Journal of Asia-Pacific Entomology 17 (2014) 155–159

Contents lists available at ScienceDirect

Journal of Asia-Pacific Entomology

journal homepage: www.elsevier.com/locate/jape

Eriophyoid mite (Acari: Eriophyoidea) assemblages on Yushan Cane (Poaceae: Bambuseae) in Taiwan's Montane area

Chin-Fah Wang [a], Jeng-I Tsai [b], Fong-Long Feng [b], Kun-Wei Huang [c,*]

[a] General Education Center, National Chiayi University, Chiayi 600, Taiwan, ROC
[b] Department of Forestry, National Chung Hsing University, Taichung 402, Taiwan, ROC
[c] Department of Biology, National Museum of Natural Science, Taichung 404, Taiwan, ROC

ARTICLE INFO

Article history:
Received 28 March 2013
Revised 26 November 2013
Accepted 1 December 2013

Keywords:
Eriophyoid mite
Yushan cane
Taiwan
Canonical correspondence analysis
Multidimensional scaling

ABSTRACT

Eriophyoid mites inhabit Yushan canes at elevations from 1650 to 3400 m in Taiwan. A total of 1491 eriophyoid mite specimens collected between 2001 and 2008 from 18 sites in Taiwan belonging to 10 genera and 15 species were examined and recorded to evaluate the relationships between species composition and environmental factors. The environmental factors assessed consisted of climate data, cane leaf length, and vegetation type. Among the 15 species, *Abacarus panatics* Kefier, 1977 and *Tetra yushania* Huang, K.W., 2001. Eriophyoid mites of Taiwan: description of eighty-six species from the Tengchih area. Bull. Natl. Mus. Nat. Sci. 14, 1–84 occur at all 18 survey sites. Canonical correspondence analysis was used to analyze the relationships among sites, eriophyoid mite occurrences, and environmental variables. Eriophyoid mite species composition and plant community types were analyzed using non-metric multidimensional scaling (MDS). Canonical correspondence analysis (CCA) indicated that temperature and leaf length were major factors that influenced changes in eriophyoid mite assemblages. MDS results showed that eriophyoid mite species composition is unrelated to plant community types. The distribution patterns of the 15 eriophyoid mites is hypothesized to be randomized by forest fires initially and subsequently influenced by temperature and leaf length.

Introduction

Species composition patterns can be useful tools for taxonomists and ecologists engaged in conservation management and studying of the potential factors that influence community diversity. Regardless of whether composition patterns arise from interspecific interactions or environmental factors, even stochastic processes are relatively difficult to confirm. Indeed, species distributions are affected by a combination of vicariant events and environmental factors. It is difficult to demonstrate historical alterations in species dispersal that are due to climate change. Likewise, a drastic geographic change cannot be used to predict the distribution of species.

Biological species responding to environmental gradients show nonlinear curves. Summarizing species–environment relationships by using correlation coefficients is inappropriate (Ter Braak, 1986). Canonical correspondence analysis (CCA) is a multivariate direct gradient analysis technique that can be used to determine whether a set of species is directly related to a set of environmental variables. The resulting diagram shows the main pattern in community composition as accounted for by environmental variables and the distribution of species according to each environmental variable. Species and sites are represented by points, and environmental variables are represented by arrows.

Another unconstrained ordination procedure, non-metric multidimensional scaling (MDS), was employed without specifying an a priori hypothesis. MDS was used to determine community dissimilarity, which is based on any data set of distance or dissimilar measures of rank order. MDS reduces dimensions and new spaces generated are monotonically related to original distances.

Eriophyoid mites are tiny, feeble, creatures that are obligate phytophagous species of various plants. These mites are difficult to observe in the field unless a high-powered magnifying lens is used to detect them on leaf surfaces.

The corresponding author has field-collected eriophyoid mites from Yushan canes for taxonomic study since the 1980s. Yushan cane (*Yushania niitakayamensis* (Hayata) Keng f.) is found above 1500 m in Taiwan, is in the bamboo subfamily (Bambusoideae), and is sparsely distributed in Southeast Asia (Taiwan, southern China, and northern Philippines). The genetic variation in Yushan cane in Taiwan is high within a given sampling site but not significantly different among different localities (Hsiao and Lee, 1999; Huang, unpublished (NSC project report NSC90-2311-B-003-005)). After publishing the taxonomy of eriophyoid mites on Yushan canes in 2011 (Wang and Huang, 2011), we re-sorted the species distribution data and discovered that the distribution patterns for the 15 species were indefinite. Among them,

---

* Corresponding author. Tel.: +886 4 23226940; fax: +886 4 23232146.
E-mail addresses: chin-fah@yahoo.com.tw (C.-F. Wang), eri@mail.nmns.edu.tw (K.-W. Huang).

1226-8615/$ – see front matter © 2013 Korean Society of Applied Entomology, Taiwan Entomological Society and Malaysian Plant Protection Society. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.aspen.2013.12.001

Abacarus panatics Keifer, 1977 and *Tetra yushania* Huang, 2001 were identified on Yushan canes throughout Taiwan. *Aceria tosichella* occurred sparingly at Syue Mountain at 2500 m (C31), Syue Mountain at 3100 m (C34), Syue Mountain at 3400 m (C35), and TaTachi (S1). *Aceria niitakayamensis* occurred sparingly at Taipingshan (N1), Bilu (E2), and DoChaiTu Mountain (C2). Certain species occurred at only one site. *Phytoptus formosanus* occurs sparingly at 3100 m on Syue Mountain (C34), *Abacarus niitakayanensis* occurs at Bilu (E2), *Tetra paikoutashansis* occurs at Paikoutashan (C1), and *Apodiptacus taipingshansus* occurs at Taiping Mountain (N1). Moreover, we discovered that eriophyoid mite species richness was different at each site, with seven species occurring at C34 but only three at E1.

Research on the topic of high montane areas is neglected and rare due to remoteness, inaccessibility, danger, and limited infrastructure. We hope that this study of eriophyoid mite species composition and their relationships to environmental factors in high montane areas provides encouragement for studies of different biological species.

Describing eriophyoid mite assemblages on Yushan canes in Taiwan was the primary goal of this study. Our secondary goals were to (1) determine the differences among environmental factors that contribute to species composition and (2) determine the species composition associated with plant community type.

Materials and methods

Species and survey sites

We re-sorted the data for the distribution of eriophyoid mites that we collected on Yushan canes from 2001 to 2008 at 18 sites in Taiwan at elevations ranging from 1650 to 3400 m (Fig. 1; Table 1). Specimens were collected from plants by randomly searching with a 30× hand lens. When active eriophyoid mites were discovered on the lower surfaces of Yushan cane leaves, we walked along the trail for 3 m in both directions or created a 3 m^2 sample site to collect leaves for random sampling. Leaves were then returned to the laboratory to prepare microscope slide mounts of mites for identification (Huang and Wang, 2009). A total of 1491 slides of male, female, and immature specimens belonging to 15 species of eriophyoid mites were used in this study (Table 2).

Environmental factors and vegetation classification system

The five environmental factors used in this study are annual mean temperature (MT), seasonality (S) (S, °C; the difference between the highest [August] and lowest [January] monthly temperatures), total annual rainfall (TR), annual mean relative humidity (RH), and leaf length (P). The P obtained from each locality was represented by the average length of 30 randomly selected *Y. niitakayamensi* leaves (cm) measured from the leaf tip to petiole base. Climatic data between 1991 and 2008 were obtained from the Forest Inventory and Analysis & Spatial Informatics Lab of National Chung Hsing University in Taichung, Taiwan. That organization compiles temperature, rainfall, and relative humidity data from the Taiwan Central Weather Bureau, including 26 weather and 818 rainfall stations. Three climatic variables were stored in a geographic information system (GIS) data set with a spatial resolution of 40 × 40 m (Kao and Feng, 2003) (Table 1).

The vegetation classification system was obtained from a database provided by the Council of Agriculture, 2009. The vegetation classification system uses physiognomy and vegetation structure to define the units that might be distinguishable on aerial photos or other practical mapping tools. There are three higher levels in this system: class, subclass, and formation. Over 43 formations (plant communities) are recognized and grouped into eight subclasses and four classes (Hsieh, 2007). The four classes used in this study are coniferous forest (FC), mixed broadleaf-conifer bush (SM), mixed broadleaf-conifer forest (FM), and broadleaf forest (FB).

Analysis

The five assessed environmental variables were standardized to zero means and variances prior to analysis (Table 1) (Ter Braak, 1986). The presence or absence of a species at a site and its plant community type were coded for analysis (Tables 2 and 3). The CCA and multidimensional scaling analysis (MDS) of similarities using simple matching coefficients were implemented in PC-ORD ver. 5.

Results

Species composition related to environmental factors

The first three CCA axes explained 33.2% of the variability in the species–environment relationship. The eigenvalues for Axes 1 to 3 were 0.37, 0.16, and 0.13, respectively (Table 4). The most important environmental variables in Axis 1 represented the annual average temperature (MT) and leaf length (P). The most important environmental variables in Axis 2 were the annual mean relative humidity (RH) and P. The most important environmental variable in Axis 3 was RH (Table 4).

The CCA diagram indicates that the 15 species of eriophyoid mites can be divided into four subgroups in relation to environmental factors. The low annual average temperature groups (LT) are Te_4, Te_3, Eri, Ac_1, and Phy. The smaller leaf groups (IP) are Apo, Neo, Teg, and Ac_2. Apo only occurs on Taipingshan (N1). The warm groups (W) included Ab_2, Epi, Te_2, and Acu. The general groups (dominant group) (G) included Ab_1 and Te_1. Most species situate at distant places with a single record (Apo, Phy, Te_2, and Ab_2).

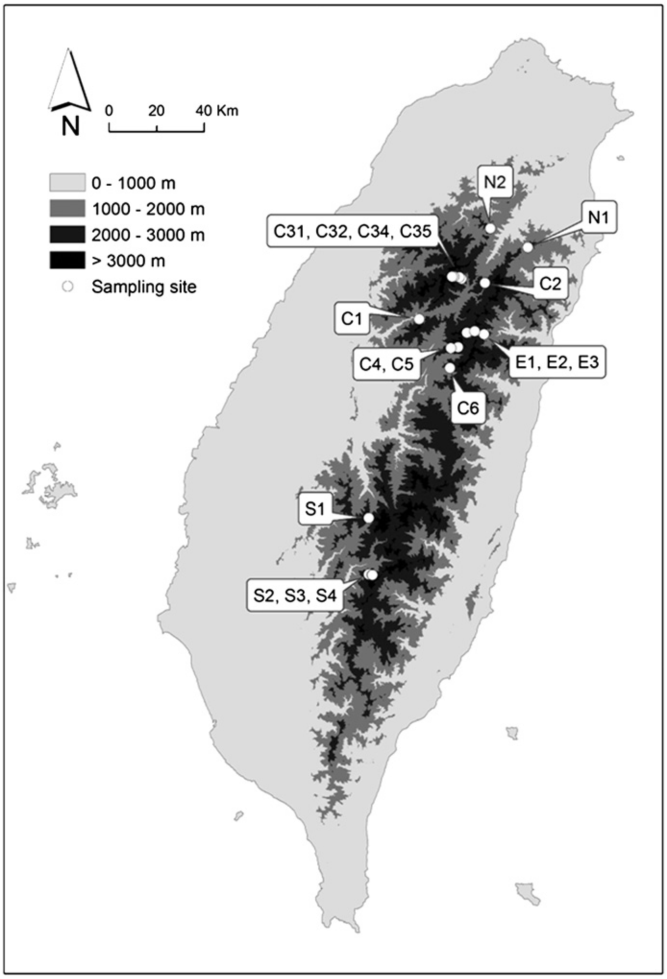

Fig. 1. Location (in abbreviation code) of the study sites in this study.

Table 1
Environmental data in 18 sites (in abbreviation) in this study.

Locality[a]	Number of species	Coordinate (meter)		Altitude (m)	Annual mean temperature (MT)(°C)	Seasonality (S) (°C)	Total annual rainfall (TR) (mm)	Annual mean relative humidity (RH) (%)	Leaf length (P) (cm)
		X	Y						
N2	3	290,300	2,719,100	1650	13.3	11.3	3228.8	79.0	9.8
N1	6	306,100	2,711,100	1800	10.7	10.9	3509.5	76.6	8.2
C1	5	287,700	2,674,500	2200	10.6	10.8	2826.5	76.7	10.2
E1	3	260,300	2,680,800	2200	10.3	10.4	3112.4	81.4	13.3
C6	3	273,300	2,660,300	2250	10.4	11.8	3155.3	79.4	12.9
E2	5	283,700	2,675,800	2350	7.7	9.8	2593.7	79.4	8.1
C31	6	278,100	2,697,900	2463	8.6	10.9	3250.9	77.5	12.8
S2	5	240,500	2,573,200	2550	9.6	9.1	3463.4	72.4	10.4
E3	4	280,400	2,675,200	2600	8.3	11.8	3386.4	82.2	8.5
C5	4	273,700	2,668,600	2750	7.2	12.9	2612.0	82.1	8.4
S3	4	240,700	2,573,200	2760	8.3	9.2	3455.7	72.4	10.7
C32	3	277,300	2,698,500	2800	6.6	10.9	3263.8	79.5	10.2
C2	4	276,800	2,669,000	2800	7.1	11.0	2722.3	74.9	9.8
C4	4	288,000	2,696,100	2800	6.0	10.6	2749.4	79.5	10.7
S1	5	239,100	2,597,200	2800	7.3	12.0	2561.6	80.7	9.2
S4	3	239,100	2,573,500	3010	6.8	9.1	3518.2	72.4	10.2
C34	7	266,500	2,680,700	3100	4.8	10.9	3240.3	77.5	14.3
C35	5	274,200	2,698,800	3400	3.0	8.6	3236.0	79.4	12.9

[a] See Fig. 1.

Species–vegetation relationships

The plant community type showed no significant relationship with the species composition of eriophyoid mites ($P = 0.451$ with 9999 permutations) (Fig. 3).

Discussion

The CCA diagram shows Ab_1 and Te_1 near the centroid, indicating that they are less affected by the five environmental factors. Most species lie at endpoints, indicating that environmental factors have a strong effect on distribution (Fig. 2). Te_4 and Phy may have an evolutionary adaptation to low temperature. Phy belongs to the Phytoptidae, most species of which feed on conifers (the family seems to be a temperate taxon). Phe distributions at high altitudes (S_31) and low-temperature areas are reasonable. Te_3 and Te_4 only occur on Syue Mountain, and are high-altitude taxa. Most affinity species did not cluster together, other than Te_3 and Te_4. Our results show that the cogeneric species of *Abacarus*, *Tetra*, and *Aceria* are adapted to different niches.

Eriophyoid mites are obligate phytophagous species and are considered to be highly host-specific. Leaf length (P) naturally determines the distribution of eriophyoid mites. In this study, we define P as the average length of 30 randomly selected leaves. P not only equates to food supply but also space. A low value of P is equivalent to a small length or area of leaves for mites to live on. Eriophyoid mites use indirect bisexual and arrhenotokous parthenogenesis (unfertilized eggs develop only into males) for reproduction. The male deposits spermatophores on plant surfaces whether females are present or not (Katarzyn et al., 2010). Small leaves increase the opportunity for females to encounter spermatophores and pick up sperm; therefore, their inhabiting on small leaves may indirectly increase the fitness of eriophyoid mites. Contrary, the larger leaves will supply more food amount for the mite to feed.

However, the phylogenetic relationship between eriophyoid mites and their host plants are not in agreement. Sabelis and Bruin (1996) proposed a model that shows that eriophyoid mites rely on passive dispersal mechanisms, which makes the evolution of host plant specialization improbable. The affinity species did not inhabit closely related plants. Furthermore, cogeneric species fed on host plants from different families (Amrine and Stasny, 1994). The present study indicates that competitive exclusion narrowed the species niche, and therefore the affinity species shifted to an unrelated host plant. This affinity of

Table 2
Species data (binary data) of 18 sites in this study.

Locality	Ac_1[a]	Ac_2	Eri	Ab_1	Ab_2	Acu	Te_1	Tet_2	Te_3	Te_4	Epi	Neo	Teg	Apo	Phyt
C31	1	0	0	1	0	1	1	0	1	0	0	0	1	0	0
C32	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
C34	1	0	1	1	0	0	1	0	0	1	0	1	0	0	1
C35	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0
C6	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0
C1	0	0	0	1	0	1	1	1	0	0	1	0	0	0	0
C2	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0
C4	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0
C5	0	0	0	1	0	1	1	0	0	0	0	1	0	0	0
E3	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0
E1	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0
E2	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0
N1	0	1	0	1	0	1	1	0	0	0	0	1	0	1	0
N2	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0
S4	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0
S1	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0
S2	0	0	0	1	0	1	1	0	0	0	0	1	1	0	0
S3	0	0	0	1	0	1	1	0	0	0	0	1	0	0	0

[a] Ac_1: *Aceria tosichella*; Ac_2: *Aceria niitakayamensis*; Eri: *Eriophyes magnus*; Ab1: *Abacarus panticis*; Ab_2: *A. niitakaymensis*; Acu: *Aculops yushanus*; Te_1: *Tetra yushania*; Te_2: *T. paikoutashansis*; Te_3: *T. syuesis*; Te_3: *T. niitakayamensis*; Epi: *Epitrimerus niitakayamensi*; Neo: *Neopentamerus deciensus*; Teg: *Tegolophus bashaniae*; Apo: Apodiptacus niitakayamensi; Phy: Phytoptus formosanus.

Table 3
Species data (binary data) of vegetation system[a] (category variable) in this study.

Locality	FB	FC	FM	SM
N2	0	1	0	0
N1	0	0	1	0
C1	1	0	0	0
E1	0	0	1	0
C6	0	1	0	0
E2	0	1	0	0
C31	0	1	0	0
S2	0	0	0	1
E3	0	1	0	0
C5	0	0	1	0
S3	0	0	0	1
C32	0	0	0	1
C2	0	1	0	0
C4	0	1	0	0
S1	0	0	0	1
S4	0	0	0	1
C34	0	0	0	1
C35	0	0	0	1

[a] Vegetation system see text and Fig. 3.

eriophyoid mites to feed on a variety of host plants has resulted in a high diversity of mites.

Eriophyoid mites mainly rely on passive dispersal mechanisms (e.g., wind) and are rarely transported by larger organisms (phoresy). Dispersal is normally limited to adult females (Lindquist and Oldfield, 1996; Sabelis and Bruin, 1996). Eriophyoid mites can move around on a plant or from one plant to another (with distances ranging from several centimeters to several meters), or be passively dispersed by air currents or rain (distances ranging from several kilometers to across a continent). If female eriophyoid mites arrive on non-preferred host plants accidentally, they will have a high tendency toward dispersal (Katarzyn et al., 2010). Although their defense of host plants may reduce the probability of host switching, eriophyoid mites have simple structures and physiological functions and thus may digest essential nutrients (or secondary compounds similar to those of the original host plant) from a new plant and establish a new population when immigrating to a new host plant via passive dispersal. They may also evolve into a new species after a long period of separation from the maternal population. Moore and Howard (1996) hypothesized that the original host of *Aceria guerreronis* (Keifer, 1977) was a non-coconut palm and that it switched to the coconut palm somewhere along its invasion route (Navia et al., 2006). Moreover, this mite has been found to infest *Borassus flabellifer* L. in Asia and *Syagrus romanzoffiana* (Cham.) in North America. Another potential example of host range expansion is *Aculops lycopersici* (Tryon) (Katarzyn et al., 2010). The original host plant of this mite was a wild solanaceous plant in the Americas, but its association with tomatoes is recent (Oldfield and Michalska, 1996). Eriophyoid mites currently have a high diversity (approximately 4000 species), but their phylogeny and that of their host plants show no parallel evolution, possibly because they can easily switch to new host plants.

Table 4
Summary statistics for the first three axes in canonical correspondence analysis (CCA) between spatial binary data of 15 mite species and 5 environmental variables.

Statistic	CCA axis 1	CCA axis 2	CCA axis 3
Eigenvalues	0.37	0.16	0.13
Variance in species data (%)	18.5	8.3	6.4
Cumulative variance of species data (%)	18.5	26.8	33.2
Intraset correlations			
MT	−0.74	−0.23	0.06
S (HT-LT)	0.1	−0.05	−0.09
TR	0.22	0.15	−0.18
RH	0.05	−0.32	−0.45
P	0.74	−0.38	0.16

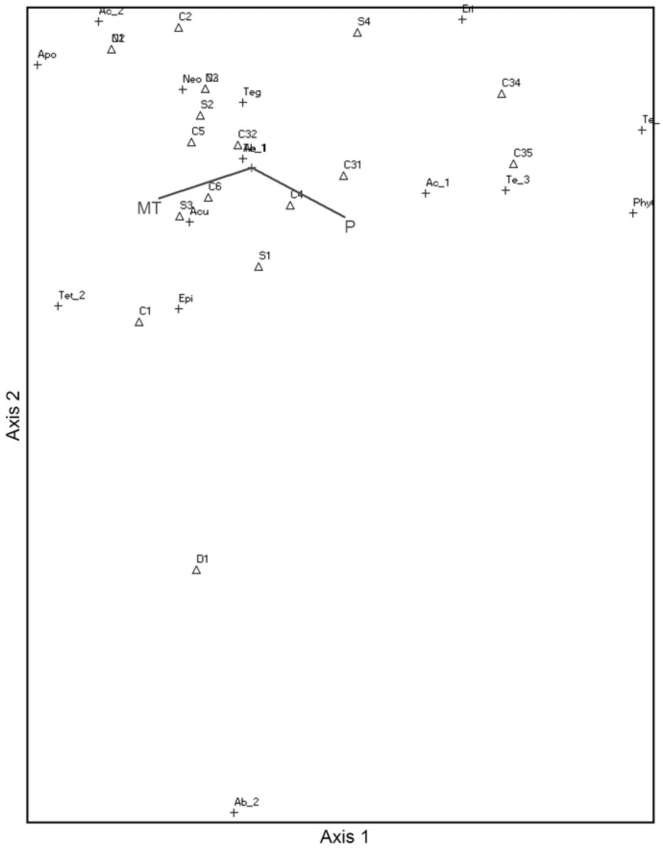

Fig. 2. Ordination triplot diagram of sampling sites (triangles), eriophyoid mite species (cross), and environmental variables (arrows) of the first tow ordination axes yielded by canonical correspondence analysis based on spatial binary date of eriophyoid mites species and quantitative environmental variables.

Their random distribution may be a result of random invasions onto new shoots of Yushan canes following catastrophic events such as forest fires (Liao et al., 2005). The distribution patterns of 15 eriophyoid mite species on Yushan canes may be randomized by forest fires initially and subsequently influenced by temperature and other environmental factors. Therefore, the species composition of eriophyoid mites on Yushan canes is unrelated to montane plant community types.

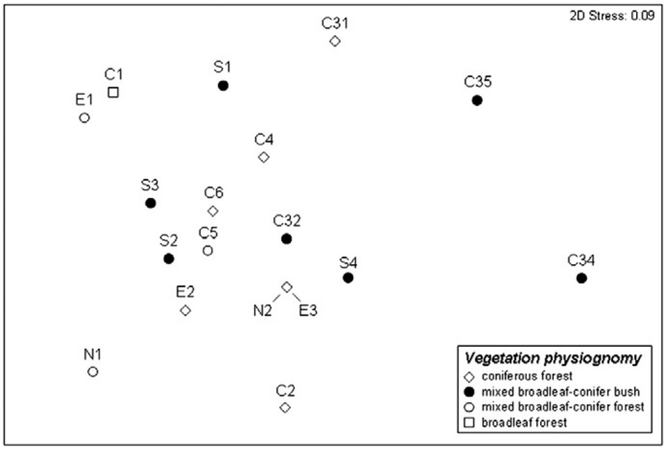

Fig. 3. Multidimensional scaling plot of the sampling sites using simple matching coefficient from 15 eriophyoid mite species binary data.

Acknowledgments

We are grateful to Dr. H. J. Shiu (National University of Tainan, Taiwan) for his valuable opinions and assistance in the data analysis. Thanks are also due to Mr. W. C. Yang for his assistance in the field trips, and to Mr. Simon Huang, Miss S. K. Hu, Miss R. Wang and Miss J. Jeng for organizing the data for analyses.

References

Amrine Jr., J.W., Stasny, T.A., 1994. Catalog of the Eriophyoidea (Acari: Prostigmata) of the World. Indira Publishing Houses, West Bloomfield.

Hsiao, J.Y., Lee, S.M., 1999. Gentic diversity and microgeographic differentiation of Yushan cane (*Yushania niitakayamensis*; Poaceae) in Taiwan. Mol. Ecol. 8, 263–270.

Hsieh, C.F., 2007. The vegetation classification system at the formation level for Taiwan. In: Lu, D.H. (Ed.), Proceedings of the fifth symposium of vegetation diversity in Taiwan. Forest Bureau, Council of Agriculture, Executive Yauan, Taipei, pp. 1–10 (in Chinese, with English abstract).

Huang, K.W., 2001. Eriophyoid mites of Taiwan: description of eighty-six species from the Tengchih area. Bull. Natl. Mus. Nat. Sci. 14, 1–84.

Huang, K.W., Wang, C.F., 2009. Eriophyoid mites of Taiwan: thirty-seven species from Yangmingshan, including one new genus and twenty-two new species. Zootaxa 1986, 1–50.

Kao, J.T., Feng, F.L., 2003. Spatial interpolation of the habitat factors and forest habitat classification. Q. Jour. Chin. For 34, 167–184.

Katarzyn, M., Skoracka, A., Navia, D., Amrine, J.W., 2010. Behavioural studies on eriophyoid mites: an overview. Exp. Appl. Acarol. 51, 31–59.

Liao, M.C., Chiou, C.A., Ou, C.H., Lu, K.C., 2005. Study on the flowering and the phenology of *Yushania niitakayamensis* (Hay.) Kenf f. at the east peak of Mt. Syue. J. Natl. Park 15, 29–44 (in Chinese, with English abstract).

Lindquist, E.E., Oldfield, G.N., 1996. Evolution of eriophyoid mites in relation to their host plants. In: Lindquist, E.E., Sabelis, M.W., Bruin, J. (Eds.), Eriophyoid mite—Their Biology, Natural Enemies and Control. Elsevier Science Publish, Amsterdam, pp. 277–300.

Moore, D., Howard, F.W., 1996. Coconuts. In: Lindquist, E.E., Sabelis, M.W., Bruin, J. (Eds.), Eriophyoid Mite—Their Biology, Natural Enemies and Control. Elsevier Science Publish, Amsterdam, pp. 561–570.

Navia, D., de Moraes, G.J., Querino, R.B., 2006. Geographic variation in the coconut mite, *Aceria guerreronis* Keifer: a geometric morphometric analysis. Int. J. Acarol. 32, 301–314.

Oldfield, G.N., Michalska, K., 1996. Spermatophore deposition, mating behavior and population mating structure. In: Lindquist, E.E., Sabelis, M.W., Bruin, J. (Eds.), Eriophyoid Mite – Their Biology, Natural Enemies and Control. Elsevier Science Publish, Amsterdam, pp. 185–198.

Sabelis, M.W., Bruin, J., 1996. Evolutionary ecology: life history patterns, food plant choice and dispersal. In: Lindquist, E.E., Sabelis, M.W., Bruin, J. (Eds.), Eriophyoid Mite – Their Biology, Natural Enemies and Control. Elsevier Science Publish, Amsterdam, pp. 329–366.

Ter Braak, C.J.F., 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67, 1167–1179.

Wang, C.F., Huang, K.W., 2011. Taxonomy of Eriophyoid Mites (Acari: Trombidiformes) infesting *Yushania niitakayamensis* (Poaceae: Bambuseae) in Taiwan. Formosan Entomol. 31, 249–280.