Biocontrol of Eucalyptus psyllid Ctenarytaina eucalypti by the Australian parasitoid Psyllaephagus pilosus: A review of current programmes and their success

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Review Article

Biocontrol of eucalyptus psyllid *Ctenarytaina eucalypti* by the Australian parasitoid *Psyllaephagus pilosus*: a review of current programmes and their success

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Abstract

The Australian parasitoid *Psyllaephagus pilosus* has been successfully introduced into California, Britain, France and Eire for the biocontrol of eucalyptus psyllid *Ctenarytaina eucalypti*. At each introduction site the parasitoid has rapidly established and produced major sustained reductions in eucalyptus psyllid populations. It has also spread rapidly to colonize adjacent areas. This paper explains the background and rationale to the programmes, summarizes details of the introductions and describes the subsequent dissemination of the parasitoid. Emphasis is placed on the methods employed, the potential pitfalls and the economic benefits that accrue. The effectiveness of the parasitoid as a biocontrol agent is discussed, together with some avoidable problems that might limit its efficacy. The potential for extending the biocontrol programme for eucalyptus psyllid to other regions of the world is highlighted.

Introduction

Species of *Eucalyptus* (Myrtaceae) indigenous to Australia have been widely planted in other parts of the world, including Europe, the USA, Africa, Asia and South America. Early introductions of *Eucalyptus* were mainly of novelty horticultural interest but more recently the commercial value of selected species for the production of ornamental foliage used in the cut flower industry and/or for pulp timber production has been realised. This has resulted in the widespread planting of small commercial plantations that augment the ornamental trees most commonly planted in parks and gardens. Commercial production of *Eucalyptus* is now widespread in Britain, Eire, France, Italy, Spain, Portugal, California (USA) and areas of Latin America, Africa and Asia.

Unconstrained by the absence of their native Australian insect herbivores, introduced *Eucalyptus* species have often shown accelerated rates of growth and primary production, producing foliage free from insect damage. Where eucalyptus psyllid *Ctenarytaina eucalypti* (Maskell) (Hem., Psylloidea) has been present over a long period, such as in England (Laing, 1922) and northern France (Mercier & Poisson, 1926), the presence of the pest has been largely unobserved, tolerated or dealt with by localized insecticide application. However, from the early 1970s more intensive eucalypt production, coupled with the introduction of eucalyptus psyllid into areas from which it was previously absent, led to increased demand for effective control measures. Particular impetus for biocontrol was generated following the introduction of *C. eucalypti* into Monterey Co., California in 1991, an area where *Eucalyptus* had been grown successfully for the previous 30 years with few problems (Dahlsten *et al.*, 1993). There, as elsewhere, chemical spraying proved uneconomic and often ineffective, leading to the demand for alternative biocontrol measures applicable across the widely varying climatic conditions under which the eucalypt and its associated psyllid are cultivated. Effective chemical control is often precluded by the rough nature of the terrain on which *Eucalyptus* plantations are situated, which limits ground spraying. Even within a commercial eucalypt nursery in Wales, good control of *C. eucalypti* was only achievable by repeated spraying at two- to three-week intervals, a situation ideal for the rapid development of insecticide resistance.

Table 1. Recorded introductions and spread of *Ctenarytaina. eucalypti.*

Country/Region	Reference
Bolivia	D. Hollis (pers. comm.)
Brazil (probably)	C. Wilcken (pers. comm.). Requires confirmation
Colombia	D. Hollis (pers. comm)
Eire	Hodkinson & White 1979
France	Mercier & Poisson 1926, Martinez 1983, Bertaux et al. 1996
Germany	Burckhardt 1998
Italy	Cavalcaselle 1982
New Zealand	Froggatt 1903, Tuthill 1952
Papua New Guinea	Hodkinson 1983
Portugal (mainland)	Nogueira 1971, Azevedo & Figo 1979
Portugal (Madeira)	Burckhardt 1998
Portugal (Azores)	I. Hodkinson unpublished
South Africa	Pettey 1925, Stuckenberg 1961, Capener 1970
Spain (mainland)	Rupérez & Cadahia 1973, Cadahia & Rupérez 1979, Cadahia 1980
Spain (Canary Is.)	Hodkinson 1990
Sri Lanka	Azevedo & Figo 1979
UK	Laing 1922, Fox-Wilson 1924, Hodkinson & White 1979
USA, California	Dahlsten *et al.* 1993

Table 2. The *Eucalyptus* species from which *Ctenarytaina eucalypti* has been recorded in Britain. Breeding on some species requires further confirmation. [* indicates species that commonly support large breeding populations.]

archeri Maiden & Blakely
cinerea F.Muell ex. Benth.
citriodora Hook
cordata Labill.
crenulata Blakely & de Beuzev.
dalrympleana Maiden
glaucescens Maiden & Blakely
globulus Labill.*
gunnii Hook*
leucoxylon F. Muell
macarthuri Deane & Maiden
mannifera Mudie
neglecta Maiden*
nicholi Maiden & Blakely
nitens Maiden*
nitida Hook
perriniana F. Muell ex Benth.*
pulverulenta Sims*
rubida Deane & Maiden
urnigera Hook
viminalis Labill.

Eucalyptus psyllid is now widely established in many areas throughout both hemispheres (Table 1) and the potential for effective biocontrol on a world scale is good. This paper, therefore, reviews recent successful attempts to control *C. eucalypti* using the introduced Australian parasitoid *Psyllaephagus pilosus* Noyes (Hym., Encyrtidae). It summarizes background information on the target organism and its parasitoid, compares the efficacy of biocontrol programmes in different countries and provides recommendations as to how the control programme might be extended.

The Target Organism *Ctenarytaina eucalypti*

Ctenarytaina eucalypti was initially described from specimens collected off blue gum (*Eucalyptus globulus*) in New Zealand (Maskell, 1890). Blue gum is not indigenous to New Zealand and the tree, with its associated psyllid species, is thought to originate in Australia, most probably Tasmania (Froggatt, 1903; Tuthill & Taylor, 1955; Morgan, 1984).

Eucalyptus psyllid was introduced into southern England, northern France and South Africa as early as the 1920s (Laing, 1922; Pettey, 1925; Mercier & Poisson, 1926). Even within these areas, reintroduction has continued. For example, a recent wave of importation into Britain took place during the Liverpool Garden Festival when several species of *Eucalyptus* infested with psyllids were brought from nurseries in Western Australian to plant an Australian Garden (I. Hodkinson, unpublished).

The eucalyptus psyllid is narrowly host-specific, feeding only on a limited range of *Eucalyptus* species (Table 2). It causes particular problems on *E. globulus* and *Eucalyptus pulverulenta* which are widely grown in plantations. The biology of *C. eucalypti* in southern European *Eucalyptus* plantations is described by Azevedo & Figo (1979), Cadahia & Rupérez (1979), Cavalcaselle (1982), Martinez (1983) and Alma & Arzone (1988). The life cycle in the British Isles is continuous, with several overlapping generations and in California there are four generations per year. The egg, five larval and adult life stages were described by Lal (1937), Hodkinson & White (1979) and White & Hodkinson (1981). In cooler regions, such as Britain and Eire, overwintering of both larvae and adults takes place in the rolled evergreen leaves of the host plant: elsewhere reproduction is less temperature limited.

Larvae and adults feed on the growing shoots of young succulent plants or on the new growth of older trees. Mature trees, with a greater proportion of older foliage, are less susceptible to attack than young saplings or seedlings. The eucalyptus psyllid is thus particularly abundant in forest nurseries and newly established plantations. Direct effects of psyllid feeding include severe shoot dieback, leaf curl and leaf discoloration. Feeding larvae also produce copious amounts of honeydew that adheres to the leaf and becomes a site of infestation for sooty moulds. Where foliage is required for decorative purposes, such as flower arranging, even superficial cosmetic damage is highly detrimental.

There are apparently only two published records of hymenopterous parasitoids attacking *C. eucalypti* outside its native range. These are an indet. species of *Syrphoctonus* (Ichneumonidae) in Portugal and *Pteroptrix maskelli* Ashmead (Aphelinidae) in New Zealand (Gourlay, 1930; Alma & Arzone, 1988). The non-specific predator complex feeding on *C. eucalypti* comprises the same taxa that feed ubiquitously on most sedentary Hemiptera throughout the world and includes hoverfly larvae, ladybirds, lacewings, anthocorids and spiders (Alma & Arzone, 1988; Dahlsten *et al.*, 1993; I. Hodkinson, unpublished) but these are largely ineffectual in restricting population growth.

The Parasitoid *Psyllaephagus pilosus*

Psyllaephagus pilosus was described from specimens bred from larvae of *C. eucalypti* collected in New Zealand (Noyes, 1988). However, it is almost certainly native to the cooler parts of southern Australia and Tasmania and its presence in New Zealand reflects the introduction of its host: it has subsequently been collected from larvae of *C. eucalypti* in Tasmania, Victoria, South Australia and Canberra A. C. T. (Dahlsten *et al.*, 1993). It is thus not included in Riek's (1962) account of the *Psyllaephagus* species of Australia.

Psyllaephagus pilosus appears specific to *C. eucalypti* and its natural distribution reflects that of its psyllid host, which in turn mirrors the distribution pattern of the *Eucalyptus* host plants. Adult females usually lay a single egg on or in the psyllid larva. The hatching larva feeds on the psyllid body contents, first immobilizing and then killing the psyllid. Pupation takes place within the mummified remains of the psyllid larva from which single adult wasps emerge by chewing an exit hole (Robinson, 1970; Dahlsten, 1996). Female wasps are able to discriminate psyllid larvae of sufficient size to support larval development.

Species of *Psyllaephagus* parasitize psyllids exclusively. They are widely recorded from throughout the Holarctic regions, from California in North America to the western Mediterranean, central Asia, Mongolia and Japan (Jensen, 1957; Trjapitzin, 1982). Thus, potentially, *P. pilosus* may compete with indigenous congeneric species for psyllid hosts. However, *Eucalyptus* belongs to the plant family Myrtaceae, which is largely absent from north temperate and African floras and is thus taxonomically and chemically isolated. The chances of the wasp transferring from Myrtaceae to attack a native psyllid species on a north temperate host are remote. The probability is further reduced by the fact that *C. eucalypti* is a diminutive species about half the size of most other psyllids. For example, in Britain its small size is only matched by three species, two *Strophingia* species on heather and *Rhinocola aceris* (L.) on field maple (Hodkinson & White, 1979). There is thus a major size mismatch between the wasp and most potential alternative psyllid hosts. Monitoring of other psyllid species at a parasitoid introduction site in Britain indicates that transfer onto a native host species has not occurred (I. Hodkinson, unpublished).

History of Release

The initial release of *P. pilosus* for biocontrol of eucalyptus psyllid was in the USA, at eight sites in San Diego, San Luis Obispo, Monterey, Alameda and Sonoma counties, California during 1993. The released parasitoids were bred by Prof. Don Dahlsten in the quarantine facility of the Division of Biological Control, University of California, to ensure hyperparasite free stock, from nine samples collected off *E. globulus, E. pulverulenta, Eucalyptus bicostata* and *Eucalyptus nitens* in southeastern Australia and the North Island of New Zealand (Dahlsten *et al.*, 1993). This Californian stock provided the parasitoids for subsequent introductions into north Wales, UK during 1994 (Hodkinson, 1994) and the Tanneron Massif of SE France during 1997 (INRA, 1997; Malausa & Girardet, 1997; Anon, 1998). *Psyllaephagus pilosus* introduced into Co. Kerry, Eire in 1997 were collected near Nice in France (G. Purvis, pers. comm.).

Method of Release

Numbers of adult parasitoids released at a given site ranged from 500 in Wales to an average of 800 per site in California (Hodkinson, 1994). The introduction into Eire varied in that it included both 200 adult parasitoids and 2000 mummified psyllid larvae (G. Purvis, pers. comm.). Mesh cages, placed over psyllid infested bushes have usually been used to retain the parasitoids for two to seven days and aid establishment. However, at the Welsh site, direct release of 300 individuals onto infested *E. nitens* trees adjacent to aggregations of psyllid larvae on a still day proved as effective as releasing 200 individuals into cages covering infested *Eucalyptus neglecta* plants. Both methods resulted in subsequent high levels of parasitism.

Monitoring Programmes

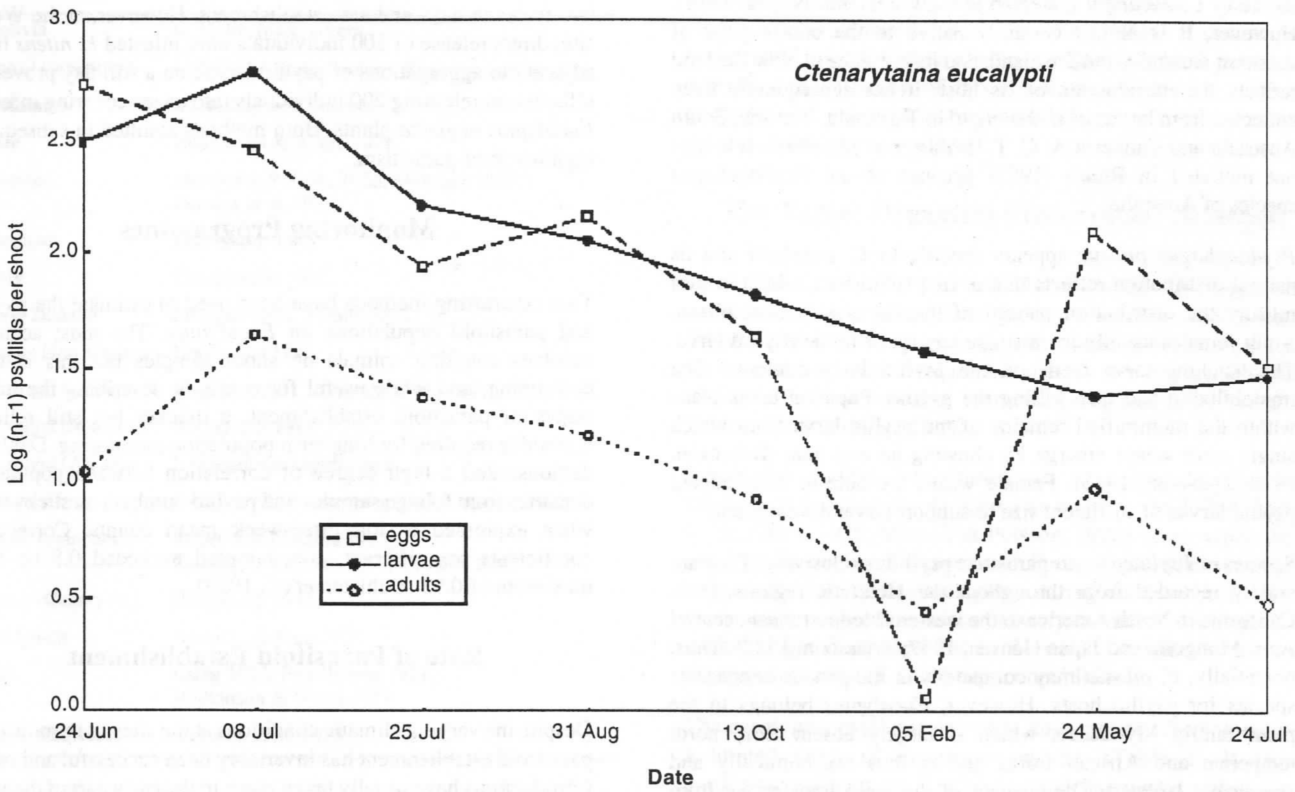
Two contrasting methods have been used to estimate the psyllid and parasitoid populations on *Eucalyptus*. The most accurate involves counting animals on shoot samples but this is time consuming, and while useful for carefully describing the initial stages of parasitoid establishment, a quicker but still reliable method is required for long term population monitoring. Dahlsten demonstrated a high degree of correlation between population densities from foliage samples and psyllid numbers on sticky traps when expressed as log three-week mean counts. Correlation coefficients for different sites sampled exceeded 0.8 up to a maximum of 0.93 (Dahlsten *et al.*, 1993).

Rate of Parasitoid Establishment

Despite the varying climatic conditions at the sites of introduction, parasitoid establishment has invariably been successful and rapid. Introductions have usually taken place in the early part of the year, as psyllid population densities have begun to increase. By the end of the first year the parasitoid has become well established throughout the site and has produced a major reduction in psyllid populations compared with those experienced in previous years or at sites where the parasitoid is absent. Figure 1 shows typical establishment data for the introduction site in Wales. *Psyllaephagus pilosus* was released on 24 June, significant numbers of mummified larvae were first recorded on 25 July and new generation adult parasitoids had emerged by 31 August, a maximum generation time of 68 days. This is slightly longer than the 49 days recorded for Eire (G. Purvis, pers. comm.) but indicates that the parasitoid is capable of undergoing several generations per annum, particularly within warmer Mediterranean climates.

Dispersal from Introduction Site

Following all introductions, the rate of spread by *P. pilosus*, out of the initial introduction sites, has invariably been rapid. Subsequent to its release in California in 1993, *P. pilosus* was found 18 km from the introduction site by mid-1994 and by 1995 was dispersed throughout the *Eucalyptus* growing areas (Dahlsten, 1996). Similarly, within three months of introduction into the Tanneron Massif in SE France the parasitoid was found throughout the Massif and by the end of the year had colonized sites throughout the Alpes-Maritimes and the eastern Var (Malausa & Giradet, 1997). Early the following year it was recorded 85 km from the site of introduction, spreading naturally in the direction of the *Eucalyptus* growing areas of Liguria, northern Italy. In Eire dispersal over 75 km was observed in the first year and in Britain, five years after introduction, *P. pilosus* had dispersed nearly 200 km (I. Hodkinson, unpublished; G. Purvis, pers. comm.). The main limiting factor for the spread of *P. pilosus* thus seems likely to be the patchy distribution of host plants within the landscape rather than the parasitoid's dispersal capabilities.



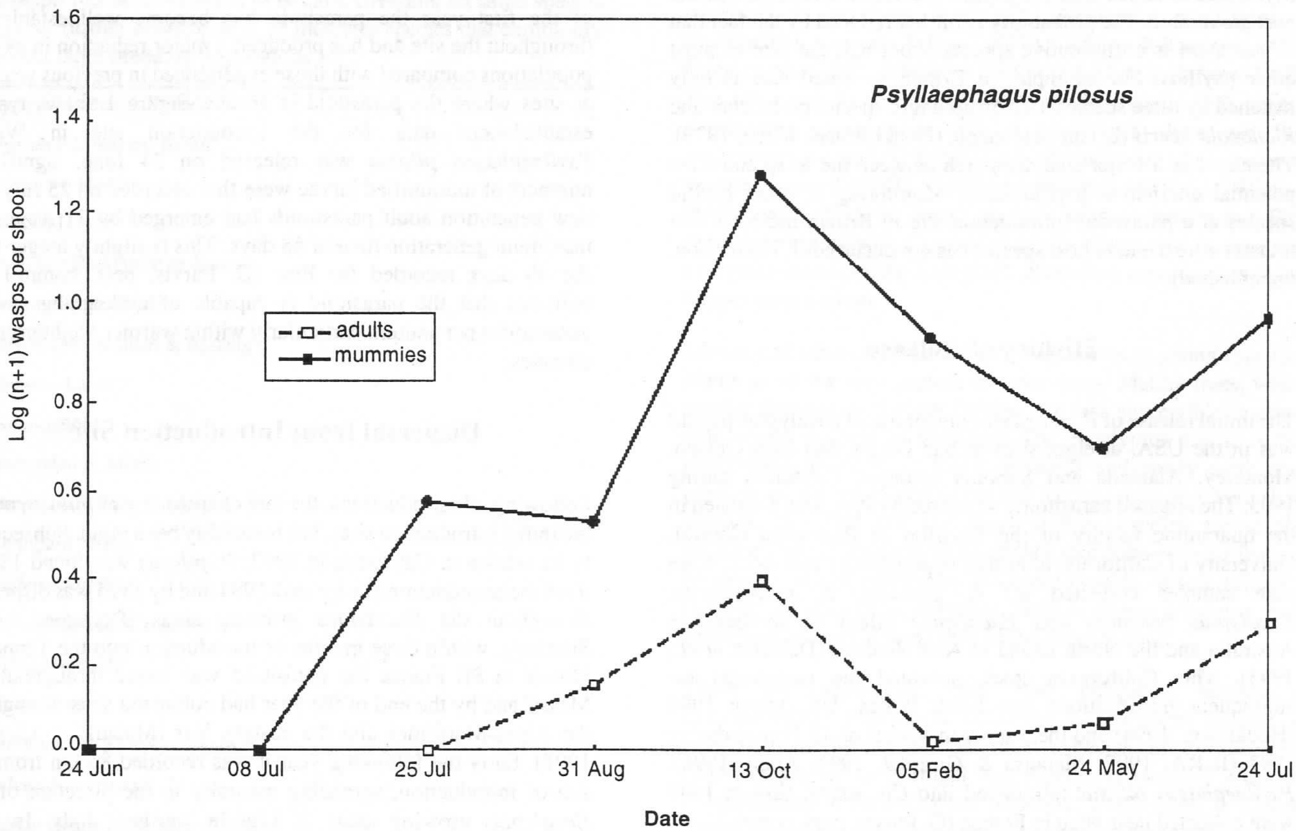


Figure 1. Population changes in eggs, larvae and adults of *Ctenarytaina eucalypti* and of its parasitoid *Psyllaephagus pilosus* (adults and mummified psyllid larvae) over the one year period 1994/5 following its introduction at a site in Wales, UK. Data are for a population on twelve *Eucalyptus nitens* trees.

Cold Tolerance of Psyllid and Parasitoid

Several of the *Eucalyptus* hosts of *C. eucalypti* originate from temperate Australia and Tasmania and often have a degree of cold tolerance that allows them to be cultivated successfully at sites that experience cold winters, such as lower hill sites in Wales. Problems of winter survival by *P. pilosus* and their impact on the plant–psyllid–parasitoid interaction are probably not important in the warmer temperate regions of southern France, Italy, Spain and California. There is, however, the possibility that successfully established *P. pilosus* populations, overwintering as mummified pupae, will be detrimentally affected by very cold winters at more northerly sites. Laboratory experiments in constant temperature cabinets showed that overwintering *P. pilosus* successfully emerged as adults after surviving –10°C for up to two weeks (I. Hodkinson, unpublished). Furthermore, at a hill site in Wales *P. pilosus* has successfully survived five winters during which the minimum air temperature was –14°C. Lack of cold hardiness thus appears unlikely to present a problem.

Economic Benefits and Potential Problems

Psyllaephagus pilosus has proved highly effective, wherever it has been introduced, in significantly reducing *C. eucalypti* populations on *Eucalyptus* species and in preventing mass outbreaks that lead to die back or death of plants. It has been most effectual at limiting populations on newly established plants or the immature foliage of larger trees, such as in forest nurseries or newly established plantations. In many places the need for chemical control has been removed with significant cost benefits. Dahlsten *et al.* (1999) estimated the benefit:cost ratio, resulting from savings in insecticide application alone, to vary between 9:1 and 24:1 for sites in California.

Eucalypts tend to be grown as scattered and isolated islands of plantation or as specimen trees in suburban gardens. Thus, within the general range of *P. pilosus*, where the *Eucalyptus* is isolated and the parasitoid has not yet established, it may still be necessary artificially to accelerate the rate of spread to achieve effective control of psyllid populations.

It must be remembered that the parasitoid does not eliminate its host: a low residual psyllid population is essential to sustain the population. Where high quality *Eucalyptus* foliage is required for floral arrangements the temptation remains to spray and thus remove all psyllids. This could potentially lead to the elimination of the parasitoid within restricted areas and a potential loss of control. Similarly, as eucalypts mature the foliage hardens and psyllid populations decline. Widespread coppicing followed by foliage removal may also lead to the loss of parasitoids. It may thus be necessary for growers to retain sufficient immature foliage to sustain reservoir populations of both the psyllid and its parasitoid.

Potential for Introduction Elsewhere

There still remain large areas of the world where *Eucalyptus* is grown commercially and where *C. eucalypti* is a significant problem, including the Iberian Peninsula, several North Atlantic islands and Latin America (Table 1). There seems little reason why *P. pilosus* cannot be introduced successfully into those areas. The methodology is simple, inexpensive and now well tested: the cost-benefit advantage is high. Furthermore, the host plant, psyllid and parasitoid are all non-native species and the potential impact on local species is, therefore, likely to be minimal. The methodologies developed for the *C. eucalypti – P. pilosus* model system may also have relevance for the control of other related species of Australian psyllid that are becoming important pests of other species of eucalypts outside Australia. Most importantly these include species of *Blastopsylla* in California, Mexico, Paraguay and Brazil (Hodkinson, 1991; Burckhardt, 1998).

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