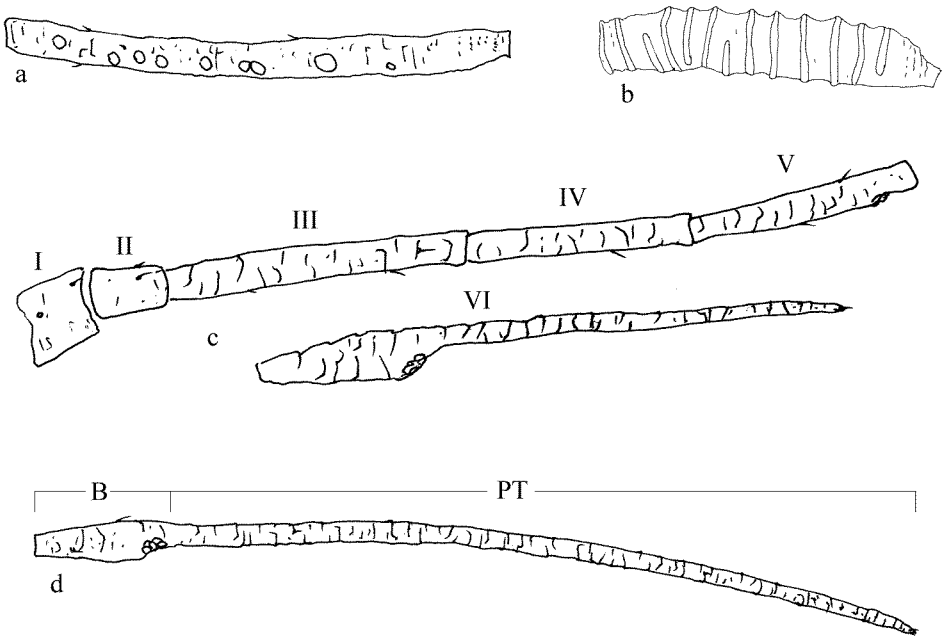

Fig. 3. Aphid features (illustrations not to scale). a, *Pentalonia nigronervosa*, sensorial on antennal segment III circular; b, *Tetraneura* sp., sensoria on antennal segment III annular [after Pike et al. 2000]; c, *Aphis gossypii*, filament of sixth antennal segment longer than third; d, *Hysteroneura setariae*, antennal segment VI, (PT) processus terminalis 5x longer than base (B) of segment.

9(8) Processus terminalis > 5x base of segment (Fig. 3d); grass feeder
.....*Hysteroneura setariae* (Thomas)
Processus terminalis < 3x base of segment (Fig. 3c); not on grass
.....*Aphis gossypii* Glover

10(1) Antennal segment III sensoria transverse to annular (Fig. 3b) 11
Antennal segment III sensoria circular (Fig. 3a) 12

11(10) Antenna 6-segmented; media of fore wing unbranched (Fig. 4d).....
.....*Tetraneura* sp.
Antenna 5-segmented; media once-branched.....Cerataphidini
[Includes: *Cerataphis brasiliensis*, *Astegopteryx bambusae, A. esakii, A. rhapidis* (latter three species not seen by authors)]

12(10) Fore wing radial sector fused with median vein; wing veins conspicuously bordered (Fig. 4e) .... *Pentalonia nigronervosa* Coquerel
Fore wing radial sector not fused with median vein; veins not bordered ... 13

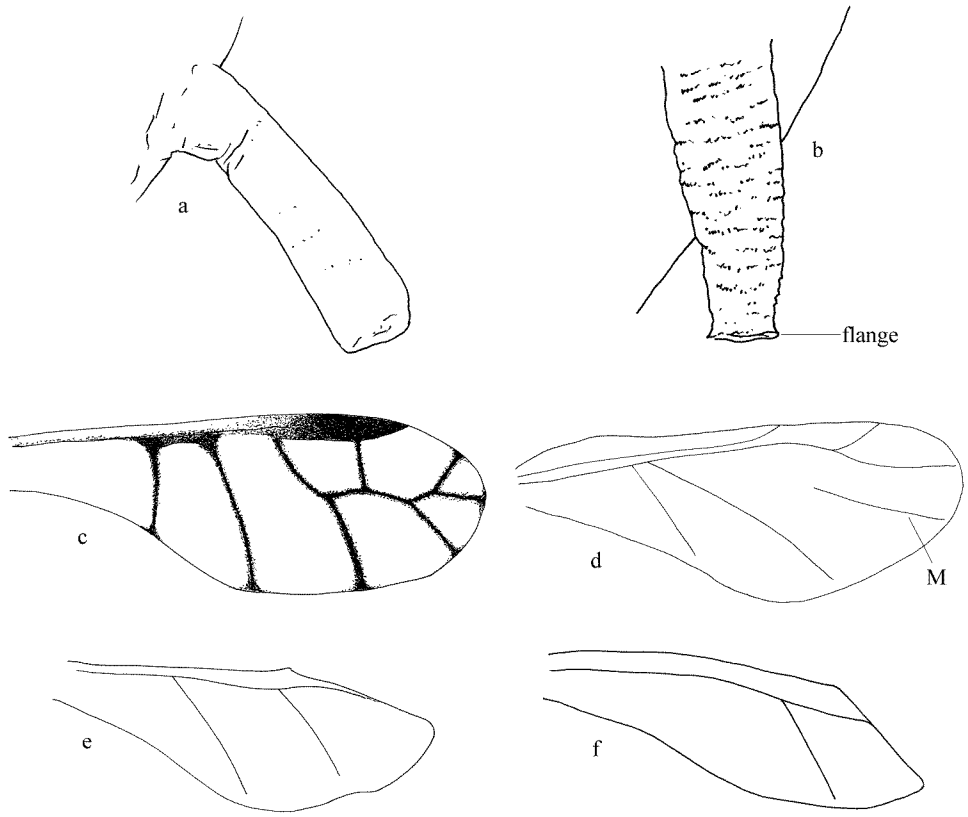

Fig. 4. Aphid features (illustrations not to scale). a, *Hyalopterus pruni*, tip of cornicle flangeless; cornicle shorter than or equal in length to cauda; b, *Rhopalosiphum maidis*, tip of cornicle flanged; cornicle slightly longer than cauda; c, *Pentalonia nigronervosa*, wing veins bordered; d, *Tetraneura* sp., (M) media of fore wing unbranched [after Pike et al. 2000]; e, *Aphis* sp., hind wing with two cross veins. f) *Hysteroneura setariae*, hind wing with a single cross vein.

13(12) Hind wing with one cross vein (Fig. 4f) . *Hysteroneura setariae* (Thomas)
Hind wing with two cross veins (Fig. 4e) 14

14(13) Cornicle flangeless (Fig. 4a)..... *Hyalopterus pruni* (Geoffroy)
Cornicle flanged (Fig. 4b)..... 15

15(14) Antennal segment IV with sensorial ..... *Rhopalosiphum maidis* (Fitch)
Antennal segment IV without sensorial 16

16(15) Cauda pale, or paler than cornicles ..... *Aphis gossypii* Glover
Cauda and cornicles equally dark..... *Aphis craccivora* Koch

KEY TO SOME ANTS OF PALAU

Key to Subfamilies based on workers

1 Gaster attached to mesosoma (alitrunk) by a petiole consisting of 2 segments (Figs. 7b, 7c & 7d,) ..... Myrmicinae
Gaster attached to mesosoma by a petiole consisting of a single segment (Figs. 6a & 6b) 2

2(1) Sting well developed ..... Ponerinae
Sting absent 3

3(2) Circular cloacal orifice fringed with hair (Figs. 5a & 5b) ..... Formicinae
Slit-like orifice (Figs. 5c & 5d) ..... Dolichoderinae

Key to ants of Subfamily Formicinae, based on workers

1 Petiole with horn-like spines; medium-sized, black (Figs. 5e & 5f) ..... *Polyrhachis dives* Smith
Petiole without spines 2

2(1) Thoracic dorsum convex and smooth (Figs. 5g & 5h) 3
Thoracic dorsum not smoothly convex (Figs. 6a & 6b) 5

3(2) Head and alitrunk clear yellow or light brown ..... *Camponotus chloroticus* Emery
Head and alitrunk reddish brown or darker 4

4(3) Basal face of propodeum strongly concave; posterior margins of abdominal tergites whitish (Fig. 5g) ..... *Camponotus reticulatus* Roger
Dorsal face of propodeum convex; abdominal tergites all brown (Fig. 5h) ..... *Camponotus navigator* Wilson

5(2) Antennal scape at least 1.5X as head length; body thin and elongate (Figs. 6a & 6b) 6
Antennal scape not more than 1.5X head length; body average to robust ..... *Paratrechina bourbonica* (Forel)

6(5) Yellow; dorsum of mesosoma nearly devoid of standing hair; mesonotum viewed from side weakly concave (6a) .... *Anoplolepis gracilipes* (Smith)
Dark brown; dorsum of mesosoma bearing numerous long, erect hairs; mesonotum viewed from side weakly convex (Fig. 6b) ..... *Paratrechina longicornis* (Latreille)

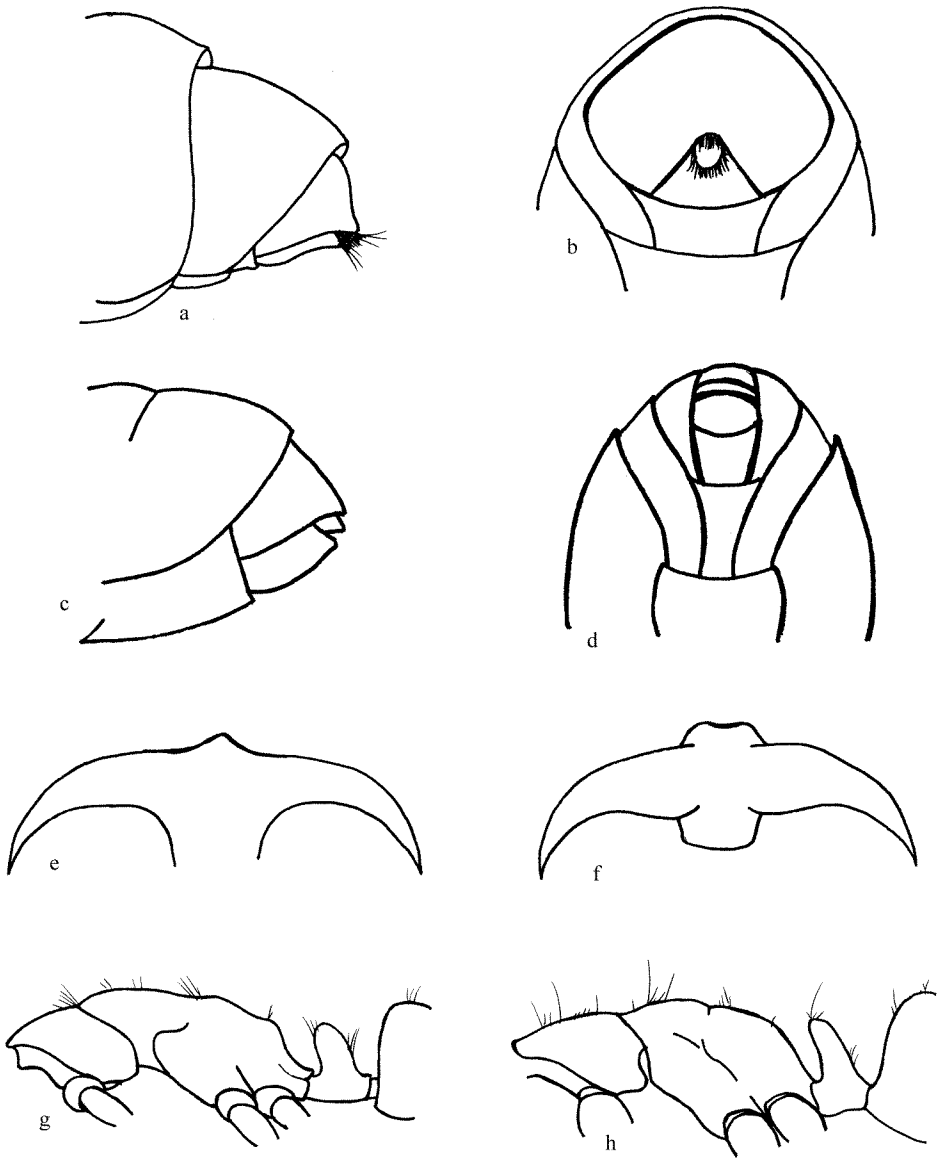

Fig. 5. Ant features (not to scale) (redrawn from Wilson and Taylor, 1967). a–b, Formicinae: a, lateral-circular orifice; b, ventral view-circular orifice. c–d, Dolichoderinae: c, lateral-slit like orifice; d, ventral view-slit like orifice. e–f, *Polyrhachis dives:* e, horn-like spines lateral; f, horn-like spines posterior; g, *Camponotus reticulates,* basal face of propodeum-concave; h, *Camponotus navigator,* basal face of propodeum-convex.

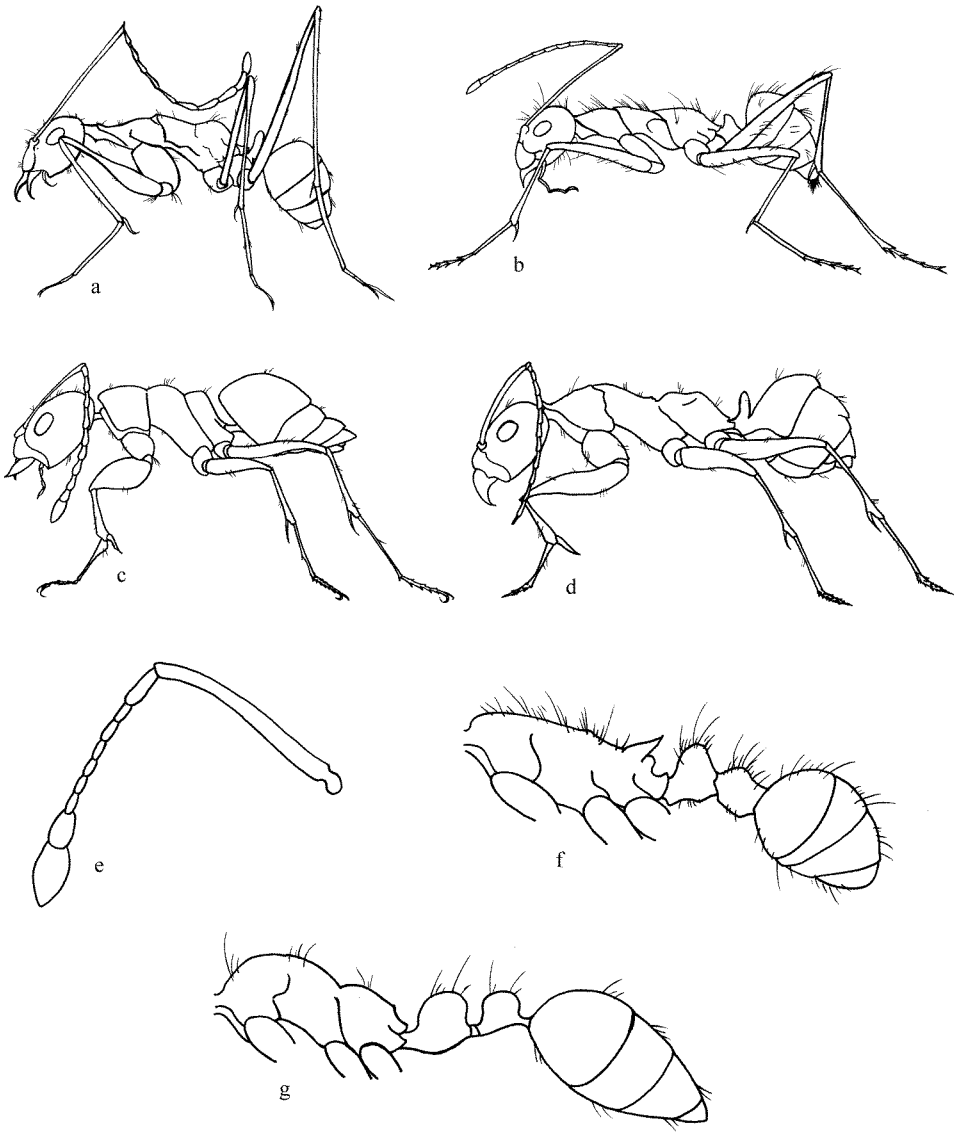

Fig. 6. Ant features (illustrations not to scale). a, *Anoplolepis gracilipes,* concave mesonotum; b, *Paratrechina longicornis,* convex mesonotum; c, *Tapinoma melanocephalum,* node – rudimentary; d, *Iridomyrmex anceps,* node – well developed; e, *Solenopsis geminata,* antenna; f, *Tetramorium* spp., propodeum with spines; g, *Monomorium* spp., propodeum without spines.

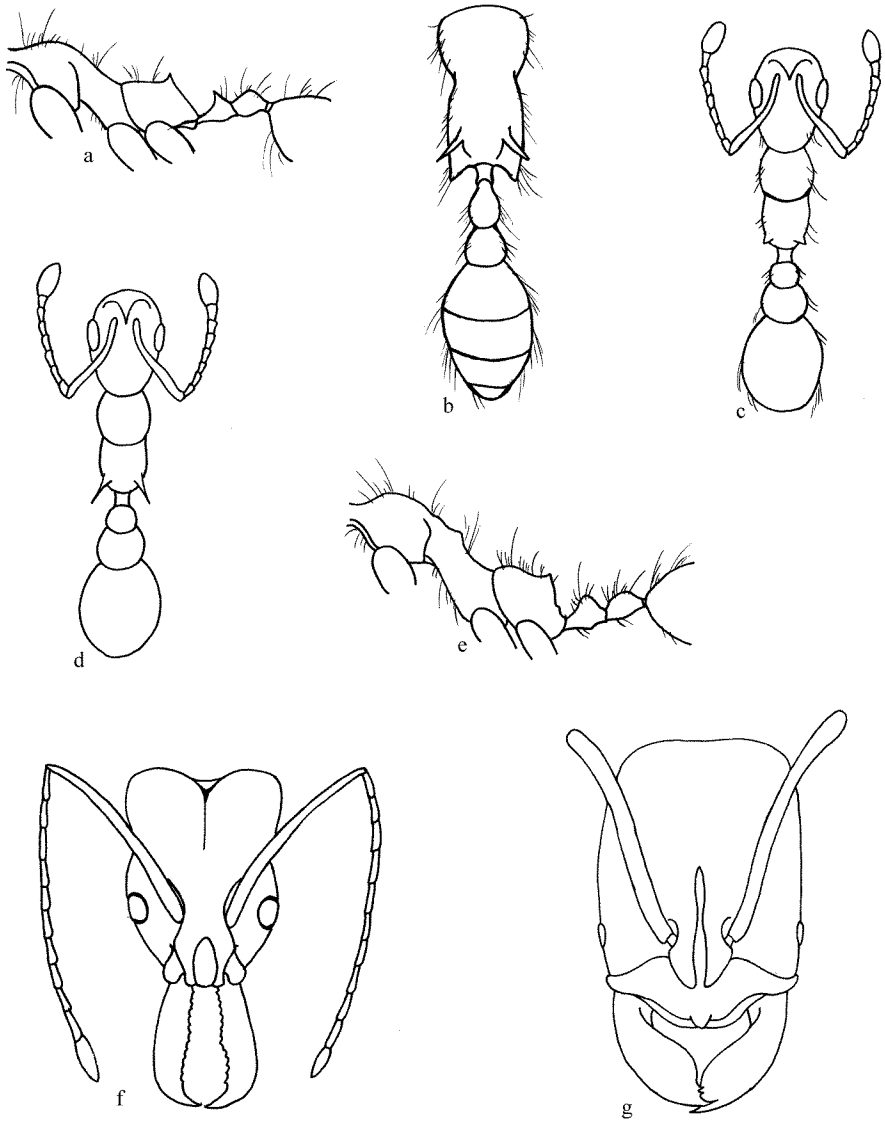

Fig. 7. Ant features (illustrations not to scale). a; *Pheidole megacephala,* pronotum and mesonotum sloped; b, *Tetramorium* spp., narrow postpetiole; c, *Cardiocondyla emeryi,* short propodeal spines; d, *Cardiocondyla wroughtonii,* long propodeal spines; e, *Pheidole* spp., convex mesonotum; f, *Odontomachus simillimus,* mandibles near midline; g, *Pachycondyla croceicornis,* mandibles triangular.

Key to ants of Subfamily Dolichoderinae, based on workers

1 Minute, head width about 0.40mm 2
Large, head width >0.60mm 3

2(1) Petiolar node rudimentary; antennal scape surpassing occipital lobe by more than the length of 1st funicular segment (Fig. 6c)
.....*Tapinoma melanocephalum* (F.)
Not as above ..... *Tapinoma* sp.

3(1) Node well developed, mesosoma feebly shining (Fig. 6d)
..... *Iridomyrmex anceps* (Roger)
Node rudimentary, mesosoma shagreened; tarsal segment whitish
.....*Technomyrmex albipes* (Smith)
Not as above ..... *Technomyrmex* sp.

Key to ants of Subfamily Myrmicinae, based on workers

1 Antenna with 7 segments or less 2
Antenna with at least 8 segments 3

2(1) Head width >1.2 mm; large eyes, dorsolaterally placed .....
..... *Eurhopalothrix procera* (Emery)
Head width < 0.60 mm; small eyes, laterally placed
.....*Pyramica karawajewi* (Brown)

3(1) Antenna with 10 segments; 2 segmented club (Fig. 6e) .....
.....*Solenopsis geminata* (F.)
Antenna with 11-12 segments; 1 or 3 segmented club 4

4(3) Propodeum with spines (Fig. 6f) 5
Propodeum without spines (Fig. 6g) 12

5(4) Pro and mesonotum smooth and flat, at or near the same level (Fig. 6f) 6
Pro and mesonotum not flat, mesonotum steeply sloped from pronotum (Fig. 7a & 7e) 9

6(5) From above postpetiole at most 1.3X broader than petiole (Fig. 7b) 7
From above, postpetiole 2X broad as petiole (Figs. 7c & 7d) 8

7(6) Body length 1.5 mm, dark brown or black, long silvery bifid or trifid hairs ..... *Tetramoriuim lanuginosum* Mayr

Body length 2.25-3.5 mm, orange brown with black gaster, devoid of silvery hairs ..... *Tetramorium bicarinatum* (Nylander)

8(6) Propodeal spines short and stout (Fig. 7c) ..... *Cardiocondyla emeryi* Forel
Propodeal spines moderately long and prominent (Fig.7d) .....*Cardiocondyla wroughtonii* (Forel)

9(5) Head width of minor about 0.4 mm; head width of soldier about 0.8 mm; both castes light reddish yellow ..... *Pheidole umbonata* Mayr
Head width of minor worker 0.5 mm; head width of soldier about 0.8 mm; both castes light to dark reddish brown 10

10(9) Soldier occiput smooth and shining; minor with mesonotum flat in side view (Fig. 7a) ..... *Pheidole megacephala* (F.)
Soldier occiput rugoreticulate; minor with mesonotum convex in side view (Fig. 7e) 11

11(10) Area between antennal insertion and eye rugoreticulate ..... *Pheidole fervens* Smith
Not as above ..... *Pheidole* sp.

12 (4) Mesosoma yellow to light brown with dark head and gaster .....*Monomorium floricola* (Jerdon)
Mesosoma evenly reddish brown to black brown .....*Monomorium monomorium* Bolton

Key to ants of Subfamily Ponerinae, based on workers

1 Mandibles inserted near midline, long and straight (Fig.7f) ..... *Odontomachus simillimus* Smith
Mandibles triangular, with numerous small teeth along inner margins (Fig.7g) ..... *Pachycondyla croceicornis* (Emery)

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