A New Pest Species of the Mealybug Genus *Ferrisia* Fullaway 
(Hemiptera: Pseudococcidae) from the United States

P. J. GULLAN, 1 D. A. DOWNIE, 1, 2 AND S. A. STEFFAN 3


**ABSTRACT** A new pest species of *Ferrisia* (Hemiptera: Pseudococcidae), *Ferrisia gilli* Gullan, is described and illustrated based on the adult female, third-instar female, and first- and second-instar nymphs. Observation of pharate third-instar males and females failed to reveal sexual dimorphism of the second instar. Diagnosis of this new species was facilitated by the collection of nucleotide sequence data from fragments of a mitochondrial gene (COI) and two nuclear genes (EF-1α and 28S). The first phylogenetic study of *Ferrisia* is presented; combined and separate analyses of the three gene regions support monophyly of *F. gilli* and suggest that *Ferrisia virgata* (Cockerell) is a species complex. The known distribution of *F. gilli* from California and the southeastern United States is reported. It may be native to the southeastern states. This mealybug seems to be polyphagous because it feeds on a variety of species of woody plants, both evergreen and deciduous, as well as on monocots. It has at least three generations annually in central California, where it is newly recognized as a pest in pistachio and almond orchards, but has been present in northern California since at least 1968. The main problems caused by this mealybug in pistachio orchards are contamination of foliage and fruit with honeydew and the concomitant promotion of two major fungal pathogens.

**KEY WORDS** Pseudococcidae, mealybugs, *Ferrisia*, phylogeny, taxonomy

Mealybugs of the genus *Ferrisia* Fullaway, and especially the polyphagous *F. virgata* (Cockerell) and *F. malacastra* (McDaniel), are well known as plant pests (McKenzie 1967, Williams and Watson 1988, Miller et al. 2002). They damage plants primarily by sap removal and by contamination with copious honeydew that frequently serves as a substrate for sooty molds and sometimes they transmit plant viruses (reviewed by Williams 1996). The most recent taxonomic synopsis of *Ferrisia* (Williams 1996) recognized 10 species and provided a key to distinguish 8 of these species. The other two species, *F. neovirgata* Khalid and Shafee and *F. quaintancii* (Tinsley), seem to have been described based on immature females and thus were not included in Williams’ key. *Ferrisia* seems to be of New World origin (Williams and Granara de Willink 1992, Williams 1996), although *F. malacastra* and *F. virgata* are more widespread, probably as the result of human activities.

There is a history of problems in distinguishing *Ferrisia* species, especially the biparental *F. virgata*, which has many synonyms (Williams 1996) and was confused with the parthenogenetic *F. malacastra* for many years. The latter was known as the uniparental strain of *F. virgata* (Williams 1985) and then as *F. consobrina* (Williams and Watson 1988) until Williams’ (1996) revision. Nur (1977) used electrophoretic methods to recognize two sexual and one parthenogenetic species from specimens that were identified as *F. virgata*, but these electrophoretic taxa were never associated with any morphological forms of *F. virgata*. Williams and Granara de Willink (1992) reported morphological variation in the number and position of minute tubular ducts present on the lateral margins of the abdomen of adult female specimens assigned to *F. virgata*. These ducts range from few in number on some specimens to occurring in distinct clusters of up to 17 on each margin of abdominal segments VI and VII. This morphological variation and Nur’s results for *F. virgata* as well as the occurrence of unusual specimens that cannot be assigned definitively to any named species suggest the existence of further species of *Ferrisia*. For example, specimens of *Ferrisia* infesting pistachio trees in central California probably would be identified as *F. malacastra* in Williams’ (1996) key, but the adult females exhibit several morphological differences from *F. malacastra*.

Complexes of morphologically similar species are known in other mealybug genera, and detailed study of morphological and/or biological differences often reveals new species. For example, Beardsley (2001) provided evidence for two new sibling species of the coconut mealybug *Nipaecoccus nipae* (Maskell), and previously, Beardsley (1959, 1965) resolved the tax-
onomy of the pineapple mealybug complex involving the pest *Dysmicoccus brevipes* (Cockerell) and closely related species. In contrast, there are examples of environmentally induced variation in morphology in mealybugs (Cox 1983), and such variation can lead to the erroneous recognition of more than one species of mealybug. The best example is the recent synonymy of *Pseudococcus calceolariae* (Maskell) and *F. similans* (Lidggett), based on detailed morphological study of mealybugs reared under controlled conditions (Charles et al. 2000) and supported by molecular data (Beuning et al. 1999). Thus, new mealybug species should only be described after careful study, preferably using multiple data sources.

The main purpose of the present work is to clarify the taxonomic status of the pest *Ferrisia* specimens that occur on pistachio trees in California. We used a combination of morphological and molecular data to achieve this goal, and we formally describe and name a new species of *Ferrisia*, *F. gilli* Gullan, from a range of host plants in Alabama, California, Georgia, and Louisiana. This new species may be native to the southeastern United States. We provide taxonomic descriptions and illustrations of the adult and third-instar females and the first- and second-instar nymphs and describe the biology of this new species in the San Joaquin Valley, CA. This paper also provides the first systematic investigation of *Ferrisia* species based on molecular data. We present an estimate of the phylogenetic relationships among the common *Ferrisia* species found in the United States based on nucleotide sequence data from a mitochondrial gene and two nuclear genes.

Materials and Methods

Molecular Methods

Freshly collected specimens of four *Ferrisia* species, *F. macleastra*, *F. terani* Williams and Granara de Willink, *F. virgata*, and the putative new species *F. gilli*, were obtained preserved in 95–100% ethanol and one additional new species from an old collection made in Puerto Rico was obtained in 75% ethanol (Table 1). Four other mealybug species were used as outgroups: *Anisoccoccus adenostomae* (Ferris), *Maconellicoccus australiensis* (Green and Lidggett), *Planococcus citri* (Risso), and *Pseudococcus longispinus* (Targioni Tozzetti). These four outgroups were chosen because they represented four separate groups in a larger molecular data set (DAD and PJG, unpublished data). Before DNA extraction, all specimens were examined under the microscope for the presence of parasitoids. DNA was extracted from single parasitoid-free adult females with the DNeasy tissue kit (Qiagen, Valencia, CA) with a final wash performed with sterile water, rather than the supplied buffer, and at half volume.

Polymerase chain reaction (PCR) products were generated from a mitochondrial gene, cytochrome oxidase I (COI), and two nuclear genes: a protein coding gene, elongation factor 1-α (EF-1α), and the D2 expansion region of the large subunit ribosomal DNA gene (28S) (Michot et al. 1984). Primers for both amplification and sequencing were 5′-CAACATTTATTGTGATTGTTTGG-3′ (C1-J-2136 aka Jerry) (Simon et al. 1994) and 5′-CGWACREATATGKATCATG-3′ (C1-N-2568 aka BEN3R, designed by T. R. Schultz, Smithsonian Institution) (Brady et al. 2000) for COI; 5′-GARGACTATACAAAACTCGG-3′ and 5′-GCAAAGTGCCGGTGGCA-3′ for EF-1α (similar to M51.9 and rcM53–2 of Cho et al. 1995 enclosing a fragment from bases 2832–3149 in the *Drosophila melanogaster* sequence); and 5′-AGAGAGACAGATCAAGATAGCTG-3′ and 5′-TGTTGTCCTGTGTTCAAGACGGG-3′ for 28S (Belshaw and Quicke 1997). PCR reaction components and final concentrations were 1.5–2.5 mM MgCl2, 0.2 mM dNTPs, and 1 U Taq polymerase in a proprietary buffer (PCR Master Mix, Promega Biotech, Madison, WI), 0.2 μM each primer, and 5 μL DNA template in a final volume of 25 μL. The PCR cycling protocol for COI was 95°C for 7 min, followed by 40 cycles of 95°C for 1 min, 45°C for 1 min, and 72°C for 1.5 min, with a final extension at 72°C for 5 min. Protocols for EF-1α and 28S were 94°C for 4 min followed by 35–45 cycles of 94°C for 1 min, 49–52°C for 1 min, and 72°C for 1.5 min, with a final extension at 72°C for 4 min.

PCR products were purified by exonuclease I and shrimp alkaline phosphatase digestion of single-stranded DNA (primers) and dNTPs (ExoSAP-IT; USB, Cleveland, OH). Products were sequenced on both strands using the ABI Big Dye terminator sequencing reaction kit (Perkin-Elmer/ABI, Weiterstadt, Germany) on an ABI Prism 3100 automatic sequencer (Perkin-Elmer) on 5% acryl/bisacryl Long Range gels.

Sequences from both strands were assembled using Sequencher ver. 4.0.5 (Gene Codes, Ann Arbor, MI) and multiple alignments were done with Clustal X ver. 1.81 (Thompson et al. 1997) and edited in MacClade version 4.0 (Maddison and Maddison 1992). Maximum parsimony (MP), as well as maximum-likelihood (ML) and neighbor-joining (NJ), was used to estimate trees. For parsimony, a heuristic search was run with 100 replications of random sequence addition. For distance-based analyses, the model of sequence evolution that best fit the data was found by testing 56 models using an iterative likelihood procedure implemented in Modeltest ver. 3.06 (Posada and Crandall 1998). Support for clades was estimated by bootstrapping (1,000 replications for MP and NJ; 100 replications for ML). An incongruence length difference (ILD) test (Farris et al. 1994) was used to determine whether to combine data from the three gene fragments. All phylogenetic analyses were executed in *PAUP* version 4.0b10 (Swofford 2002).

All molecular laboratory work and data analyses were conducted by DAD. Slide-mounted voucher specimens were prepared by PJG from samples used for DNA analysis, and in some cases, the cuticle of the actual specimens from which DNA was extracted was retained as vouchers. In these cases, DNA was extracted by the salting-out method of Sunnucks and Hales (1996). The latter vouchers are generally poor taxonomic specimens, but they allowed accurate spe-
Table 1. Collection details of *Ferrisia* specimens and outgroup taxa from which DNA was extracted

<table>
<thead>
<tr>
<th>Species</th>
<th>Code</th>
<th>Host data</th>
<th>Collection locality</th>
<th>Collection date</th>
<th>Collector</th>
<th>Genbank accession no. (CO1)</th>
<th>Genbank accession no. (28S)</th>
<th>Genbank accession no. (EF-1α)</th>
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<tr>
<td><em>F. gilli</em> sp.n.</td>
<td>CA1</td>
<td><em>Pistacia vera</em> L.</td>
<td>near Tulare, CA, USA</td>
<td>July 31, 00</td>
<td>R. E. Rice</td>
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<td>AY179455</td>
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<td></td>
<td>CA2</td>
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<td>near Tulare, CA, USA</td>
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<td></td>
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<td><em>Fatsia japonica</em> (Thunb.)</td>
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<td>AY179461</td>
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<td></td>
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<td><em>F. malacra</em></td>
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<td><em>F. tenax</em></td>
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<td><em>F. virgata</em> s.l.</td>
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<td><em>Gaultheria</em> variegata (L.) A. Juss.</td>
<td>Auburn, AL, USA</td>
<td>Oct. 8, 01</td>
<td>K. Gonzales</td>
<td>AY179434</td>
<td>AY179454</td>
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<td></td>
<td>FL2</td>
<td><em>Conocarpus</em> sp.</td>
<td>Florida City, FL, USA</td>
<td>May 8, 02</td>
<td>J. P. &amp; D. R. Miller</td>
<td>AY179441</td>
<td>AY179462</td>
<td>AY179485</td>
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<td>CA</td>
<td>mulberry</td>
<td>El Centro, CA, USA</td>
<td>Oct. 17, 01</td>
<td>W. Roltsch</td>
<td>AY179449</td>
<td>AY179457</td>
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<td></td>
<td>AZ</td>
<td>Desylirion sp.</td>
<td>Oro Valley, AZ, USA</td>
<td>Aug. 24, 02</td>
<td>J. P. &amp; D. R. Miller</td>
<td>AY179444</td>
<td>AY179469</td>
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<td></td>
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<td><em>Persea americana</em> Mill.</td>
<td>Tucumán, Argentina</td>
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<td>June 4, 00</td>
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<td>Jan. 5, 02</td>
<td>T. Kondo</td>
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<td>AY179458</td>
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<td><em>F. sp.n.</em></td>
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<td><em>Anisococcus adenostomae</em></td>
<td></td>
<td><em>Adenostoma fasciculatum</em> Hook &amp; Am.</td>
<td>Mix Canyon, CA, USA</td>
<td>Aug. 5, 02</td>
<td>P. J. Gullan</td>
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<td><em>Maconellicoccus australiensis</em></td>
<td></td>
<td><em>Acacia dealbata</em> Link</td>
<td>Tharwa, ACT, Australia</td>
<td>Jan. 20, 02</td>
<td>P. J. Gullan</td>
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<td>AY179453</td>
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<tr>
<td><em>Planococcus citri</em></td>
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<td><em>Citrus sinensis</em> (L.) Osbeck</td>
<td>Davis, CA, USA</td>
<td>July 13, 01</td>
<td>S. K. Kelley</td>
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<td><em>Pseudococcus longispinus</em></td>
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<td><em>Citrus sinensis</em></td>
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<td>M.-M. Huynh</td>
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</table>
cies determination when only one or few specimens were available or if mixed-species collections were suspected. Only adult females were used for DNA extraction.

Taxonomic Methods

Adults and immature specimens of the new *Ferrisia* species were studied taxonomically. All freshly collected specimens were slide-mounted in Canada balsam by PJG using the method described in Williams and Granara de Willink (1992), except that xylene was used instead of clove oil. Specimens of the new species were compared with slide-mounted museum specimens (including types) of other *Ferrisia* species from four U.S. collections of scale insects: the Auburn University Coccoidea Collection (AUCC), Auburn, AL; the Bohart Museum of Entomology (BME), University of California, Davis (UCD); the California Department of Food and Agriculture (CDFA), Sacramento, CA; and the United States National Collection of Coccoidea of the National Museum of Natural History (USNM), Smithsonian Institution, housed at the United States Department of Agriculture (USDA), Beltsville, MD. These museum specimens served as the main source of distribution and host-plant data for the new *Ferrisia* species. Type specimens (holotypes and/or paratypes) of the following species were examined by PJG: *F. malvastra*, *F. quaintancii* (Tinsley), *F. setosa* (Lobdell), *F. terani*, and *F. virgata*.

The morphological terms used in the descriptions are explained by Williams (1985) and Williams and Granara de Willink (1992). All measurements are maximum dimensions (e.g., body width was recorded at the widest part) and are expressed as the range. Tarsal length excluded the claw. Setal lengths included the setal base. Each figure represents a generalized individual based on several of the specimens used for the description. The enlargements around the central drawing are not drawn to the same scale as each other. The sexes could not be distinguished in the first or second instar. Male prepupae (third-instar nymphs), pupae (fourth-instar nymphs), and adults were readily distinguishable from other instars by their possession of wing buds or wings, but these stages are not dealt with here. The taxonomic descriptions and illustrations were prepared by PJG, and authorship of the new species should be credited to PJG alone.

All type specimens of the new species have been deposited in the Coccoidea Collection of the BME or belong to the AUCC, except for two paratype females that have been deposited in the Natural History Museum (BMNH), London, UK, and three that have been deposited in the USNM. Voucher specimens from the DNA work are housed in the BME, and additional vouchers of specimens collected by D. R. Miller are in the USNM.

Field and Rearing Methods

Field observations, collections of specimens from pistachio trees, and rearing of the new *Ferrisia* species were conducted by SAS. Mealybug specimens were sampled in a pistachio (*Pistacia vera L.*) (Anacardiaceae) orchard (cultivar ‘Kerman’) near Tulare, CA (Tulare Co.). The orchard was visited four times—in November 2001 and in February, early May, and early August 2002—to make collections and observations of the mealybugs and their predators. Small camel hair brushes were used to remove individual mealybugs from the infested trees. Individuals were placed in vials of 100% ethanol for DNA sampling and in 75% ethanol for taxonomic purposes.

Cuttings of pistachio branches bearing mealybugs were collected in November 2001, placed in a large plastic bag, and taken to the Kearney Agricultural Center (Parlier, CA) to initiate a colony on a young pistachio tree (2 yr old, 0.5 m tall). Initially, the cuttings were kept outside under natural conditions, in a large transparent plastic bag that allowed for observation. In January 2002, ~25–30 nymphs were placed on a dormant pistachio sapling within a mesh sleeve-cage. The sapling was kept indoors (68–72°F) until March 2002, when it was placed outdoors. Development of the mealybug population was observed to determine approximate number and timing of generations. By July, the small pistachio tree had died either because of the effects of the large mealybug population (hundreds) or a soil pathogen. The bulk of the population was transferred to two new pistachio trees (3 yr old, 1.5 m high), and again they were caged using mesh sleeve-cages. Each tree had a population of ~50 mealybugs in mid-August 2002. Sampling was discontinued in September 2002.

Results and Discussion

Molecular Systematics

The molecular data clearly demonstrate that specimens of *Ferrisia* from Tulare, CA, and Auburn, AL, are genetically distinct from the other species of *Ferrisia* with which they might be confused based on morphology. This new species is described as *F. gilli* Gullan in the section on taxonomy below, and the new name is used in this section for clarity.

The 28S and EF-1α sequences varied in length because of an intron at positions 242–319 of the EF-1α fragment and various indels for 28S. Regions of 28S where the alignment was ambiguous were deleted. Although aligned unambiguously among in-group taxa, analyses with and without the EF-1α intron (defined by GT-AG splicing sites) were compared. The tree topologies were mostly unaffected by editing, but trichotomies between *F. terani* and the *F. gilli* and *F. virgata* clades, and including *F. virgata* from Colombia, were resolved, the number of phylogenetically informative characters was substantially greater (166 versus 209), and bootstrap support for nodes was higher with inclusion of the intron. All results reported here are from the unedited dataset. The complete dataset contained 385 bases of COI, 334 bases of 28S, and 378 bases of EF-1α (1,097 characters). Of 209 parsimony
10 changes

Fig. 1. Maximum likelihood tree found from combined COI, EF-1α, and 28S sequence data. The NJ tree and single MP tree were identical to this tree (length of MP tree = 692, CI = 0.678, RI = 0.662). Only bootstrap values (ML/MP) >50% are shown; bootstrap values from NJ were comparable. Only bootstrap values (ML/MP) >50% are shown; bootstrap values from NJ were comparable. The model of sequence evolution that best fits the entire dataset; however, support for this relationship is weak. It is interesting to note that genetic structure within F. virgata s.l. is as great, or greater, than that between F. gilli and other clades. For example, 20 changes occur along the branch leading to F. virgata (FL1 + CA + AZ + BEL), six of which are synapomorphies (distance between the two F. virgata clades = 0.054). Although morphological characters distinguishing taxa within F. virgata s.l. have not been described, the molecular data (Nur 1977, this study) strongly suggest that F. virgata is a species complex and further systematic work is needed.

Taxonomy

The first-instar nymph and all female stages of the new species, F. gilli, are described and illustrated. Descriptions of immature females are useful for identification when only nymphs are available and may be valuable to future taxonomic work, especially because at least one, and perhaps two, Ferrisia species are known only from third-instar females (Ferris 1953, Williams 1996). Almost all other species of Ferrisia have been described based on the adult female only. Two exceptions are an Egyptian and an Indian population of F. virgata for which all stages have been described (Awadallah et al. 1979, Paul and Ghose 1989), but the illustrations accompanying the latter descriptions are not detailed.

Type specimens have been designated only from the two localities for which molecular data are available to avoid including genetic variants in the type series. A number of specimens from other localities clearly belong to this species based on morphology, but other specimens display slight morphological variation, and it is not clear whether these differences are genetically or environmentally determined (refer to Diagnosis below). Measurements for the description of the adult female were taken only from some of the type specimens and a few other females that closely match the types, although many additional specimens were examined.

Adult females of the new Ferrisia species might be misidentified as F. malvastra in Williams’ (1996) revision. They readily key to couplet six, but the features used as alternative states of this couplet are problematic. In the key, specimens would be identified as F. malvastra if setae associated with each dorsal tubular duct were situated outside of the sclerotized rim of the opening of the duct, whereas if the setae are within the rim, then one proceeds to the last couplet of the key. The feature of setae within or outside the duct rim is extremely difficult to apply in practice because of difficulty of delimiting the duct rim and also the position of setae relative to the duct rim often varies on different parts of the body of one individual. The diagnosis given for the new species describes the features that best separate it from other described Ferrisia species. A modified version of Williams’ (1996) key is not provided because further taxonomic research is
required to elucidate the status of _F. virgata_, which seems to be a species complex.

**Ferrisia gilli** Gullan, sp.n.

**Type Material.** HOLOTYPE: 1♀, ex pistachio, CA, Tulare Co., Avenue 196, V-9–2002, S.A. Steffan (BME). PARATYPES: 5♀, five slides of first-instar nymphs, same data as holotype (BME); 2♀, same data as holotype (BMNH); 2♀, same data as holotype (USNM); 3♀, third-instar ♀, 10× second-instar nymphs, 2× prepupal ♂, ex pistachio, CA, Tulare Co., II/III-2002, S.A. Steffan (BME); 8♀, 1× third-instar ♀, 2× second-instar nymphs, ex almond and barnyard grass, CA, Tulare Co., IX-11–2002, G. Weinberger (BME, except 1♀ to USNM); 3♀, 3× second-instar nymphs, two slides of first-instar nymphs, ex pistachio branch, CA, Tulare Co., 3 mi (4.8 km) S Tulare, XI-3–2001, S.A. Steffan (BME); 6♀, 5× third-instar ♀, 8× second-instar nymphs, ex _Pistacia vera_, CA, Tulare Co., c. 5 km SW Tulare, VII-31–2000, R.E. Rice (BME); 19♀, ex pistachio, CA, Tulare Co., 5 mi (8 km) S Tulare, IX-8–1998, R. Rice (CDFA); 3♀, ex _Ilex vomitoria_, AL, Lee Co., Auburn, Auburn Univ., IV-23–2002, T. Kondo, AL-070–2002A (AUCC); 7♀, four slides of first-instar nymphs, ex _Ilex vomitoria_, AL, Auburn, II-20–2002, IV-28–2002, T. Kondo (BME); 2♀, ex _Fatsia japonica_, AL, Auburn, II-28–2002, T. Kondo (BME).


**Etymology**

This species is named in honor of Ray Gill, who is an expert on the mealybugs of California and who first recognized the distinct nature of some specimens of this new species and suggested the research reported in this paper.

**Diagnosis of Adult Female**

_Ferrisia gilli_ can be diagnosed by the following combination of features: absence of anterior ostioles; presence of multilocular disk pores immediately anterior and posterior to vulva on venter of abdominal segments VII, VIII, and IX, and sometimes one to two pores on abdominal segment VI as well; anal lobe cercari each with only two conical setae; dorsal enlarged tubular ducts numbering in total ≈90–120; small clusters of ventral minute oral-collar tubular ducts, 6–9 μm long, on margins of posterior abdominal segments, and numbering ≤7 per cluster (usually 1–5) on segment VII, singly or very occasionally in cluster of 2–3 on margins of some segments on rest of body; and slightly larger minute oral-collar tubular ducts, 10–13 μm long, usually present singly on submargins of ventral abdominal segments and scattered elsewhere. The only other species that lack the anterior ostioles are _F. claviseta_ (Lobdell), _F. quaintancii_ (Tinsley), and _F. setosa_ (Lobdell), but in the first two species, the dorsal enlarged tubular ducts usually number as few as 12 altogether, are irregular in distribution, and absent from the margins except for lateral groups on segment VII, whereas _F. setosa_ typically has >2 conical setae in each cercarius and ≥6 setae in the anal ring. The most important features that distinguish _F. gilli_ from members of the _F. virgata_ complex are the absence of the anterior ostioles and the small number or absence of multilocular disk pores on the venter of abdominal segment VI (_F. virgata_ s.l. has a row of pores on abdominal segment VI). _F. gilli_ can be separated readily from _F. malacastera_ and _F. terani_ because the latter two species possess anterior ostioles. Although _F. gilli_ can be readily distinguished from all of the currently described _Ferrisia_ species, there are a number of other specimens that may belong to a new species, closely related to _F. gilli_ and easily confused with it. These collections are from the southeastern United States, including from as far north as Virginia and Maryland and from two localities in California. The adult females differ from those of _F. gilli_ primarily in possessing a cluster of two to many minute oral-collar tubular ducts marginally on most segments around the entire body and with a cluster always near the base of each antenna. Otherwise, these specimens closely resemble _F. gilli_. Unfortunately no fresh material of this alternative phenotype was available for DNA analysis, and thus, these specimens are excluded from the description of _F. gilli_ in case another cryptic species is present.

**Description of the Adult Female**

**Field Features.** Body color mostly pinkish-gray, covered in a white, mealy wax coating interrupted segmentally by sparse wax areas along intersegmental lines; each segment with a pair of dark spots where wax absent, these spots forming two rows longitudinally on dorsum, giving appearance of two dorsal stripes (Fig. 2). Mature adult females and larger nymphs with white, filamentous wax secretion resembling “fur” and covering both mealybug and host plant; wax filaments reaching 5–10 mm in length and making infestation highly visible. Each mealybug also produces some long glassy rod-like filaments of variable length but often 1–4 mm long, which can criss-cross to form an enclosing “fortress.” Ovisacs present, with newly emerged crawlers within; eggs not observed.
Slide-Mounted Features (measurements based on 20 specimens). Body 2.0–5.0 mm long, 1.1–2.9 mm wide (Fig. 3). Eye marginal, 50–75 μm wide. Antenna 8-segmented, 500–700 μm long; apical segment 105–140 μm long, 25–34 μm wide. Clypeolabral shield 180–210 μm long, 140–190 μm wide. Labium 3-segmented, 170–230 μm long, 95–160 μm wide. Spiracles 60–100 μm long, 30–65 μm wide across atrium, posterior pair always slightly larger than anterior pair. Circulus highly variable in size, 100–200 μm wide, divided by intersegmental line. Legs well developed; hind trochanter + femur 330–490 μm long, hind tibia + tarsus 335–470 μm long, hind claw 35–40 μm long. Ratio of lengths of hind tibia + tarsus to hind trochanter + femur 0.88–1.12, ratio of lengths of hind tibia to tarsus 1.95–2.50, ratio of length of hind trochanter + femur to greatest width of femur 3.55–5.76. Tarsal digitules subequal 50–55 μm long, both capitare. Claw digitules subequal 30–40 μm long, both capitare. Translucent pores on hind legs present on coxa, especially medi ally, a few scattered on femur, and very few mostly distally on tibia. Ostioles: anterior pair absent; posterior pair well developed, each ostiole with 25–55 trilocular pores and 8–17 setae. Anal-ring 110–125 μm wide, with six anal-ring setae 175–250 μm long.

Dorsum. Cerarii absent except on anal lobes; anallobe cerarius with two subequal conical setae, 28–40 μm long, 25–50 trilocular pores and 5–7 bluntly-tipped auxiliary setae. Dorsal body setae slender, bluntly tipped, 8–45 μm long, sparsely scattered. Multilocular disk pores absent. Trilocular pores evenly scattered. Minute discoidal pores ≈2.5 μm in diameter, very rare, scattered; a small cluster of 4–8 pores, often contiguous and appearing bilocular, near base of each antenna. Enlarged tubular ducts abundant, up to a total of ≈120 on body, each duct 30–38 μm long, opening surrounded by a circular sclerotized rim enclosing 0–3 (mostly 1–2) oval discoidal pores and with 2–7 (mostly 2–4) bluntly-tipped setae, 20–35 μm long, usually either within rim (especially on abdomen) or on edge of rim (especially on head), occasionally just outside rim; ducts distributed in segmental clusters around margins of head, thorax and abdomen, on margins of abdominal segments in groups of 2–5 (mostly 2–4), except 4–8 (mostly 5–7) ducts on each side of abdominal segment VII; also 10–16 medially to submarginally on head and thorax, usually one duct submarginally on each side of abdominal segments I and II, and total of 5–7 medially to submedially on abdominal segments III–VI. Oral-collar tubular ducts absent.

Venter. Body setae slender, bluntly tipped, 8–175 μm long, except up to 230 μm long medially on head, sparsely scattered; apical seta of anal lobe 250–320 μm long. Multilocular disk pores on abdominal segments anterior and posterior to vulva: 0–2 pores on VI, 5–13 on VII, 3–10 on VIII and 2–8 on IX, with pores on VI on average smaller (6–9 μm in diameter) than pores on other segments (7–10 μm diameter). Trilocular pores evenly scattered. Minute discoidal pores ≈2.5 μm in diameter, often 1–2 near opening of minute tubular ducts, a few scattered. Enlarged tubular ducts absent. Oral-collar tubular ducts minute, of two sizes (6–9 and 10–13 μm long), sparsely distributed, submedial to marginal on head and thorax, submarginally to marginal on abdomen plus 1–2 submedially on each side of all abdominal segments anterior to vulva; margins of posterior abdominal segments with clusters of smaller sized ducts as follows: 0–2 on each side of V, 0–4 on VI, 0–7 on VII, and 0–1 on VIII.

Notes. The adult female can be distinguished readily from all other instars by the presence of a vulva opening in the ventral intersegmental membrane between abdominal segments VII and VIII and by the presence of multilocular disk pores anterior and posterior to the vulva. There is very little morphological variation among specimens from the different localities listed for F. gilli, but refer to Diagnosis above for possible confusion with variant specimens that may represent another new species.

Description of the Third-Instar Female

Slide-Mounted Features (measurements based on eight specimens). Body 0.91–1.70 mm long, 0.42–0.92 mm wide (Fig. 4). Eye marginal, 30–42 μm wide. Antenna 7-segmented, 300–420 μm long; apical segment 85–115 μm long, 23–30 μm wide. Clypeolabral shield 130–145 μm long, 125–135 μm wide. Labium 3-segmented, 125–145 μm long, 83–93 μm wide. Spiracles 45–62 μm long, 20–30 μm wide across atrium. Circulus 85–140 μm wide, divided by intersegmental line. Legs well developed; hind trochanter + femur 190–270 μm long, hind tibia + tarsus 210–285 μm long, hind claw 28–30 μm long. Ratio of lengths of hind tibia + tarsus to hind trochanter + femur 1.00–1.11; ratio of lengths of hind tibia to tarsus 1.07–1.35; ratio of length of hind trochanter + femur to greatest width of femur 3.12–3.97. Tarsal digitules subequal 35–50 μm long, both capitare. Claw digitules subequal 23–30 μm long, both capitare, apex smaller than on adult female. Translucent pores absent from legs. Ostioles: anterior pair absent; posterior pair well developed, each ostiole...
with 8–18 trilocular pores and 3–5 setae. Anal-ring 65–83 μm wide, with six anal-ring setae 100–145 μm long.

**Dorsum.** Cerarii on anal lobes only, each anal-lobe cerarius with two subequal conical setae, 20–27 μm long, 8–16 trilocular pores and 2–3 bluntly-tipped auxiliary setae. Dorsal body setae slender, bluntly tipped, 10–28 (mostly ≤25) μm long. Trilocular pores scattered. Minute discoidal pores ≈2 μm in diameter, rare, scattered. Enlarged tubular ducts 24–30 μm long.

Fig. 3. Adult female of *F. gilli* Gullan.
Fig. 4. Third-instar female of *F. gilli* Gullan.
opening of each duct surrounded by a circular sclerotized rim enclosing oval discoidal pores and with bluntly-tipped setae. 20–25 μm long, either within, on edge or outside rim; on head each duct 24–27 μm long with 1–4 (mostly 2–3) setae on edge or outside rim and 0–2 (mostly 1) pores; on posterior abdomen each duct 25–30 μm long with 1–4 (mostly 2–3) setae usually inside rim and 0–2 (mostly 1–2) pores; ducts distributed around margins in groups of 1–3 (mostly 1–2), except always four ducts on each side of abdominal segment VII, 7–12 medially to submarginally on head, thorax and anterior abdomen, and 4–6 medially to submedially on abdominal segments IV–VI. Oral-col lar tubular ducts absent.

Venter. Body setae slender, bluntly tipped, 12–85 μm long except up to 100 μm long medially on head; apical seta of anal lobe 150–200 μm long. Multilocular disk pores absent. Trilocular pores scattered on head and thorax, mostly in segmental rows on abdomen. Minute discoidal pores ≈2 μm in diameter, rare, scattered but sometimes near opening of minute tubular ducts. Enlarged tubular ducts absent. Oral-coll ar tubular ducts minute, 7.0–7.5 μm long, 2.5–3.0 μm wide distally, distributed marginally or submarginally around body, usually one duct on each side of all abdominal segments except absent on VIII, also a few medial to coxae on thorax.

Notes. The third-instar female can be distinguished most easily from the adult female by lacking a vulva and multicellular disk pores and from earlier instars by having seven segmented (rather than six segmented) antennae.

Description of the Second-Instar Nymph

Slide-Mounted Features (measurements based on 12 specimens). Body 0.95–1.20 mm long, 0.51–0.69 mm wide (Fig. 5). Eye marginal, 21–25 μm wide. Antenna 6 segmented, 240–280 μm long; apical segment 80–90 μm long, 20–25 μm wide. Clypeolabral shield 100–113 μm long, 95–105 μm wide. Labium 3 segmented, 88–95 μm long, 50–65 μm wide. Spiracles 33–38 μm long, 13–15 μm wide across atrium. Circulus 60–75 μm wide, indistinctly divided by intersegmental line. Legs well developed; hind trochanter + femur 150–165 μm long, hind tibia + tarsus 170–190 μm long, hind claw 22–24 μm long. Ratio of lengths of hind tibia + tarsus to hind trochanter + femur 1.03–1.20; ratio of lengths of hind tibia to tarsus 0.92–1.12; ratio of length of hind trochanter + femur to greatest width of femur 3.19–4.00. Tarsal digitules subequal 32–37 μm long, both capitate. Claw digitules subequal 18–22 μm long, both capitate, apex smaller than on adult female. Translucent pores absent from legs. Ostoiae: anterior pair absent; posterior pair relatively weakly developed, each ostiole with 4–5 trilocular pores and one seta. Anal-ring 50–55 μm wide, with six anal-ring setae 80–95 μm long.

Dorsum. Cerarii on anal lobes only, each anal-lobe cerarius with two subequal conical setae, 12–20 μm long, 5–7 trilocular pores and one bluntly-tipped auxiliary seta. Dorsal body setae slender, bluntly tipped, 12–23 μm long. Trilocular pores scattered. Minute discoidal pores rare or absent. Enlarged tubular ducts 22–27 μm long, opening of each duct surrounded by a circular sclerotized rim enclosing oval discoidal pores with bluntly tipped setae either within, on edge or outside rim; on head each duct 22–24 μm long with 1–2 (mostly 2) setae outside rim, or outer rim absent, and 0–2 (mostly 1) pores; on posterior abdomen each duct 25–27 μm long with 1–3 (mostly 2) setae usually inside rim and 0–1 (mostly 1) pore; ducts distributed around margins in groups of 1–2 (mostly 1), always two on each side of abdominal segment VII, 3–6 submedially to submarginally on thorax and 2–5 medially to submedially on abdominal segments IV–VI. Oral-coll ar tubular ducts absent.

Venter. Body setae slender, bluntly tipped, 12–48 μm long except up to 80 μm long medially on head; apical seta of anal lobe 100–130 μm long. Multilocular disk pores absent. Trilocular pores scattered on head and thorax, mostly in segmental rows on abdomen. Minute discoidal pores ≈2 μm in diameter, rare, scattered but sometimes near opening of minute tubular ducts. Enlarged tubular ducts absent. Oral-coll ar tubular ducts minute, 6–8 μm long, 2–3 μm wide distally, distributed marginally or submarginally around body, usually one duct on each side of all abdominal segments except absent on VII and VIII, also a few medial to coxae on thorax.

Notes. The gender of the second-instar nymph could be determined only for specimens containing the pharate third-instar male or female. No differences in cuticular morphology could be discerned for second-instar males and females, in contrast to previous published reports for F. virgata (Awadallah et al. 1979, Paul and Ghose 1989), in which second-instar males were claimed to lack enlarged tubular ducts and have oral collar tubular ducts on the dorsum. The second-instar nymph can be distinguished most readily from the third-instar and adult female by its six segmented antennae, from the third-instar male by its lack of wing buds and multicellular disk pores, and from the first-instar nymph by having enlarged tubular ducts.

Description of the First-Instar Nymph

Slide-mounted features (measurements based on 10 specimens). Body 0.40–0.47 mm long, 0.19–0.24 mm wide (Fig. 6). Eye marginal, 14–18 μm wide. Antenna 6 segmented, 160–200 μm long; apical segment 68–78 μm long, 20–24 μm wide. Clypeolabral shield 70–83 μm long, 65–80 μm wide. Labium 3 segmented, 60–80 μm long, 40–60 μm wide. Spiracles 25–30 μm long, 7–11 μm wide. Circulus 50–65 μm wide, not divided by intersegmental line. Legs well developed; hind trochanter + femur 89–110 μm long, hind tibia + tarsus 115–143 μm long, hind claw 16–20 μm long. Ratio of lengths of hind tibia + tarsus to hind trochanter + femur 1.26–1.38, ratio of lengths of hind tibia to tarsus 0.77–0.82, ratio of length of hind trochanter + femur to greatest width of femur 2.71–3.45. Tarsal digitules subequal 30–34 μm long, both capitate. Claw digitules subequal 16–18 μm long, both capitate. Translucent
Fig. 5. Second-instar nymph of *F. gilli* Gullan.
Fig. 6. First-instar nymph of $F. gilli$ Gullan.
hosts are woody shrubs or trees, both evergreen and deciduous.

Biology and Pest Status in Central California

By mid-2002, F. gilli was firmly established in five pistachio orchards and an almond orchard near Tulare in the San Joaquin Valley, central California, with a total of ≈325 acres of pistachio trees and 8 acres of almond trees affected. The first infested pistachio orchard was found in 1997 or 1998, but the mealybugs probably were present for a few years before they reached observable populations (G. Weinberger, personal communication). For several years, the infestation was limited to ≈20 rows, but by the summer of 2002, the mealybugs were scattered throughout the orchard (100 acres) and seemed to have spread significantly during the 2002 growing season (G. Weinberger, personal communication). All other mealybug-infested orchards are located within 10 mi of the initial infestation.

Infested pistachio trees often support so many mealybugs that the exuded wax from the insects produces a fibrous, furry, white “beard” hanging from the tree scaffolding. Mealybugs feed on branches, rachises, fruit, petioles, and leaves. Honeydew exuding from individuals at these locations is evidence that they were feeding at these sites. In fall and winter, mealybugs were observed on the trunk and even below ground, but there was no evidence of feeding. Copious wax and honeydew production seems to be the predominant form of damage. The honeydew is a particular problem because it leads to the germination of fungal pathogens. Pistachio trees have serious problems with fungal pathogens, especially Botryosphaeria dothidea (Moug.;Fr.) Ces. and De Not. (Michailides 1991). Also, direct feeding on the rachis or nut may have consequences for kernel development and/or proper shell-split.

Ferrisia gilli is multivoltine in the San Joaquin Valley, with at least three generations annually. The mealybugs seem to overwinter as nymphs (second or third instars) and move to the base of new shoots by April. Three separate flights of adult males were observed in 2002: the first, in April, apparently consisted of adults from the overwintering generation, the second occurred in early July, and the third by mid-September, when adult males were found within the sleeve-cages. The first crawlers of 2002 probably emerged in mid-May; mealybugs were difficult to find in May and June, probably because the crawlers are small and have little of the waxy coating. The life cycle is estimated to be ≈3 mo long in spring and ≈2 mo long in midsummer. During fall 2001, mealybug nymphs were found sheltering in bark cracks and crevices on the main trunk and branches, under bark and in old nut-clusters, and even below the soil around the base of trees, sometimes several inches below ground.

In November 2001, mealybugs were found under bark, crawling about on the outside of the bark, on old rachises, fruit, and in the soil close to the base of the tree. By February 2002, the size and instar of the
mealybugs in the orchard did not seem to have changed from the November visit. In early May, larger mealybugs, possibly including adult females, were collected in the orchard. In early August, large populations of mealybugs were observed feeding directly on developing fruit. Honeydew build-up was becoming an apparent mortality factor for the mealybugs by late summer. Nymphs tended to aggregate, and their wax production was observed forming a web-like network, often at the node of a leaf petiole, on which beads of viscous honeydew would cling and trap nymphs and adult males.

The main predators of *F. gilli* appeared to be predatory hemipterans. In November 2001, a mealybug nymph was observed being preyed on by an adult bug, *Phytocoris reluticus* Knight (Miridae), which actively probed the body of the mealybug. Nymphal minute pirate bugs, *Orius* sp. (Anthocoridae), were found under the bark of the pistachio trees in fall 2001, a few adult minute pirate bugs were seen in February 2002, and in spring 2002, adult minute pirate bugs were found under the bark, closely associated with nymphal mealybugs. Only one parasitoid individual (an unidentified larva, probably hymenopteran) was observed in association with this mealybug in California, but collections from one locality in Auburn, AL, included mealybugs containing the pupal cocoons of an endoparasitic aphelinid wasp.

Although this mealybug species has probably been in California since 1968 (earliest definite record is from Redding in Shasta County), its full pest potential may not have been realized. In central California, it is presently confined to a limited area near Tulare where the first infestation was noticed in 1997, but it is likely to spread to other orchards in the region during the next few years. The major economic problem associated with the presence of the mealybug in pistachio orchards is considered to be facilitation of germination of two major fungal pathogens, *Botryosphaeria dothidea* and *Alternaria alternata* (Fr.) Keissler are serious problems (Michailides 1991, Michailides et al. 1995), and any free water on tissue surfaces allows germination of these fungi. Sugar-rich honeydew represents a potentially significant source of germination media. Also, it is obvious that fruit harvesting will be affected by viscous, sticky, waxy masses that can be present throughout a tree. There are a number of documented insect pests of pistachio in California (e.g., Bentley et al. 2000), but *F. gilli* is not currently recorded in this literature.

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**References Cited**


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