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Natural biological control of the pine processionary moth *Thaumetopoea pityocampa* (Den. & Schiff.) by the Argentine ant *Linepithema humile* (Mayr) in Portugal

M. J. Way,[1] M. R. Paiva[2] and M. E. Cammell[1]

[1]Imperial College of Science, Technology and Medicine, Silwood Park, Ascot, Berks SL5 7PY, U.K. and [2]Universidade Nova de Lisboa, FCT, P-2825 Monte de Caparica, Portugal

Abstract

1 Defoliation by larvae of the pine processionary moth, *Thaumetopoea pityocampa*, is negligible in stands of *Pinus pinaster* colonized by the Argentine ant *Linepithema humile* which preys fiercely on the young moth larvae. In contrast, such damage is widespread where pine plantations are colonized by native ants, predominantly *Tapinoma nigerrimum* and *Lasius niger*, which seemingly disregard the larvae.

2 Where *L. humile*- and native ant-occupied sectors adjoin, there is a 20–50 m overlap in the transition area between *L. humile*- and native ant-occupied pines. This was most evident in a > 500 ha plantation where there was severe or very severe *T. pityocampa* attack in native ant sectors contrasting with none in adjoining *L. humile* sectors.

3 Predation by *L. humile* is no doubt enhanced by its existence as super-colonies over very large areas, by its foraging activity and recruitment on trees throughout the time when *T. pityocampa* and other prey are present, and by honeydew-producing Homoptera which help retain foraging *L. humile* workers in pine tree crowns.

4 The role of *L. humile* could be enhanced by cultivations that disturb the soil and restrain ground vegetation.

Keywords Biological control, *Linepithema humile*, *Pinus pinaster*, predation, Portugal, *Thaumetopoea pityocampa*.

Introduction

Several ant genera, notably *Oecophylla*, *Formica*, *Dolichoderus* and *Solenopsis* spp. are recognized as important biological control agents (Way & Khoo, 1992). In such circumstances their beneficial roles greatly outweigh any harm they may do by attending Homoptera for honeydew (Way, 1963; Way & Khoo, 1992). However, *Solenopsis* spp., and the Argentine ant *Linepithema humile* (Mayr) are nuisance and public health pests particularly in urban environments. Worldwide, *L. humile* has invaded regions with Mediterranean-type temperatures where it is almost invariably regarded as a serious nuisance and as a pest because it may interfere with, or prey on, beneficial natural enemies (Frazer & van den Bosch, 1972; Panis, 1974; Dreistadt *et al*., 1986; Haney *et al*., 1987). It has been recorded as predatory on some pests (Wong *et al*., 1984; Olkowski & Olkowski, 1989), and in Portugal is an egg predator on the eucalyptus borer *Phoracantha semipunctata* but ineffective as a biological control agent (Way *et al*., 1992). We now report the first evidence of the relationship between *L. humile* presence and damage by the pine processionary moth *Thaumetopoea pityocampa* (Den. & Schiff.) which can severely defoliate pine plantations throughout Portugal and parts of the Mediterranean region of Europe.

Correspondence: M. J. Way. E-mail: m.cammell@ic.ac.uk

Methods

Thaumetopoea pityocampa damage

Surveys of *T. pityocampa* damage were made in pine plantations, mostly of *Pinus pinaster*, in the regions of Abrantes, Muge and Marinha Grande. The work was done in May when ants are active and when it is still easy to record the previous year's late season defoliation and also the empty larval 'nests', constructed

Table 1 Relationships between ant species on baits at tree bases and *T. pityocampa* attack at 20 sites in *P. pinaster* plantations.

Season of attack	No. of sites	Total no. ant species per set of sites	Dominant ant ant species	% tree baits with ants		Damage by *T. pitycampa*	
				L. humile	Native ants	Damaged trees	Severity of attack on damaged trees
Summer	3	1	*L. humile*	100	0	0	None
	3	7	*L. niger*	0	100	100	Moderate to very severe
Late season	4	2	*L. humile*	100	3*	3	Slight
	6	6	*L. niger*	0	100	6	Slight to moderate
	4	6	†*T. nigerrimum* or *A. senilis* +*L. humile*	4	27	14	Slight to moderate

* One *A. senilis* on one bait.

† Three of the four sites were at the boundary between exclusively *L. humile*- and native ant-dominated areas.

in the previous October–December, most of which had remained firmly attached to the branches. Nests formed during earlier attacks in July–September were not so durable. The routine samplings in May were all based on assessments of defoliation by larvae on the previous year's growth on lower branches as follows: no damage; slight damage – about 1–5% of twigs with some needles partly, but rarely completely, eaten; moderate damage – about 5–25% of twigs damaged with some needles completely eaten; severe – about 25–100% of twigs attacked with most needles destroyed apart from a few at the distal end of the youngest twigs available at the time of attack; very severe – all twigs stripped of available needles apart from a few distal stubs. In May, all trees bore new undamaged growth that developed after larval attack had ceased, although some defoliated branches of very severely damaged trees had been killed. Irrespective of the severity of damage, the tops of the crowns of some larger trees remained relatively undamaged.

Ant surveys

The presence and abundance of different ant species in sampled sites were determined using sugar baits at the base of each tree (Cammell *et al*., 1996; Paiva *et al*., 1998). Initially, baits were placed within areas mostly occupied either by *L. humile* or by native ants, and involved up to 30 trees at each of 20 sites. Bait transects were also made across boundaries between *L. humile*- and native ant-dominated areas. The activity of ants in trails on tree trunks was noted. After 1 h the numbers of each ant species at each bait were counted and compared with the damage by *T. pityocampa* seen on the trees.

Results

Where *L. humile* was the sole ant species at baits, there were usually well-defined trails up the tree trunks, and only one set of sampled pines showed evidence of slight *T. pityocampa* attack (Table 1). Elsewhere there were up to eight native species at a particular site, usually with one very common species, namely *Pheidole pallidula* (Nylander) or *Tapinoma nigerrimum* (Nylander) or *Lasius niger* L., exclusively occupying most of the baits at the tree bases. These species sometimes formed trails up the tree trunk which were usually much less pronounced than those of *L. humile*, and their presence did not prevent *T. pityocampa* damage (Tables 1–3). The most striking contrasts were in the > 500 ha Leiria pine stand between Marinha Grande and S. Pedro de Moel. Here, undamaged *L. humile*-occupied trees contrasted with trees severely damaged by *T. pityocampa* in adjoining areas occupied only by native ants (Table 1, summer). Outside this region, the 1997 attacks, unlike those in 1996, were mostly slight. The worst damage in 1997 was at Muge, where the sampled areas were all at edges of boundaries between *L. humile*- and native ant-occupied parts of a plantation; hence some overlap of ant species (Table 1, late season).

Current work shows that branches with nests containing young *T. pityocampa* larvae, transferred to pine trees foraged by *L. humile*, were fiercely attacked and the larvae killed and removed. In contrast, similarly transferred larvae were disregarded by native dominant ants (E. B. Moura, M. R. Paiva and M. E. Cammell, unpublished).

The boundaries between parts of a plantation occupied by *L. humile* and native ants are usually well defined (Way *et al*., 1997), so detailed counts were made in May 1998 along transects across such boundaries, one where there had been light (Table 2), and three where there had been severe attacks by *T. pityocampa* (Table 3). At Abrantes (Table 2) there was a sharp transition from exclusive *L. humile*- to native ant-occupied trees, with *T. nigerrimum* dominant among five recorded ant species, of which *Plagiolepis schmitzii* Forel and *Crematogaster auberti* Emery were also common. The ant changeover coincided with a change from an *L. humile* sector with no *T. pityocampa* damage to a native ant sector where most trees were damaged and bore larval nests. Counts were also made along three transects in a large plantation heavily attacked in summer at Leiria. The combined results (Table 3) show insignificant damage in sectors occupied by *L. humile* but severe and very severe damage in the adjoining native ant-occupied sectors where *L. niger* was the commonest ant. However, in the 20–50 m wide transition areas, 46% of trees were exclusively occupied by small populations of *L. humile* (35 per occupied baits compared with 342 within the *L. humile* sectors). Of the remaining 54% of baits, 67% were

Table 2 Damage by a late season light attack of *T. pityocampa* in relation to ant species at tree baits along one transect from an *L. humile*- to a native ant-dominated area in a *P. pinaster* plantation near Abrantes.

Approx. distance along transect (m)	Total no. of ants at baits at bases of 10 trees					No. of damaged trees
	L. humile	*T. nigerrimum*	*P. schmitzii*	*C. auberti*	Others	
1–20	50	0	0	0	0	0
21–30	0	211	40	70	7	6
31–40	0	213	2	3	30	8
41–50	0	45	11	11	30	5
51–60	0	115	36	4	0	4
61–70	2	23	113	7	5	8

Table 3 Combined data on damage to *P. pinaster* by *T. pityocampa across three transects from L. humile*- to native ant-dominated sectors in the Lieria plantation.

Ants at baits across transects	No. of occupied tree baits	Mean no. of *L. humile* per occupied bait ± SE	% damaged trees				
			Zero	Slight	Moderate	Severe	Very severe
L. humile sectors	63	342 ± 42	78	22	0	0	0
Transition sectors							
L. humile	17	35 ± 12	0	35	35	24	6
Native ants	18	0	0	6	39	38	17
Native ant sectors							
Native ants	50	0	0	0	14	64	22

unoccupied. This scarcity of native ants at baits in a transition area confirms earlier work in oak plantations (Way *et al*., 1997). One transect, examined in detail (Fig. 1), showed that *L. humile* numbers decreased from nearly 800 per bait 60 m within the *L. humile* sector to 18 at the adjoining part of the transition area and only one per bait where it adjoined the native ant sector. In the transition area, the slight and moderate damage to some trees adjoining the *L. humile* sector changed to 100% severely or very severely damaged by *T.pityocampa* adjoining the native ant sector where 65% of baits were occupied exclusively by *L. niger*, and of the remainder 13% were unoccupied. *Pheidole pallidula*, a recognized dominant in some habitats (Cammell *et al*., 1996; Paiva *et al*., 1998), was scarce within the native ant sector but, corresponding with this sector, it exclusively occupied all baits placed at 10 m intervals along an adjoining road verge. However, at the transition point a single unoccupied bait marked the change to exclusive occupation of the verge baits by *L. humile* (Fig. 1). The obvious presence of either *P. pallidula* or *L. humile* along a verge can therefore be a good indicator of the nature of the ant community within a plantation.

Topography, soil conditions and understorey vegetation can affect the distribution of *L. humile* (Way *et al*., 1997). Soil types, however, appeared identical across the transects – sandy loam at Abrantes and sand elsewhere. All the transects were on slightly sloping land, however, with only about 2–3 m difference along lengths of 150–200 m. *Linepithema humile* occurred at the higher level at the Abrantes site (Table 2), and native ants at the other sites, although with negligible altitude differences across the transitions. Whilst no effect of such differences can be envisaged as affecting the ants (Way *et al*., 1997) or the damage, this was confirmed in a level plantation near Marinha Grande, where in 1997 an ≈ 3 ha patch of native ant-occupied *P. pinaster* with many *T. pityocampa* nests and slight to moderate damage was completely surrounded by a large area of undamaged *L. humile*-occupied trees.

Discussion

The results confirm the absence, except at boundaries, of damage by *T. pityocampa* within *P. pinaster* plantations occupied by *L. humile*. It is surprising that this striking relationship associated with fierce predation by *L. humile* has not previously been recognized. The workers can be powerful predators, as is evident from the well known ability of introduced *L. humile* to kill and displace native ants, as in Portugal (Cammell *et al*., 1996; Way *et al*., 1997), and also to prey on brood in wasps nests in spite of defending wasp workers (Gambino, 1990).

Known natural enemies such as some birds and Tettigonidae (e.g. Ledesma, 1971; Gonzalez-Cano, 1981) seem unlikely to have a significant impact on *T. pityocampa* except possibly during endemic phases. Unlike such conventional natural enemies, many predaceous ants possess the unique attributes of being able to survive abundantly even when prey is scarce and to respond quickly to prey density (Way & Khoo, 1992). This is based on a dependable source of energy food from honeydew-producing Homoptera (Way, 1954, 1963). For example, a *Formica rufa* diet comprised 62% of honeydew (Wellenstein, 1952). In some intimate relationships, particular species of Homoptera are essential for success (Way, 1954; Khoo & Chung, 1989). *Linepithema humile*, however, is a more

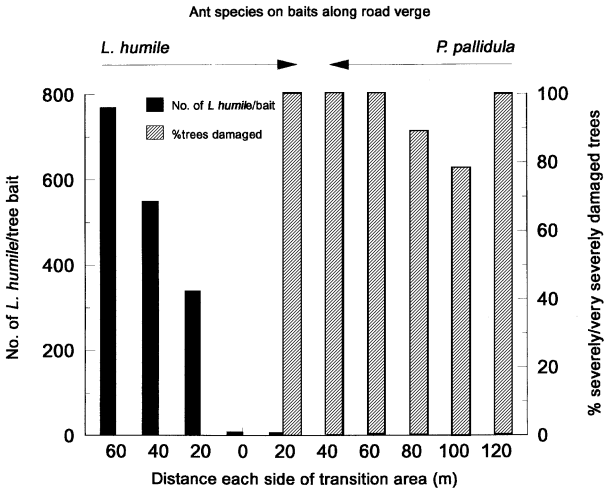

Figure 1 Relationship between presence of *L. humile* and damage by *T. pityocampa* along a transect from an *L. humile*- to a native ant-occupied area in a *P. pinaster* plantation.

generalized species and the workers tend many different Homoptera on different herbs, shrubs and trees, particularly aphids, as on pine trees in Portugal. Its persistent attendance at aphid aggregates, together with foraging in pine trees for a wide range of foods, no doubt ensures that workers are already present in trees when *T. pityocampa* becomes available as prey between August and November. Moreover, the workers quickly recruit others to good food sources (Way *et al*., 1992) like aggregates of *T. pityocampa* larvae (E. B. Moura, M. R. Paiva and M. E. Cammell, unpublished). In preventing a massive outbreak of *T. pityocampa*, *L. humile* epitomizes the qualities of a highly efficient predatory ant species. It is also unique as a beneficial predatory ant because it occurs as multiqueen super-colonies with many closely spaced nests throughout large areas sometimes covering at least 2000 ha. Within and between such colonies there is no aggression between workers, even when isolated by sea (Way *et al*., 1997). In contrast, species such as *Oecophylla* and *Formica* form relatively small spaced-out competing colonies (Way & Khoo, 1991, 1992). *Formica* spp. have been recognized as beneficial predators since the 19th century (Gosswald, 1990) but, within colony boundaries, their impact on lepidopteran pests, for example, is localized and inversely related to distance from the nest (Wellenstein, 1954; Adlung, 1966). In contrast, our evidence indicates that, in favourable conditions, *L. humile* can completely and uniformly protect very large pine plantations. *Linepithema humile* is unable to colonize certain soil types in Portugal, particularly those based on metamorphic rocks (Way *et al*., 1997; Paiva *et al*., 1998). Otherwise it can flourish and displace the native ants where ground vegetation is sparse or frequently disturbed, but is absent where such vegetation is thick and undisturbed (Way *et al*., 1997). In some undisturbed pine plantations a commonly occurring undisturbed ground mat of moss overlying a peaty layer of partly decomposed needles also seems to inhibit *L. humile*, especially in dense pine plantations. In intermediate conditions there is intense fighting along transitions between *L. humile*- and native-occupied plantations (Way *et al*., 1997). Our transects across boundaries between *L. humile* and native ants were made in conditions where the understorey vegetation was intermediate, with bare patches and sometimes with wild shrubs, as well as herbaceous ground vegetation or undisturbed moss-covered peat. Simple soil cultivations to restrain ground vegetation, as is done in many Portuguese oak and eucalyptus plantations, should encourage the spread of *L. humile* into some commercial pine plantations now occupied by native ants. There are, therefore, opportunities for exploiting its predatory role. The effects on *L. humile* of pine stand density and soil disturbance are subjects of current research which also involves work on the predatory behaviour of *L. humile*, including its possible effects on ovipositing *T. pityocampa*. *Linepithema humile* is not disseminated by winged queens so there is no reason to believe that encouraging it within pine plantations will favour its incidence as a pest in other habitats.

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