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STUBBORN, GREENING AND RELATED DISEASES

Biological Control of the African and Asian Citrus Psyllids (Homoptera: Psylloidea), Through Eulophid and Encyrtid Parasites (Hymenoptera: Chalcidoidea) in Reunion Island

B. Aubert and S. Quilici

ABSTRACT. The principal damage of the leaf sucking citrus psyllids *Diaphorina citri* Kuwayama and *Trioza erytrae* (Del Guercio), is the transmission of a bacterium-like organism which threatens seriously the citrus production of Africa and Asia. The control of the two psyllid vectors is thus a most important priority for citrus production in these areas.

Two eulophid ectoparasites (super family of Chalcidoidea, O. Hymenoptera): *Tetrastichus dryi* Waterston and *Tetrastichus radiatus* Waterston, were introduced, bred and released in Reunion Island.

In the absence of hyperparasitism, the populations of the two psyllid vectors were reduced drastically 24 months after an original rate of release of 30 to 50 eulophid ectoparasites per square kilometer of the citrus area. A strongly limited population of the greening vectors is presently maintained.

Five non citrus Rutaceae, indigenous to the Island, or imported as ornamentals, were monitored regularly. Only *Murraya paniculata* harboured the Asian psyllid, *D. citri*.

Index words. psyllid vectors, greening disease, endo and ectoparasites of nymphs.

Until recently, the spread of the greening disease in Reunion Island was associated with severe outbreaks of the two psyllids: *Diaphorina citri* Kuwayama and *Trioza erytrae* (Del Guercio). Orchard populations of psyllids were originally controlled on this island by two main factors: climate, and flushing rhythm of the trees. Spraying of insecticides were irregular. Parasitoid insects, represented by five occasional predators were unable to reduce the psyllid buildups during the spring flush.

Hymenopterous primary parasites have been used for a program of biological control which was initiated at the end of 1974. This program has brought about a drastic reduction of the psyllid populations and significant improvements of orchard sanitation were subsequently obtained.

This paper deals with the evolution of *D. citri* and *T. erytrae*

populations after the introduction and release of chalcid hymenopterous parasites originating from Africa or Asia.

PSYLLIDS FEEDING ON CITRUS IN REUNION ISLAND

The Oriental psyllid. The oriental psyllid, *D. citri*, tends to develop preferentially in hot and dry climates of the leeward side of Reunion, although it can also appear in the humid windward side. The nymphs which crawl and feed on young stems or petioles from the first to the fifth instars are fully exposed to environmental conditions. They excrete white pellets or threads which cover the shoots, giving the lower leaves the appearance of having been dusted. The nymphs pass through five moults and, on the fifth instar, give rise to adults. Adults feed generally, but not exclusively on the lower side of the leaves near the midrib. After

mating, the female lays from 200 to 800 eggs during its lifetime.

The African psyllid. Although the whole of Reunion is within the climatic range of *T. erythrae* (11), the African psyllid has been mostly observed in cool, moist areas of the Island above 500 m, with a marked preference for lemon shoots. After the second moult, the nymphs generally stop crawling and settle in galls or pits which they induce on the underside of the young leaves. Adults emerge after the completion of the fifth instar. The leaves which have supported the colonies of nymphs remain galled and curled. The female of *T. erythrae* is capable of laying up to 2500 eggs but usually no more than half this number is laid (1).

The winged adults of these two citrus psyllids breed exclusively on young shoots, the egg-laying process being stimulated by the presence of a new flush. The instar duration of both psyllids varies from 16-18 days up to 45 days or more under cool conditions. On dormant trees, adults are forced to feed on mature leaves and twigs. Their longevity is 3 to 4 months which provides good chances for becoming infectious. Due to the extreme fecundity of the females, phenomenally high populations may suddenly occur. The citrus psyllids are then able to exploit their environment in a relatively short period of time. They can breed on alternate non-citrus host plants belonging to the Rutaceae family.

Several inspections on indigenous Rutaceae of Reunion have not revealed individual host plants harbouring citrus psyllids. These indigenous plants included different *Evodia* species, as well as *Toddalia asiatica* (L.), *Xanthoxylum heterophyllum* (Lam.) Smith, and *Vespris lanceolata* (Lam.) G. DON. The latter, which was recognized as attracting *T. erythrae* (18), is

represented only by a few specimens in Reunion. Two imported Rutaceae can harbour *D. citri*: *Murraya koenigii* (L.) Spreng, the carry plant, and *Murraya paniculata* (L.) Jack. The latter, which is often used for ornamental hedges, can support large breeding colonies of the Asian psyllid on young shoots.

Before the implementation of biological control, adults and nymphs of a third psyllid: *Trioza eastopi* Orian were frequently observed on the citrus leaves. Winged adults of *T. eastopi* were also noticed feeding on avocado, papaw and vanilla leaves (3). *T. eastopi* has a marked preference for breeding on a Lauraceae: *Litsea chinensis* Jacq, which is a common weed shrub of the island. If the population reaches the stage of saturating the young flushes of *L. chinensis*, the females of *T. eastopi* will choose citrus leaves as oviposition sites. The nymphs of this polyphagous psyllid crawl but do not move down to the twigs. They usually remain on the underside of the young leaves and settle during the last instars in shallow pits. After the emergence of adults, the leaves remain gently curled. A survey made in 1975 showed that *T. eastopi* was distributed all over the island from low-lying areas up to 1000-1200 meters elevation. *T. eastopi* was apparently recorded in Reunion for the first time in 1898 on vanilla (8) and described later from Mauritius (19). Evidence of transmission of greening through this *Litsea* psyllid is still lacking. Adults of a fourth psyllid *Mesohomatoma lutheri* (Enderlein) have been seen on citrus leaves for short feeding periods, but this is an extremely rare occurrence. *Hibiscus* sp. is the preferential host of *M. lutheri*. The female of this fourth psyllid does not lay eggs on citrus flushes.

Eggs, nymphs and adults of

the three psyllids able to feed and breed on citrus are presented on fig. 1, together with a winged adult of *M. lutheri*.

PRIMARY PARASITES OF CITRUS PSYLLIDS

Eulophids. From an orchard survey made in 1973 (11), it became apparent that parasitized mummies of the citrus psyllids were non-existent on Reunion Island.

Two Eulophid parasites (superfamily Chalcidoidea; O. Hymenoptera): *Tetrastichus dryi* Waterston and *Tetrastichus radiatus* Waterston, were introduced bred and released in Reunion (2, 3, 4, 14).

Both parasites were established in a self-perpetuating cycle with an original rate of release of 30 to 50

adults per square kilometer of citrus area. These two Eulophids have a similar biology and life history. The females lay eggs on psylla nymphs of the third, fourth and fifth instars. The larva is ectoparasitic and sucks out the body contents of the psyllid nymphs. Adults pupate in the mummy of the nymphs and emerge after 9 to 14 days by chewing a hole through the thorax of the host. *T. dryi*, a parasite of *T. erytreae*, was obtained from southern Africa, and *T. radiatus*, a parasite of *D. citri* from India. Adults of these two eulophids exhibit the same conspicuous dorsal white patch on the gaster; the tarsi of their legs having four segments.

Slight differences of the antenna distinguish the African from

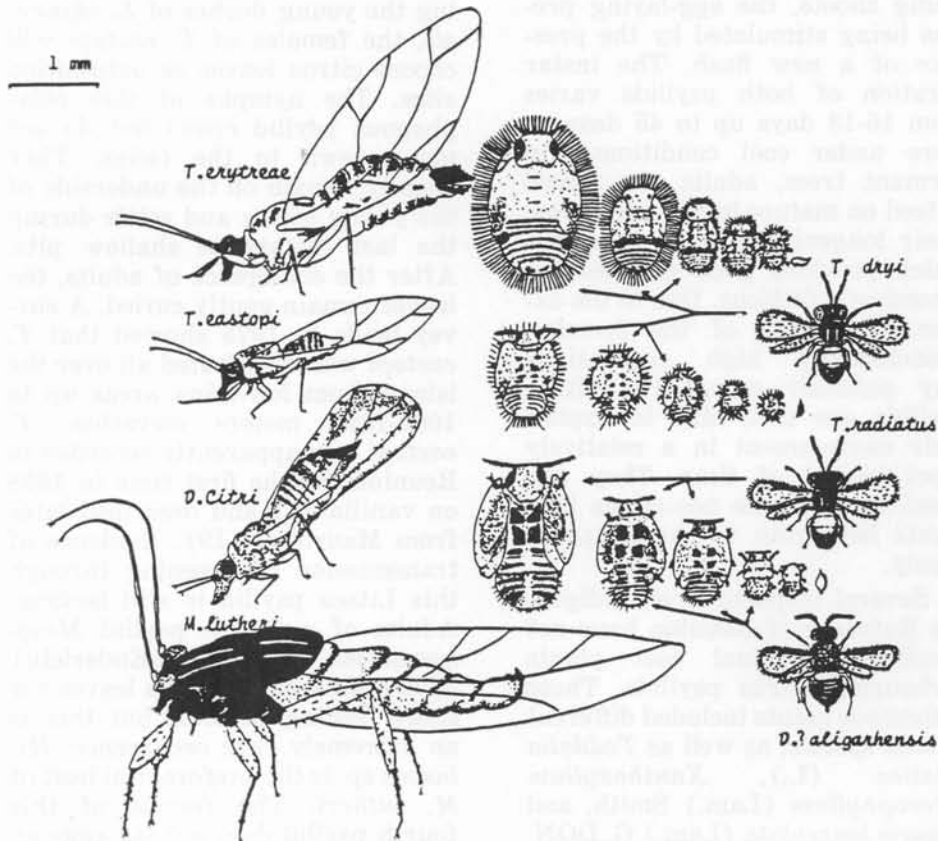


Fig. 1. Psyllids feeding and (or) breeding on citrus in Reunion Island, with the primary parasites presently established.

the Asian species. The males of *T. dryi* have a scapal sensorium situated further from the base of the antenna than that of *T. radiatus*. The males of the Asian hymenopteran have a scape and funicle averaging the same length (23). Besides, the female of *T. dryi* has more slender funicle than *T. radiatus* and all three segments are subequal in size, each longer than wide (20) (fig. 2).

In 1978, an Eulophid parasite was discovered for the first time on mummies of *T. eastopi*. A first observation did not reveal any difference between this eulophid and *T. dryi*; Prinsloo who made a taxonomic study of this psyllid (non-published), found it to be conspecific with *T. dryi*.

Encyrtids. The African encyrtid, *Psyllaephagus pulvinatus* (Waterston), known as a primary parasite of *T. erythrae* was introduced bred and released in Reunion with rates as high as 250 adults per square kilometer of citrus area (14).

This endoparasite which de-

velops internally on the second, third and fourth instar of psyllid nymphs could not establish on the Island and disappeared several months after being released.

The Asian encyrtid, *Diaphorencyrtus aligarhensis* (Shafee et al.), was discovered recently in Reunion. *D.*, *aligarhensis* might have been mistaken for *Psyllaephagus harrisoni* Robinson, an African encyrtid formerly described in Reunion (14). *D.?* *aligarhensis* is a primary Asian endoparasite of *D. citri*.

The life cycle of *P. pulvinatus* is close to 20 days. Adults can emerge from the underside of the psyllid nymph or chew a hole through the thorax of the mummy. The biology of *D. aligarhensis* seems very similar of that of *P. pulvinatus*.

EVOLUTION OF CITRUS POPULATION AFTER THE INTRODUCTION OF FOREIGN CHALCIDOIDEA

Soon after the introduction of foreign chalcid hymenoptera, the infestations of psyllids were

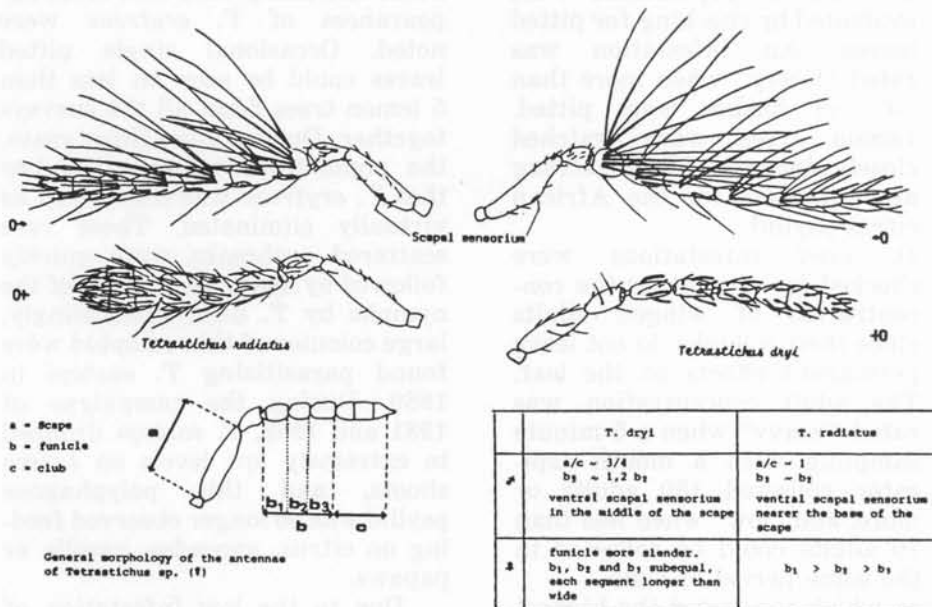


Fig. 2. Male and female antennae of *T. Radiatus* and *T. Dryi*. (After Waterston (23) and Prinsloo (20)).

monitored both in citrus orchards and on wild or ornamental Rutaceae.

Orchard inspections: Material and Methods. The orchard inspections started on 15 ha in 1974, but larger areas were covered every year to reach a total of 200 ha by the end of 1982. Newly planted groves amounted to about 50 ha per year.

Six operators were trained for field surveys and were checked periodically for the accuracy of their inspection. Several growers were also shown the attacks of citrus psyllids and asked to indicate their observations.

Between January 1974 and January 1978, data was collected from the infested trees twice a year: early summer and early winter. From January 1978 only summer data were collected due to the decreased psyllid populations. This early summer checking was found to be representative since it included the spring outbreaks on the main flush of the year. The following procedure was then used:

—*T. erytreae* populations were evaluated by checking for pitted leaves. An infestation was rated "heavy" when more than 50% of flushes were pitted. Lemon trees were watched closely since they show a strong attractiveness for the African citrus psyllid.

—*D. citri* infestations were checked by estimating the concentration of winged adults since their nymphs do not leave permanent effects on the leaf. The adult concentration was rated "heavy" when a 5-minute sampling with a mouth aspirator collected 150 adults or more, and "low" when less than 10 adults could be collected in the same period of time.

Trees which supported the highest psylla infestations were noted for

each orchard or a group of orchards.

During the spring flush, a few representative citrus zones were also examined weekly for the sequential appearance of psyllids and parasites. Samples of 50 parasitized nymphs were collected and hymenoptera emerging from the mummies were observed for species determination. Between November 1982 and January 1983 young shoots of *M. paniculata* harbouring *D. citri* nymphs were also sampled weekly to check the evolution of parasitism.

Results of orchard inspections.

In the high-lying areas (above 500 m of elevation) a drastic reduction of *T. erytreae* infestations was noticed two years after the first release of *T. dryi*. Only lemon flushes exhibited curled leaves in a few scattered areas which were recorded on maps (fig. 3). One of these areas, situated at 900 meters of elevation in a very humid climate, showed low infestations of the African psyllid in January 1978 and January 1979. In 1980-81 and 1982, extremely rare and brief appearances of *T. erytreae* were noted. Occasional single pitted leaves could be seen on less than 5 lemon trees from all the surveys together. During these three years, the populations remained so low that *T. erytreae* was considered as virtually eliminated. These rare scattered outbreaks were quickly followed by heavy parasitism of the nymphs by *T. dryi*. Interestingly, large colonies of this eulophid were found parasitizing *T. eastopi* in 1980. During the campaigns of 1981 and 1982, *T. eastopi* dropped to extremely low levels on *Litsea* shoots, and this polyphagous psyllid was no longer observed feeding on citrus, avocados, vanilla or papaws.

Due to the low infestation of citrus pests (insects and mites) in

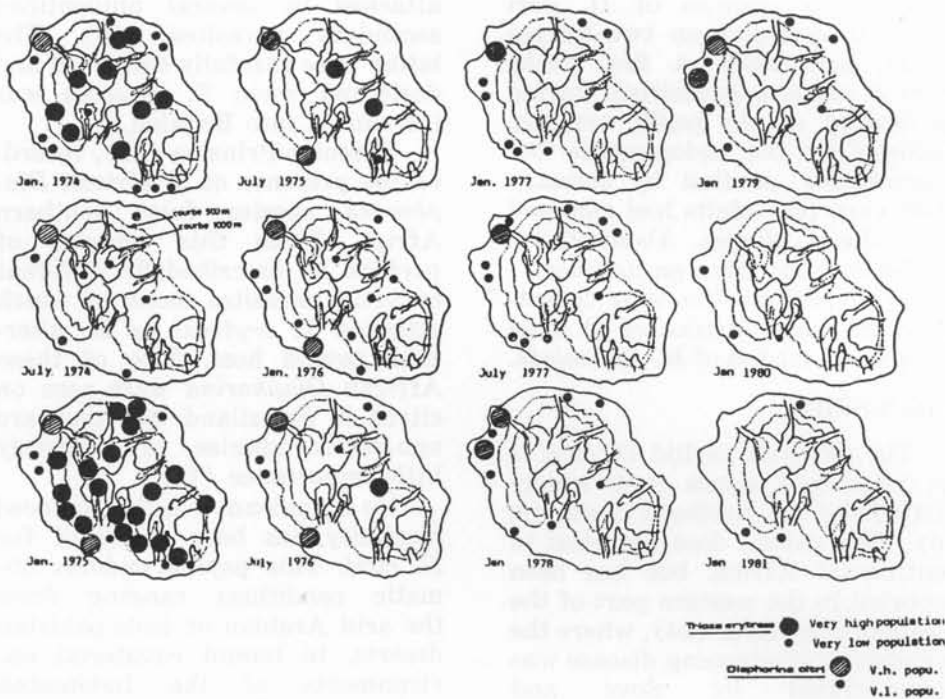


Fig. 3. Evolution of *T. Erytrae* and *D. citri* populations from 1974 to 1981.

high-lying areas of Reunion, chemical sprays are still very rare and the citrus orchards in these areas tend to be under full biological control.

For the low-lying areas (below 500 m of elevation) the situation is somewhat different. First of all, *T. radiatus* was imported and released four years later than *T. dryi*, i.e. in 1978. The reduction of the Asian psyllid population started to decrease significantly in 1980. As previously noted, it took some 24 months for the new eulophid to really establish itself. Furthermore, *T. radiatus* was unable to parasitize any psyllid other than *D. citri*. A third difference was due to the management of the orchards which, in warm areas, required sprays against several citrus pests.

Integrated pest management was progressively developed by the use of corrective sprays selected for protection of the natural enemies of these pests. This integrated control contributed to the elimina-

tion of *D. citri* from the citrus orchards. The Oriental psyllid could only be detected in neglected groves or on occasional backyard trees. The 1980 and 1981 attacks are shown on maps in fig. 3. In 1982, the parasitism of *T. radiatus* and *D. aligarhensis* rose to such levels that *D. citri* disappeared from these neglected citrus trees, and was relegated to *M. paniculata* hedges in two localities.

Inspections of wild and ornamental Rutaceae. In the rainforest on the windward side of the Island, several inspections were carried out on an indigenous Rutaceae, *Xanthoxylum heterophyllum*, but no citrus psyllids or traces of them could be detected. In the dry areas of the leeward side, *Evodia* sp., *Toddalia asiatica* and *Vepris lanceolata* did not show any traces of citrus psyllids.

The young flushes of *M. paniculata* were discovered to be very attractive for the egg-laying females of *D. citri*. In November

1982, large colonies of *D. citri* began to establish on two hedges of *M. paniculata*. A few weeks later *T. radiatus* parasitism started to develop on the psylla nymphs, followed by the endoparasite *D. aligarhensis*, so that by January 1983 very few adults had emerged from these colonies. About 92.5% of the nymphs were parasitized.

No hyperparasites were collected from the mummies of *D. citri* sampled on flushes of *M. paniculata*.

DISCUSSION

The Oriental psyllid *D. citri* is an important citrus pest widely distributed in southern Asia (9, 10). This psyllid does not exist in continental Africa, but has been reported in the western part of the Arabian Peninsula (24), where the occurrence of greening disease was demonstrated by Bove and Garnier in 1983 (8). On the other hand, a *Diaphorina* very similar to *D. citri* was mentioned in Brazil (13), but greening disease has not been recorded there.

T. radiatus and *D. aligarhensis*, in the absence of their natural secondary parasites, have proved their extreme efficiency in controlling *D. citri* populations in Reunion. The persistence of *D. citri* colonies on *M. paniculata* was observed in hedges pruned several times a year, thus offering to *D. citri* survivors a possibility of bridging the short gaps between numerous new flushes. Private gardens on the nearby island of Mauritius are commonly fenced with *M. paniculata*, and large colonies of *D. citri* were observed on these shrubs (5). Paradoxically, *M. paniculata* is used as a wind-break in some citrus orchards on this island.

The failure of *T. radiatus* to limit *D. citri* populations was noticed in some parts of India as early as 1924 (16). *T. radiatus* was in fact discovered later as being

attacked by several unidentified secondary parasites (10). The latter were carefully discarded and destroyed when *T. radiatus* was introduced into Reunion.

Recently Prinsloo (21), recorded the presence of 8 African *Diaphorina* species from southern Africa. From this complex of psyllids he described 20 different encyrtid parasites, none of which attacked *T. erytrae* as an alternate psyllid host. Two of these African *Diaphorina* were seen on citrus in Swaziland, but they are non-vector species of relatively little importance (12).

No significant weather-induced mortality has been described for *D. citri*. This psyllid endures climatic conditions ranging from the arid Arabian or Indo-pakistan deserts, to humid equatorial environments of the Indonesian archipelago. However, the populations of the Asian psyllid are generally lower in wet areas.

In Africa, *T. erytrae* is the host of *T. dryi* and *P. pulvinatus*.

These two parasites have a common secondary parasite (or hyperparasite) *Aphidencyrthus casatus* Annecke, recorded from South Africa, Zimbabwe, Swaziland, Angola and Kenya (21). *Cheiloneurus cyanonotus* Waterston is another hyperparasite reared from *T. erytrae* in Zimbabwe (17). The action of these two secondary parasites may significantly reduce the effect of the primary parasites of the host. As far as is known these secondary parasites have not reached Reunion Island.

In eastern and southern Africa, *T. dryi* is apparently unable to parasitize any psyllid other than *T. erytrae*. Neither *T. eastopi* nor *Litsea chinensis* occurs in this part of the world, both being of Asian origin. The introduction of *T. dryi*, an African eulophid, in the very peculiar environment of Reunion,

was followed by spectacular results through the intermediate ecosystem "*T. dryi*-*L. chinensis*."

The importance of weather-induced mortality for the immature stages of *T. erytrae* was demonstrated by Green and Catling (15) in continental Africa. For instance the egg survival drops to 20% only when the saturation deficit reaches 40 millibars during midday. Using a saturation deficit index, these authors have clearly explained the geographical distribution of *T. erytrae* in southern Africa, as well as its occasional severe outbreaks over a period of 30 years. In the absence of very efficient parasitism, *T. erytrae* populations tend to be more regulated, in Africa, by weather conditions than biological control. In comparison, the climatic conditions prevailing in Reunion are far from those inducing lethal saturation deficits to immature stages of *T. erytrae*. The driest sites of this island are still strongly affected by maritime influences and do not score saturation deficits beyond 15 millibars at midday. The cool and moist climate of the high-lying areas permanently offers ideal conditions for the development of *T. erytrae*. This explains the high population of the African

psyllid recorded in Reunion before 1974.

Preferential host plants offering frequent flushes and good quality flush for the egg-laying process, enhance the possibilities for both citrus psyllids to overcome adverse conditions of climate or parasitism. Lemons and limes are such preferential plants for the African citrus psyllid. In Zimbabwe, for instance, the problem of *T. erytrae* is more serious in Mexican lime plantations than orange groves. In the native lands, regrowth of non-grafted rough lemons show much higher percentages of pitted leaves than nearby orange or mandarin trees (6).

Although Mexican lime is a good host for *D. citri*, it was noted in Reunion and Mauritius that pruned hedges of *M. paniculata* are supporting higher population levels of the oriental citrus psyllids. This evergreen shrub, sometimes called "orange Jessamine" is widely distributed in Southeast Asia (22).

CONCLUSION

The new self renewing antagonism against the two psylla vectors has brought about a significant reduction of the greening disease in Reunion Island.

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