Causes of mite pest outbreaks in bamboo forests in Fujian, China: analyses of mite damage in monoculture versus polyculture stands

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Abstract

Damage caused by the phytophagous mites *Schizotetranychus nanjingensis* Ma & Yuan, *Aponychus corpuzae* Rimando and/or *Aculus bambusae* Kuang to the moso bamboo (*Phyllostaychs pubescens*) was examined for ten pairs of monoculture *versus* polyculture forests at six locations in Fujian, China. Mite damage in the monoculture forests (35%) was on average twice as high as that in the polyculture forests (17.5% < the injury level of 20%). The relative contribution of each mite species to total damage varied among sites, but *Ap. corpuzae* was the dominant pest at all sites except one, where *S. nanjingensis* was the major pest. Polyculture forests overall had more predatory mites than monoculture forests. Mite damage was inversely correlated with the altitudes of individual forests across sites. These results are discussed in light of ecological theories on the effects of plant diversity on animal abundance and suggestions for possible measures to control pest mites on bamboo in Fujian.

Key words: Acari, bamboo, outbreak, plant diversity, pest control.

Introduction

Phytophagous arthropods thrive when their host plants grow in pure stands, are abundant and thus are easy to find in the habitat. This resource-concentration hypothesis (Root 1973) is especially true for specialized herbivores who do best on a certian crop species but could not feed and reproduce on other plants in a polyculture (Risch *et al.* 1983).

This resource-concentration hypothesis may well apply to phytophagous mites such as *Schizotetranychus nanjingensis* Ma & Yuan, *Aponychus corpuzae* Rimando and/or *Aculus bambusae* Kuang, which were recently found causing damage to the moso bamboo (*Phyllostaychs pubescens*) in Fujian, China (Zhang *et al.* 1998a). The mite problem became acute in the late 1980s when large areas of forests in Fujian were converted to monoculture bamboo forests in order to meet the increasing demand for bamboo as a raw material in construction, furniture and food (Zhang *et al.* 2000). Before 1985, the bamboo plants were mixed with other trees in polyculture natural forests. There were only about 750 bamboo plants per hectare. After 1986, most of the natural bamboo forests were converted into artificial monoculture ones to increase production and the number of bamboo plants might surpass 2,000 per hectare.

All three phytophagous mites mentioned above specialize on the moso bamboo in these forests. It is therefore hypothesized (Zhang *et al.* 1999, 2000) that pure, dense monoculture bamboo stands facilitate the rapid growth and dispersal of these mites, which would be otherwise slowed down by unsuitable non-host plants surrounding bamboo plants in a polyculture forest. It is also hypothesized (Zhang *et al.* 1999, 2000) that monoculture reduces the abundance of natural enemies of phytophagous mites by reducing alternative habitats and food for them, which indirectly could also contribute to the outbreaks of phytophagous mites on bamboo in Fujian. In this paper, we test these hypotheses by examining the damage that phytophagous mites caused to bamboo leaves and the densities of both phytophagous mites and predatory mites in ten pairs of monoculture *versus* polyculture forests at six different locations in Fujian.

Methods

Descriptions of sites studied

Six sites located at different parts of Fujian province were selected. These sites differed in altitudes and latitudes, but each site had pairs of forests which were more or less similar in conditions except monoculture/polyculture. All had their undercover cut and the soil turned every autumn. Their ecological and environmental conditions are described below.

Site A: This site is located in Jiyang Town, Jianou city, Fujian (N26.12, E118.10; 210 m.a.s.l.). Bamboo plants in polyculture forests were mixed with broad leaf trees. Neither pesticides nor fertilizers had been used at this site since 1995. One sample was taken on 13 September 1997 (Sample A).

Site B: This site is located in Qunxian Village, Nanping City, Fijian (N26.7, E118.2; 100 m.a.s.l.). The monoculture forest had a density of 120-140 bamboo plants per mu (667 m^2). The polyculture forest had 90-120 bamboo plants mixed with 10-30 broad leaf trees per mu; bamboos consisted of 70-90% of all the trees in the forest. Neither pesticides nor fertilizers had been used at this site since 1995. One sample was taken on 20 August 1997 (Sample B1). Another sample was taken on 22 August 1997 at another pair of monoculture and polyculture forests on a different hill nearby (Sample B2).

Site C: This site is located in Tuanshi Village, Hongtian Town, Yongan City, Fujian (N25.85, E117.15; 200-220 m.a.s.l.). The monoculture forest had a density of 140 bamboo plants per mu. The polyculture forest had 120-140 bamboo plants mixed with 60-80 China fir trees and other broad leaf trees per mu; bamboo plants made up 60-70% of the trees in the forest. The moth *Pantana phyllostachysae* Chao was a pest in this area but since 1992 no pesticides nor fertilizers had been used at this site. Every autumn, the forest undercover was cut and soil turned to encourage the growth of bamboo shoots in winter. One sample was obtained on 18 August 1997 (Sample C1). Another sample (C2) was taken at another pair of monoculture and polyculture forests on 20 August 1997 on a different hill nearby.

Site D: This site is located in Shangping Village, Yongan City, Fujian (N25.9, 117.3; 450 m.a.s.l.). The monoculture forest had a density of 120-140 bamboo plants per mu. The polyculture forest had 90-120 bamboo plants per mu mixed with 10-30 broad leaf trees. Since 1995, no pesticides nor fertilizers had been used at this site. One sample was taken on 20 August 1997 (Sample D1). Another sample was obtained at another pair of monoculture and polyculture forests on a different hill nearby (Sample D2).

Site E: This site is located in Shengqing Village, Yongan City, Fujian (N25.85, E 117.2; 250 m.a.s.l.). The monoculture forest had a density of 140-260 bamboo plants per mu. The polyculture forest had 80-132 bamboo plants per mu mixed with 88-160 broad leaf trees. Neirther pesticides nor fertilizers had been used at this site since 1995. One sample was taken on 20 August 1997 (Sample E1). Another sample was taken at a pair of monoculture and polyculture forests on a different hill nearby (Sample E2).

Site F: This site is located in Chengkuan Town, Changtai County, Zhangzhou city, Fujian (N24.35, N106.3; 10 m.a.s.l.). Bamboo plants in polyculture forests were mixed with broad leaf trees. Since 1995, no pesticides nor fertilizers had been used at this site. Every autumn, the forest undercover was cut and soil turned. One sample was taken on 11 November 1997 (Sample F).

Sampling methods

Two bamboo forests with similar ecological and environmental conditions were selected at each site, so that they differed only in terms of monoculture and polyculture. In each forest, 15 plants (within a range of 7-20 plants) were arbitrarily selected. From each plant, 9-30 leaves were arbitrarily collected from different parts of the canopy and stored in black plastic jars at 5^{o}C before examination under a microscape in the laboratory. The numbers of mites (all stages) per leaf were counted. For each leaf, an damage index (defined below) was visually assigned to each leaf and an average index was calculated for each plant.

The mite damage index was estimated according to the proportion of areas infested or damaged by phytophagous mites. It was estimated slightly different for *S. nanjingensis*, which produces webbing, and for *Ap. corpusae* and *Ac. bambusae*, which are free-living on leaf surface.

For *S. nanjingensis*, the index was estimated by the proportion of leaf area covered by webbing and was grouped into six classes:

Class 0: No webnests on leaf;

Class I: 1-3 webnests per leaf or 3-7% leaf area covered by webbing;

Class II: 4-6 webnests per leaf or 4-7% leaf area covered by webbing;

Class III: 7-10 webnests per leaf or 8-15% leaf area covered by webbing;

Class IV: 11-17 webnests per leaf or 16-20% leaf area covered by webbing;

Class V: >17 webnests per leaf or >20% leaf area covered by webbing.

For *Ap. corpusae* and *Ac. bambusae*, the index was estimated by the proportion of leaf area damaged by these mites and was grouped into six classes:

Class 0: No mite damage on leaf;

Class I: <20% leaf area damaged;

Class II: 21-40% leaf area damaged;

Class III: 41-60% leaf area damaged;

Class IV: 61-80% leaf area damaged;

Class V: >80% leaf area damaged.

A weighted average index was calculated for each plant to represent the total damage to that plant by mites. Differences between two samples were tested using *t*-test and were considered significant when $P<0.05$.

The densities of phytophagous mites and predatory mites (several species but mostly *Typhlodromus bambusae* Ehara) were also averaged for each plants (but predators were calculated per 10 plants because of their low density) and compared using *t*-tests.

Results

Mite damage: monoculture vs polyculture

Mite damage, when averaged across all sites examined in this study (Table 1), was twice as high in monoculutre forests (damage index 35.0%) as in polyculture forests (damage index 17.5%). The differences in the degree of damage between two types of forests were highly significant in most forests. The only exception is the sample from Site A in Jiyang, Jianou, where damage in the monoculture forest was only 50% more than that in the polyculture forest, and the difference was close to, but not, significant (*P*=0.061). On the other extreme at site D in Shangping, Yangan, mite damage in the monoculture forest was over 8 times as high as in the polyculture forest (Table 1; sample D2).

TABLE 1. Mite damage on bamboo leaves in monoculture *versus* polyculture-bamboo forests. Mite damage is represented by average mite damage index per plant. Details of each site and sample and methods for estimation of index were described "Methods". Data are in the format: Mean±SEM (n).

Site locations	Monoculture	Polyculture	*t*-statistics	*P*
A) Jianou	0.293±0.023 (10)	0.219±0.023 (15)	1.973	0.061
B1) Nanping	0.372±0.017 (7)	0.156±0.008 (8)	10.710	<0.001
B2) Nanping	0.329±0.044 (9)	0.182±0.037 (8)	2.513	0.024
C1) Yongan	0.419±0.027 (15)	0.286±0.017 (15)	4.113	<0.001
C2) Yongan	0.459±0.054 (15)	0.229±0.042 (15)	3.345	0.002
D1) Yongan	0.241±0.034 (15)	0.125±0.010 (15)	3.258	0.005
D2) Yongan	0.221±0.028 (15)	0.027±0.010 (12)	5.913	<0.001
E1) Yongan	0.369±0.044 (11)	0.116±0.022 (20)	5.747	<0.001
E2) Yongan	0.356±0.019 (16)	0.203±0.024 (20)	4.808	<0.001
F) Zhangzhou	0.449±0.081 (10)	0.212±0.031 (10)	2.721	0.014

Damage in relation to latitude and altitude

Across different sites, mite damage index was not correlated with latitudes for monoculture sites (r=-0.424, P=0.222; Fig. 1A) and for polyculture sites (r=-0.044, P=0.905; Fig. 1B).

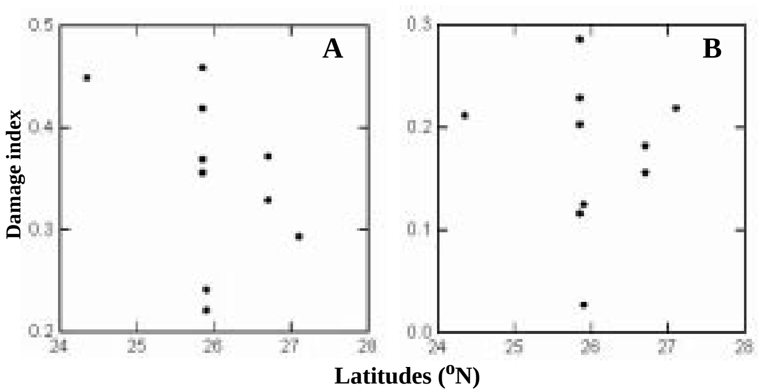

FIGURE 1. Relationships between mite damage index and latitude (°N) of monoculture bamboo forests (A) and polyculture forests (B) in Fujian, China. Detailed description of sites and methods for estimation of index in "Method".

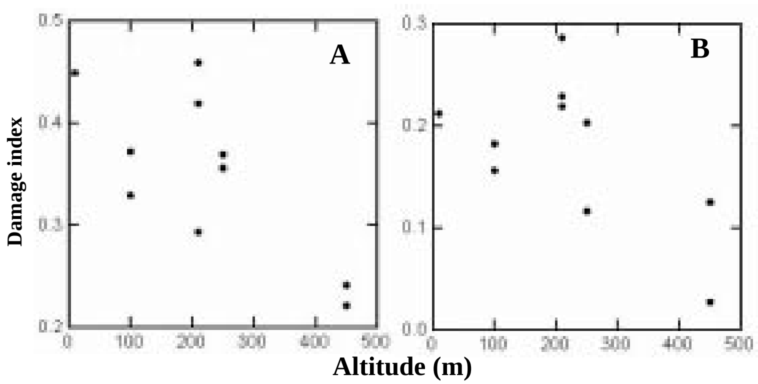

FIGURE 2. Relationships between mite damage index and altitude (meters above sea level) of monoculture bamboo forests (A) and polyculture forests (B) in Fujian, China.

In contrast, mite damage was higher in forests at lower altitudes but lower at high altitudes (Fig. 2); the inverse correlation was significant for monoculure forests (*r*=-734, *P*=0.016; Fig. 2A) and nearly significant for polyculure forests (*r*=-0.592, *P*=0.071; Fig. 2B).

Mite densities at Site A: Jiyang, Jianou

The density of *S. nanjingensis* in the monoculture forest (>2 per leaf) was over 7 times as high as that in the polyculture forest (Table 2; P<0.05). In comparison, densities of *Ap. corpuzae* in the monoculture forest were only twice that in the polyculture forest and the difference was not as significant. *Ac. bambusae* were relatively high in density in both forests with no difference between the two.

The polyculture forest had nearly twice as many predatory mites as the monoculture forest, although the difference was not significant.

TABLE 2. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaves) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site A in Jiyang, Jianou, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	2.290±0.850 (10)	0.305±0.294 (15)	2.446	0.023
Ap. corpuzae	24.13±4.75 (10)	12.71±3.61 (15)	1.948	0.064
Ac. bambusae	16.25±3.85 (10)	12.42±3.90 (15)	0.681	0.503
Predators	1.100±0.823 (10)	2.154±0.618 (15)	1.046	0.308

Mite densities in Site B: Qunxian, Nanping

The density of *S. nanjingensis* in the monoculture forest was more than 30 times as high as that in the polyculture forest and the difference was significant (Table 3). *Ap. corpuzae* was similarly very abundant (averaged 10 per leaf) in two type of forests. The density of *Ac. bambusae* in the monoculture forest was over 4 times as high as in the polyculture forest, butthe difference was not significant (Table 3).

The density of predatory mites were similar in two types of forests (Table 3).

TABLE 3. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaves) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site B in Qunxian, Nanping, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	7.133±2.910 (9)	0.225±0.150 (8)	2.218	0.041
Ap. corpuzae	9.900±1.160 (9)	10.59±3.33 (8)	0.205	0.840
Ac. bambusae	6.640±2.890 (9)	1.480±0.580 8)	1.654	0.119
Predators	1.220±0.400 (9)	1.000±0.420 (8)	0.382	0.708

Mite densities in Site C: Tuanshi, Yongan

At this site, *S. nanjingensis* was rare in both forests but *Ap. corpuzae* was very high in density in two type of forests; its density in the monoculture forest was over 2.5 times as high as that in the polyculture forest (Table 4; *P*=0.003). The density of *Ac. bambusae* in the monoculture forest (7.4 per leaf) was over 17 times as high as in the polyculture forest and the difference was significant.

TABLE 4. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaf) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site C in Tuanshi, Yongan, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	0 (15)	0.380±0.998 (15)	-	-
Ap. corpuzae	35.19±5.80 (15)	13.42±3.12 (15)	3.323	0.003
Ac. bambusae	7.360±2.930 (15)	0.420±0.400 (15)	14.5	0.024
Predators	0.130±0.090 (15)	0.400±0.210 (15)	1.145	0.261

The density of predatory mites was three times higher in the polyculture forest than in the monoculture forest, but the difference was not significant (Table 4).

Mite densities in Site D: Shangping, Yongan

At this site, *S. nanjingensis* was rare in both forests but *Ap. corpuzae* was very abundant in the monoculture forest (over 18 per leaf or over 40 times as high as that in the polyculture forest; Table 5). The density of *Ac. bambusae* was similarly low in both type of forests (1.5 per leaf).

The density of predatory mites was ten times higher in the polyculture forest than in the monoculture forest and the difference was highly significant (Table 5).

TABLE 5. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaves) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site D in Shangping, Yongan, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	0 (15)	0113±0.113 (15)	-	-
Ap. corpuzae	18.77±13.72 (15)	0.433±0.271 (15)	4.961	<0.001
Ac. bambusae	1.600±0.486 (15)	1.407±0.324 (15)	0.331	0.743
Predators	0.067±0.067 (15)	0.750±0.750 (15)	2.911	0.007

Mite densities in Site E: Shenqing, Yongan

At this site, *S. nanjingensis* was rare in both forests but *A. corpuzae* was very high in density in the monoculture forest (over 16 per leaf or over 4 times as high as in the polyculture forest; Table 6; *P*=0.001). The density of *Ac. bambusae* in monoculture forest was 5 times as high as in the polyculture forest, and the difference was highly significant.

The density of predatory mites was nearly 3 times higher in the polyculture forest than in the monoculture forest, but the difference was not significant (Table 6).

TABLE 6. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaves) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site E in Shenqing, Yongan, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	1.123±0.659 (13)	0.150±0.150 (20)	1.172	0.264
Ap. corpuzae	16.86±3.86 (13)	4.325±0.921 (20)	3.809	0.001
Ac. bambusae	5.462±1.295 (13)	0.950±0.114 (20)	4.149	0.001
Predators	0.615±0.417 (13)	1.800±0.760 (20)	1.180	0.247

Mite densities in Site F: Changtai, Zhangzhou

At this site, *S. nanjingensis* were rare but *Ac. bambuae* was very abundant (over 30 per leaf) in both types of forests, without significant increase or decrease due to monoculture (Table 7). The density of *Ap. corpuzae* in monoculture forest was 3 times as high as in the polyculture forest, and the difference was close to significant.

Predator mites were absent in the monoculture forest but the density was also very low in the polyculture forest.

TABLE 7. Densities of pest mites (*Schizotetranychus nanjingensis*, *Aponychus corpuzae* and *Aculus bambusae*; per leaf) and predatory mites (phytoseiids, mostly *Typhlodromus bambusae*; per 10 leaves) on bamboo leaves in monoculture *versus* polyculture bamboo forests at site F in Changtai, Zhangzhou, Fujian, China. Data are in the format: Mean±SEM (n).

Mite species	Monoculture	Polyculture	*t*-statistics	*P*
S. nanjingensis	0 (10)	0 (10)	-	-
Ap. corpuzae	21.96±7.10 (10)	7.290±1.540 (10)	2.018	0.059
Ac. bambusae	32.30±3.91 (10)	35.59±10.67 (10)	0.653	0.522
Predators	0 (10)	1.700±1.070 (10)	-	-

Discussion

This study shows that mite damage index in monoculture forests was on average twice as high as in polyculture forests. It is interesting to note that the damage index of polyculture forest averaged 17.5%, which is less than the acceptable level of 20% (Zhang *et al.* 1998b and unpublished data). Therefore economic injury occurred mostly in monoculture forests. These observations support our hypothesis that monoculture is one of the main cause of mite outbreaks in Fujian (Zhang *et al.* 1999, 2000).

We also noted that forests at high altitudes had lower mite damage than those at lower altitudes (Fig. 2), a finding consistent with the former obervations of Zhang *et al.* (2000). This pattern might be related to the fact that it is cooler at higher altitudes, where forests in general are also less disturbed.

The relative abundance of phytophagous mites and their contribution of total damage varied among sites.

Schizotetranychus nanjinensis was rare or absent at three sites (site C in Tuanshi, Yongan, site D in Shangping, Yongan and site F in Changtai, Zhangzhou). Where it was present in numbers that can be analyzed, it was 7-30 times as abundant in monoculture forest as in polyculture forest. It was generally less abundant than the other two species except at site B (Qunxian, Nanping), where it was the major pest contributing economic injury in the monoculture forest.

Aponychus corpuzae was usually more abundant than the other two species. It was 2-40 times as abundant in monocutlure forests as in the polyculture forests and was the major species contributing to economic injury in monoculture forests except at site B, where *S. nanjinensis* was the major pest.

Aculus bambusae was intermediate in abundance compared to the other two species and contributed to economic injury in monoculture forests at only two sites (Sites C in Tuanshi and E, in Shengqin, Yongan). However, it was the most abundant species at site F, where it was equally abundant in both forests (>30 per leaf).

It should be noted that this study reflects the patterns seen in 1997 when the samples were taken. It is possible that the relative importance of each species at various sites might be different in other years, but the general pattern of more mites and serious damage in monoculture forests than polyculture forests is likely to be consistent for different years.

The mechanisms underlying the general pattern in this study is not elucidated in this study alone. The two most likely explanations for the patterns are: (1) the movement behaviour of the herbivore in relation to plant diversity and (2) the effect of relatively more natural enemies in polyculture (Risch *et al.* 1983). Monoculture forests facilitate the dispersal of phytophagous mites, which would be otherwise slowed down by unsuitable non-host plants surrounding bamboo plants in a polyculture forest (Zhang *et al.* 1999, 2000). Only controlled experiments can corroborate this hypothesis. Alternatively, it may be hypothesized that monoculture reduces the abundance of natural enemies of plant mites by reducing alternative habitat/food for them, which may also contribute to the outbreaks of mites (Zhang *et al.* 1999, 2000). We noted that predatory mites were more numerous in polyculture forests than monoculture forests in 5 of the 6 sites examined (2-10 times and at site F 1.7 *vs* 0). However, the difference was significant for only one site (site D) and not statistically different at each sites, presumably because too many plants at these sites had no predatory mites, which affected the power of *t*-test as the non-zero data were too few. To overcome this problem of small sample size, we pooled data from all sites to perform an overall test. The average number of predatory mites per 10 leaves in polyculture forests (1.380±0.267; n=79) was over 3 times as high as that in monoculture forests (0.437±0.152; n=71), and the difference was highly significant (t=2.975, P=0.003). Predatory mites were thus generally more abundant in polyculture forests than in monoculture forests and this could have contributed to the relatively low density of phytophagous mites in polyculture forests. Risch *et al.* (1983), after reviewing 150 published studies on the effects of plant diversity on arthropod abundance, concluded that the movement behaviour of herbivores in response to diversifying plants in the habitat is more important than changes in natural enemy abundance. We need to conduct experiments to examine how monoculture bamboo forests affect the dispersal of mites in comparison with the relative natural enemy abundance.

It should be noted that monoculture not only affects the movement of mites and abundance of natural enemies, but also depletes the nutrients in the forests faster than a narural polyculture forest. The later, when combined with over-harvesting, weakens the general health of the forest and increases its susceptibility to pests and reduced its compensatory growth ability (Zhang *et al.* 2000).

In light of the discussion above, integrated mite control programmes should focus on diversifying the bamboo forests in the long term. In areas where this contradicts the short-term productivity and profits for the forestry, (1) natural enemies might be augmented for biological control, either by conservation of indigenous predators (e.g. *T. bambusae* and *A. longispinosus*) or by releasing of mass-reared predators, and (2) selective pesticides, in combination with organic fertilizers, might also be used for spot control. Integrated pest management, along with integrated forest management, should be implemented, especially in regard to diversifying plant stands, proper nutrition input and sustainable harvesting schedules.

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Abstract in Chinese

福建毛竹林害螨爆发成因：纯竹林与混交林螨类为害分析

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摘要：在福建省 6 个地点检查 10 对纯竹林与混交林南京裂爪螨，竹缺爪螨和竹刺瘿螨对毛竹造成的危害，在純竹林螨类为害（35%）平均是混交林螨类为害（17.5%<20%为害水平）的 2 倍。每种螨类为害对竹林总的螨害比例在不同地点是不同的，除了一个地点南京裂爪螨是主要害螨，其余各点竹缺爪螨是优势种。所有的混交林比純竹林具有更多的捕食螨。螨类为害与不同地点竹林的海拔高度成负相关。根据生态学理论讨论这些结果，认为植物多样性影响动物丰盛度，建议混交林作为控制福建省毛竹林害螨是一项尚可接受措施。

关键词：蜱螨亚纲，毛竹，爆发，植物多样性，害螨防治。

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