Powderpost Beetle Communities (Coleoptera: Bostrichidae) in Durian-Based Agricultural Areas in Southern Thailand

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ABSTRACT

The xylophagous powder post beetles of the family Bostrichidae are serious insect pests of forests and forest products, but studies of their ecology are rare. The present study investigated the communities of bostrichid beetles associated with durian-based agricultural areas in two study zones from southern Thailand. In total, 17 bostrichid species were collected, 15 in mixed-crop and 14 in mono-crop systems. *Xylothrips flavipes* (Illiger) was the most common species in both systems (56.8% of all beetles caught). Mono-crop durian orchards had significantly more beetles per trap than mixed-crop orchards, but the relative abundances of species were similar (percentage similarity, 86.7%). The seasonal flight pattern in the durian orchards was more or less bimodal. The first abundance peak occurred at the beginning of the rainy season (May– July) and the second peak during the final weeks of the rainy season (November –January). Bostrichid numbers were more significantly correlated with climatic variables measured during the previous two months than with the current values, suggesting an effect on beetle development.
Keywords: Coleoptera, Bostrichidae, diversity, species composition, seasonal flight pattern

INTRODUCTION

The powder post beetles (Coleoptera: Bostrichidae) are insects of economic importance in agriculture, forestry and the forest products industries (Creffield, 1991; Nair, 2007; Wagner *et al.*, 2008). In nature, xylophagous bostrichids infest weakened or dead trees and branches and gradually render the sapwood into a fine dust (Beeson and Bhatia, 1937). They tend to have a very wide host range and attack any kind of wood with suitable moisture and starch content. They are well-known destructive pests of dried and seasoned sapwood and wooden artifacts through the boring behavior of both adults and larvae (Gerberg, 1957;

Creffield, 1991; Peters *et al.*, 2002). Some species of the subfamilies Dinoderinae and Lyctinae are notable as destructive pests of bamboo, rattan and their artifacts (Stebbing, 1914; Sen-Sarma, 1977; Haojie *et al.*, 1998) or cause economically important damage to stored products (Hodges *et al.*, 1983; Delobel and Tran, 1993). Some bostrichid species will attack stressed plantation trees and are considered important silvicultural pests (Hutacharern and Choldumrongkul, 1989; Nair, 2007). The family also plays an important ecological role in decomposition and nutrient cycling in forest communities (Harmon *et al.*, 1986).

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Most recent bostrichid studies have focused on the biology and control of two economically important pests of stored product, *Prostephanus truncatus* (Horn) and *Rhyzopertha dominica* (F.) (Borgemeister *et al.*, 1997; Nansen *et al.*, 2001; Meikle *et al.*, 2002; Hill *et al.*, 2003; Hodges *et al.*, 2003; Edde and Phillips, 2006; Jia *et al.*, 2008). There have been some studies of individual species which are important wood and wood product pests in the tropics (Beeson and Bhatia, 1937; Ho and Hashim, 1997; Peters *et al.*, 2002), but almost no research has been done on the ecology of bostrichid communities in dead wood, except as part of more general surveys of xylophagous beetles (Lachat *et al.*, 2006).

In southern Thailand, bostrichids are among the insects that breed in the wood of the main tree crops—rubber (*Hevea brasiliensis* Muell. Arg.) and fruit trees, including durian (*Durio zibethinus* Murray), mangosteen (*Garcinia mangostana* L.) and longkong (*Lansium domesticum* Jack). The composition and abundance of the bostrichid fauna in rubberwood have been investigated in southern Thailand (Sittichaya and Beaver, 2009; Sittichaya *et al.*, 2009; Kangkamanee *et al.*, 2011). The diversity differs between eastern (Gulf of Thailand) and western (Andaman Sea) coastal areas. Bostrichids are more abundant during the dry season than the wet season in both areas. Abundance is related to the availability of breeding material with suitably low moisture (Sittichaya and Beaver, 2009; Kangkamanee *et al.*, 2011). Studies of xylophagous bostrichids carried out in Brazil (Dall'Oglio and Peres, 1997), and in Kalimantan in Indonesia (Makihara *et al.*, 2000) have also shown that abundance is greater in the dry season and related to the abundance of breeding material.

This study investigated: 1) the species composition and diversity of the wood-boring bostrichid communities associated with durian orchards in two study zones in southern Thailand; 2) whether these communities differ between mono-crop and mixed-crop orchards; and 3) the effects of climatic factors on the communities.

MATERIALS AND METHODS

Study areas and study sites

The study areas, all located near the eastern coast of southern Thailand, have a typical humid and maritime tropical climate. The region is dominated by large and continuous rubber plantations (1.78 million hectares; Rubber Research Institute of Thailand, 2006), interspersed with oil palm and fruit orchards, which are also valuable economic crops in Thailand. The fruit orchards are mostly planted in inland areas close to the central mountain ranges, which are otherwise covered with tropical rainforest. The study sites were selected from the two main durian (*Durio zibethinus* Murray)-growing areas in southern Thailand—Chumphon Province (zone 1) and Surat Thani and Nakhon Si Thammarat provinces (zone 2) as shown in Figure 1A. In zone 1, durian orchards are planted in large and continuous areas with a typically mosaic arrangement of mono-crop and mixed-crop durian orchards, while zone 2 is dominated by single-crop orchards. The studied areas are approximately 200 km apart and have similar weather and climate, which is typically warm with moderate to high humidity, feathering two seasons: a hot and dry summer (from February to mid April) and a rainy season (from mid April to mid February). The climate of the region is mainly influenced by the southwest and northeast monsoons. Both the southwest monsoon at the beginning of the rainy season (mid April–July) and the northeast monsoon at the end of the rainy season (September–December) bring heavy rain to the studied areas. The average annual rainfall in the study areas is approximately 2,100 mm, with an average temperature of 27 ºC and an average relative humidity of 80% (Meteorological Department of Thailand, personal communication).

Site selection and insect capture

      Durian orchards larger than 3 ha in area, with trees older than 15 years, of approximately similar structure and physiological status were identified, and of these, five durian orchards planted with durians only (mono-crop) and five with a mixed fruit-tree system (mixed-crop) were selected in each study zone. The other species of fruit trees in the mixed-crop orchards were mangosteen *(Garcinia mangostana* Linn.) or longkong (*Lansium domesticum* Corr.). For insect capture, a single transparent-vane trap was set at the middle of each selected orchard (Figure 1B). The traps were baited with 95% EtOH (release rate 68 mg.d^{-1} at 25 $^{\circ}$C) and set at a height of 1.5 m above the ground. The bait was replenished monthly before it was fully depleted. Ethylene-glycol (30%) was used as a preservative. In total, 20 traps were employed in the 20 studied orchards. The traps were checked monthly for one year (October 2009–September 2010). During each

inspection, the trap catch from each trap was emptied into a labeled 50 mL vial with 95% EtOH for storage. The temperature and relative humidity from two representative mono-and mixed cropping orchards in each study zone were recorded using a Hobo pro v2 Temperature/Humidity data logger-U23 (Onset® Computer Corporation. Bourne, MA, USA). The monthly rainfall in each study zone was obtained from the Chumphon and Surat Thani stations of the Thai Department of Meteorology (personal communication).

Climatic data

      The climatic parameters of rainfall, below-canopy temperature and relative humidity were not different between the two study zones and crop systems (Table 1). The rainfall pattern was slightly different between the study zones. In zone 1, the rainfall records indicated no distinct dry season (February–mid April) in the year of the study, with 'dry season' rainfall of 157.9 mm
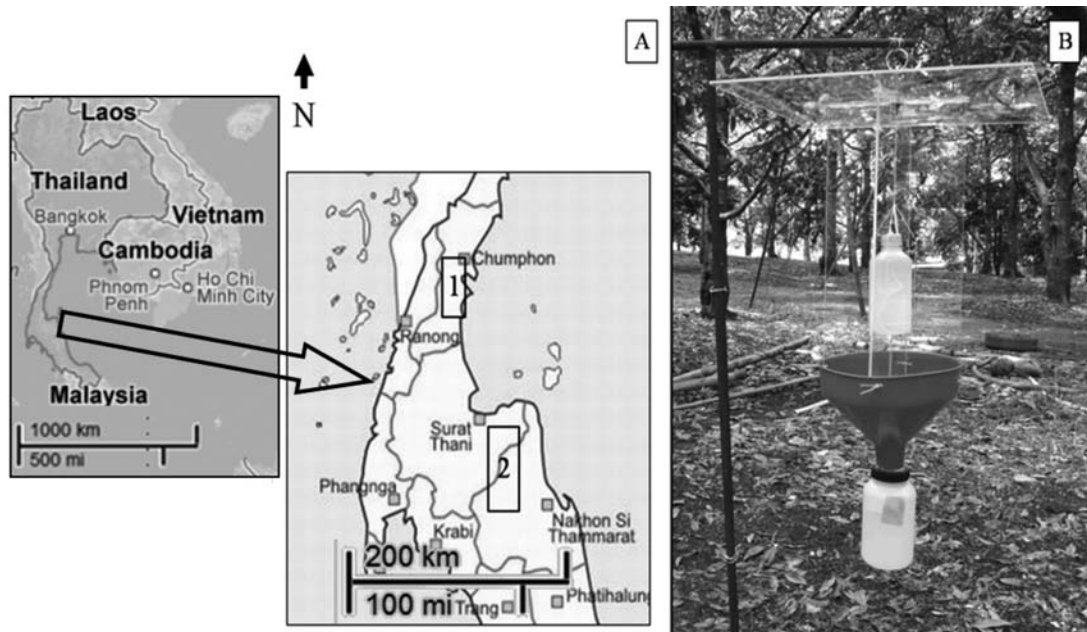

Figure 1 (A) Map of the study areas in southern Thailand showing 2 zones in boxes (zone 1 is in Chumphon province and zone 2 spans parts of Surat Thani and Nakhon Si Thammarat provinces). (B) Transparent-vane trap used in the study.

    Maps modified from: https://maps.google.com and www.panteethai.com

in March (Figure 2A), although this abnormal higher rainfall was a result of a short, high rainfall period for a week in March between long dry periods. Hence, the abnormal rainfall was excluded in the analysis and substituted with the mean rainfall of the dry period of 13.07 ± 13.33 mm. The temperature and relative humidity of the mixed-crop systems in the two study zones were almost identical, with monthly mean temperatures fluctuating between 26 and 30 ˚C with the higher temperatures in summer, while relative humidities fluctuated between 75 and 85% with the lowest humidity in summer and values over 80% in the rainy season.

Data analysis

To estimate the total powder post beetle species richness, Chao 1 (abundance-based) and Chao 2 (incidence-based) species richness estimators were used (Chao *et al.*, 2005). Diversity, species richness, and similarity of trap collections for the two cultural systems were compared using the EstimateS software (Colwell, 2005). Sørensen's quantitative index and mean Shannon's diversity values were also calculated using the EstimateS program. Bostrichid abundance figures (individuals per trap per month) were log transformed, using a log (x+1) transformation (Zar, 1999). Insect abundances between cultural systems and study zones were compared using *t*-tests.

The relationships between monthly trap catches in each cultural system and study zone and mean climatic factors were tested using simple linear regression.

RESULTS

Powder post beetle communities

A total of 1,203 bostrichids in 10 genera and 17 species were collected during the one-year study period from September 2009 to October 2010 (Table 2). Overall, the number of beetles caught in the mono-crop system (743 individuals, 61.76%) was greater than in the mixed-crop system (460 individuals, 38.24%), although the smaller numbers caught of the two most abundant species in the mixed-crop areas accounted for most of the difference. Most bostrichid species were captured in both cultural systems and study zones, with only five rarely encountered species found in a single system or zone. *Xylothrips flavipes* (Illiger) (56.77%) was the dominant species in the durian growing areas. Other frequently captured species included *Sinoxylon anale* Lesne (12.97%), *Paraxylion bifer* (Lesne) (8.56%) and *Xylopsocus radula* Lesne (7.32%). The percentage similarity of the abundances of the bostrichids in the two crop systems was high (86.7%). Species accumulation curves estimated using the Mao Tau function (Colwell *et al.*, 2004)

Table 1 Climatic data of the study zones and cropping systems.

Variable	Summer (February–April)	Rainy season (May–January)
Mean monthly Rainfall (mm) study zone 1	56.40±87.97*	124.10±39.67
Mean monthly Rainfall (mm) study zone 2	1.80±1.28	138.28±51.80
Mean below-canopy temperature (˚C) mono-crop	28.59±0.09	26.71±0.62
Mean below-canopy temperature (˚C) mono-crop	28.78±0.63	26.91±0.70
Mean below-canopy relative humidity (%) monoculture	78.41±4.43	85.02±1.58
Mean below-canopy relative humidity (%) mixed-crop	77.18±2.92	83.89±2.44

* Abnormal rain fall for one week in middle of dry season was excluded in the analysis; the mean rainfall of study zone 1 was 13.07 ± 13.33 mm

did not approach an asymptote in either of the two orchard systems. The species accumulation curves showed a faster increase in the number of species in the mono-crop system than in the mixed-crop system (Figure 3).

Both the Chao 1 and Chao 2 estimators of total species richness showed an asymptote in the mono-crop system at an estimate of 16 (with ± 95% confidence intervals (CI) of 15–26) and 17 (± 95% CI = 15–30) species, respectively. Only the Chao 2 estimator reached an asymptote in the mixed-crop system at 14 (± 95% CI =13–23) estimated species (Figure 4). In total, 15 bostrichid

species were collected from the mono-crop system and 14 species from the mixed-crop system. The Shannon diversity index of the mono-crop system (1.46) was lower than that of the mixed-crop system (1.55), due to the lower evenness of the mono-crop system (mono-crop=0.54, mixed-crop=0.58). The Sørensen similarity index of the two crop systems was 0.66.

Cultural system and study zones

The mono-crop system had significantly ($F = 3.53$; degrees of freedom (df) = 22; $P = 0.016$) more powder post beetles per trap per month (6.19
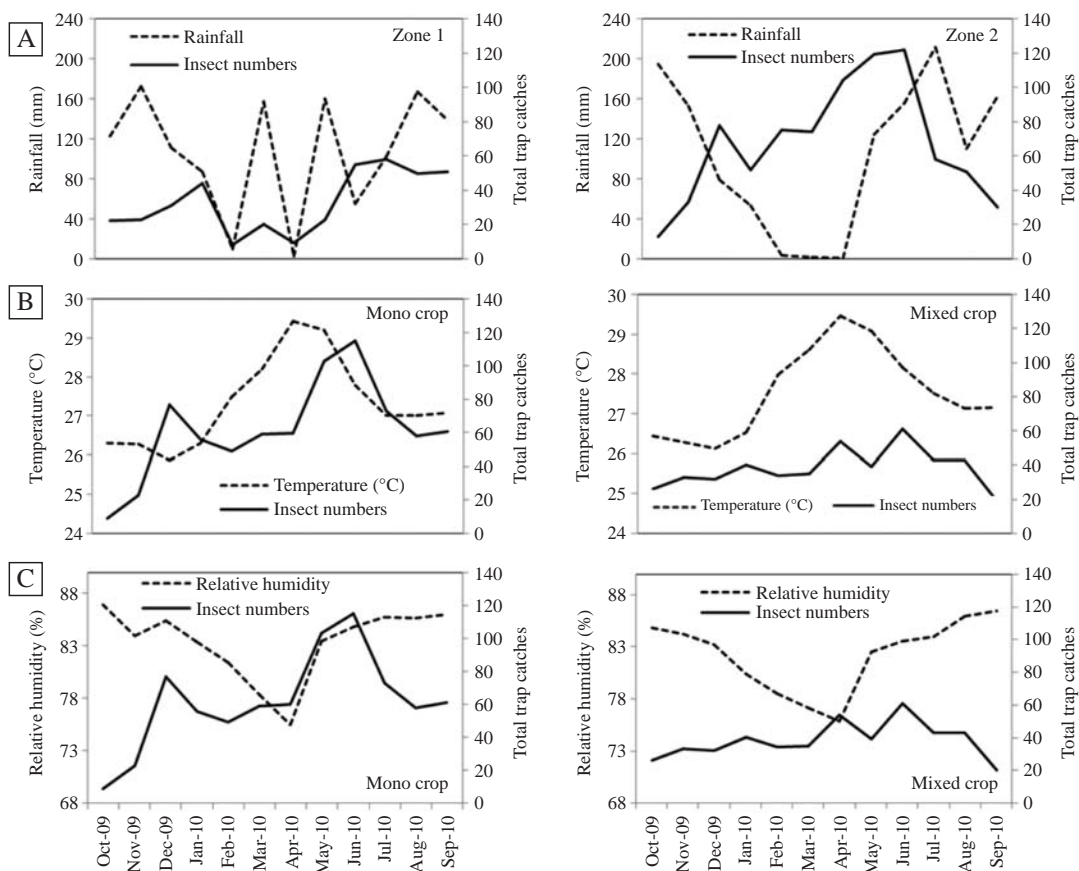

Figure 2 Relationship between climatic variation and seasonal flight activity patterns of bostrichids associated with durian orchards in each study zone and crop system: (A) Mean rainfall versus total insect numbers in zone 1 and zone 2; (B) Mean temperature versus total insect numbers trapped in mono- and mixed-crop durian orchards; (C) Mean relative humidity versus total insect numbers trapped in mono- and mixed-crop durian orchards.

± 0.84; mean ± SE) than the mixed-crop orchards (3.83 ± 0.32). The mean numbers of bostrichids per trap were also different between the mono-crop orchards in the two study zones, but not between the mixed-crop orchards. The mean number of beetles per trap in the mono-crop orchards was significantly ($F = 3.53$; df = 22; $P = 0.005$) higher in zone 2 (8.73 ± 1.49 individuals) than in zone 1 (3.25 ± 0.69). In the mixed-crop orchards, the mean number of beetles in zone 2 orchards (4.63 ± 0.70 individuals) was also slightly higher than in the zone 1 plantations (3.03 ± 0.38 individuals), but the difference was not statistically significant ($F = 1.40$; df = 22; $P = 0.057$).

Flight dynamics

The seasonal fight activity pattern of all bostrichids considered together was bimodal in zone 1. The first flight peak was during the late rainy season from November to January (year-end peak), and a second peak occurred between May and July (mid-year peak) during the early rainy season (Figure 2A). Numbers caught were lower during the dry summer season (February–April) and during the middle part of the rainy season (September– October). Bostrichid flight activity in the higher abundance zone (zone 2) showed a much less clear-cut bimodal peak, with no clear decrease during the dry season. A bimodal flight pattern was also clearly present in the durian mono-crop orchards (Figure 2B), but in the mixed-crop orchards, there was no clear evidence of bimodal flight activity.

Preliminary simple linear regression of climatic variables and bostrichid trap catches suggested that monthly rainfall was not correlated with bostrichid trap catches. Two other variables, temperature and relative humidity,

Table 2 Total numbers and relative abundance (%) of bostrichids associated with mono-crop and mixed-crop durian orchards in the study, based on monthly counts during a one-year collection period, 1 October 2009–30 September 2010.

| Species	Monoculture		Mixed-crop		Both crops	
	Total	%	Total	%	Total	%
Xylothrips flavipes (Illiger)	427	35.5	256	21.28	683	56.77
Sinoxylon anale Lesne	124	10.3	32	2.66	156	12.97
Paraxylion bifer (Lesne)	55	4.57	48	3.99	103	8.56
Xylopsocus radula Lesne	50	4.16	38	3.16	88	7.32
Dinoderus favosus Lesne	33	2.74	35	2.91	68	5.65
Xylopsocus capucinus (Fabricius)	21	1.75	31	2.58	52	4.32
Amphicerus caenophradoides (Lesne)	9	0.75	3	0.25	12	1.00
Dinoderus minutus (Fabricius)	7	0.58	5	0.42	12	1.00
Dinoderus ocellaris Stephens	3	0.25	5	0.42	8	0.67
Dinoderus exilis Lesne	4	0.33	3	0.25	7	0.58
Dinoderus bifoveolatus (Wollaston)	5	0.42	1	0.08	6	0.50
Xylocis tortilicornis Lesne	1	0.08	1	0.08	2	0.17
Xylopsocus ensifer Lesne	2	0.17	0	0.00	2	0.17
Calonistes antennalis Lesne	1	0.08	0	0.00	1	0.08
Rhyzopertha dominica (Fabricius)	0	0	1	0.08	1	0.08
Sinoxylon unidentatum (Fabricius)	1	0.08	0	0.00	1	0.08
Xylodectes ornatus Lesne	0	0	1	0.08	1	0.08
Total	743	61.80	460	38.24	1203	100.00
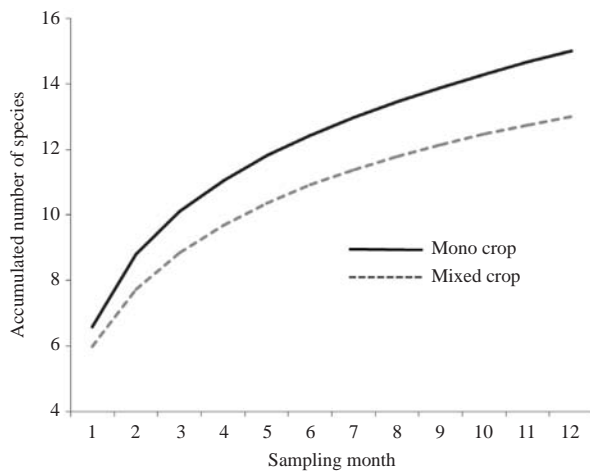
Figure 3 Species accumulation curves of bostrichids associated with durian planted in mono- and mixed-crop systems, estimated using the Mao Tau function, implemented in the Estimate S program (Colwell, 2005).
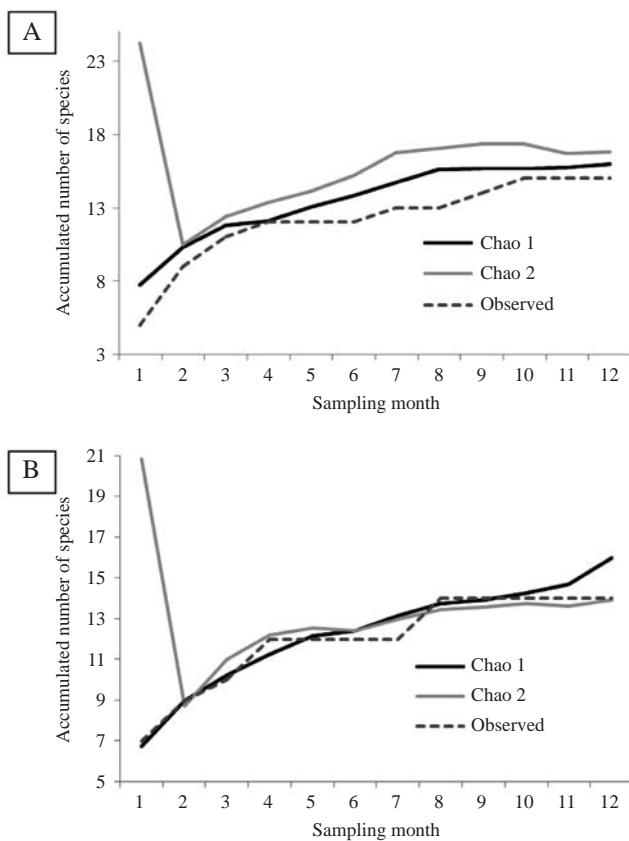

Figure 4 Chao 1, Chao 2 estimates and observed species richness for bostrichid beetles associated with durian planted: (A) Monoculture systems; (B) Mixed-crop systems.

were significantly correlated only with overall trap catches in study zone 2. Here, temperature had a positive effect on bostrichid flight activity ($r^2 = 0.525$, $F = 11.064$, df = 11, $P = 0.008$), whereas relative humidity had a negative effect ($r^2 = 0.494$, $F = 69.756$, df = 11, $P = 0.011$). No other significant correlations between climatic factors and trap catches were found. However, further analysis indicated that the climatic data of the month in which the beetles were caught had a smaller effect on trap catch than the climate of two months previously, that is, there was a two-month time lag between climatic variables and catch. All climatic variables, rainfall, temperature and relative humidity were significantly ($P < 0.05$) correlated with bostrichid trap catch two months later in study zone 2, and in mono-crop orchards in both zones (Table 3). Bostrichid abundance was again positively correlated with temperature, but negatively correlated with rainfall and relative humidity.

DISCUSSION

The abundance of xylophagous bostrichids associated with the durian orchards fluctuated more or less bimodally in both the mono- and mixed-crop systems. In the mixed-crop systems the pattern was indistinct because monthly trap catches in zone 2 fluctuated strongly from month to month. In zone 1, however, the populations were distinctly bimodal. In tropical areas, the abundance of bostrichids fluctuates seasonally with more or less influence from both temperature and relative humidity (Beeson and Bhatia, 1937; Nang'ayo *et al.*, 1993; Nansen *et al.*, 2001; Hodges *et al.*, 2003). Temperature alone may play a role as the single regulator in situations where the humidity is not limiting (Borgemeister *et al.*, 1997, Scholz *et al.*, 1998). In the present study, both temperature and humidity were significantly ($P < 0.05$) related to beetle trap catches, especially in zone 2 where there was a distinct dry season (Figure 2B and Table 3). The higher correlation with climatic data of the previous two months suggests that temperature and humidity affect the developing beetles more than the flying adults. As might be expected, low humidity has an adverse effect on development, but higher temperatures have a positive effect. However, further explanation of the relationships requires experiments on individual species. The correlations were based on the combined data for all species, and it is likely that different species will respond in different ways.

Table 3 Linear regression of climatic variables 2 months previously on bostrichid monthly trap catch in durian orchards in southern Thailand.

Variable	Zone/crop	b*	r^2	F-test	P-value
Cumulative monthly rainfall	Study Zone 1	0.026	0.001	0.007	0.936
(mm)	Study Zone 2	-0.766	0.545	14.190	0.004
Mean temperature (°C)	Study Zone 1	0.647	0.418	7.195	0.023
	Study Zone 2	0.679	0.461	8.559	0.015
	Monoculture	0.703	0.494	7.825	0.023
	Mixed-crop	0.588	0.264	4.236	0.074
Mean relative humidity (%)	Study Zone 1	-0.406	0.165	1.972	0.191
	Study Zone 2	-0.682	0.465	8.702	0.015
	Monoculture	-0.808	0.609	15.026	0.005
	Mixed-crop	-0.683	0.400	6.995	0.029

b* standardized regression coefficients, r^2 = Correlation coefficient.

The monthly catch of bostrichids in the mono-crop orchards was distinctly higher than in the mixed-crop orchards in all months except October (Figures 2B and 2C). The climate in the two systems was very similar, and climatic factors are unlikely to explain the different abundances. Two other factors that need to be considered are the availability of suitable food sources (Borgemeister *et al.*, 1997, Sittichaya and Beaver, 2009), and the presence of population-limiting natural enemies (Dial and Roughgarden, 1995; Krüger and McGavin, 2001). With regard to the availability of food resources, it should be noted that durian is a self-pruning tree which provides more dying and dead branches as an important food source for xylophagous beetles than the other fruit trees (longkong or mangosteen) in the orchards. The bostrichids found in the orchards usually infest wood with a high-moisture content, such as self-pruned branches, and newly dead durian trees (the result of attack by pathogenic fungi (*Phytophthora* spp.) or drought). They have rarely been found to infest dry branches or stems. Thus the durian mono-crop system generally has a larger available food resource compared to the mixed-crop system. This could partially explain the higher abundance of bostrichids in the mono-crop system. It was also noted that study zone 2 had a long period of drought from January to April (0.00–3.2 mm per month mean rainfall) during the study period, and most of the durian trees were under drought stress. Some of the trees died wholly or partially, especially in the monoculture orchards. Bostrichids were captured in higher numbers during this period, especially in the orchards with a high number of dead trees or branches.

The quantitative effect of natural enemies was not studied. Predators, particularly ants, such as *Oecophylla smaragdina* (F.), are abundant in the orchards, and are likely to be of importance during initial gallery establishment by the adult beetles (W. Sittichaya, R.A.Beaver, pers. obs.). There are few records of parasitoid Hymenoptera attacking bostrichids (Gordh and Moczar, 1990; Borgemeister *et al.*, 2003), and some of those are dubious (Gumovsky, 2010). Predatory Coleoptera (Cleridae, Colydiidae and Histeridae), are sometimes recorded associated with bostrichid galleries (Stebbing, 1914; Roberts, 1969; Borowski and Mazur, 2001; Sittichaya and Ngampongsai, 2009). However, predatory larvae and adults are rarely found in xylophagous bostrichid galleries (W.Sittichaya, R.A.Beaver, pers. obs.), and the mortality of the beetles and their immature stages due to natural enemies in their galleries is likely to be low.

The species composition of the bostrichid community associated with durian and other fruit trees in southern Thailand is quite different from the community associated with rubberwood at sawmills (Sittichaya and Beaver, 2009; Sittichaya *et al.*, 2009; Kangkamanee *et al.*, 2011). The Sørensen similarity index for the orchard and rubberwood communities is only 0.31, far lower than the value (0.66) for the comparison between the mono- and mixed-crop orchards. There were only four species (out of 22) in common between the two communities and the percentage similarity using abundance data was also low (20.8%). The bostrichids breeding in sawn rubberwood tended to prefer drier wood than is usually found in the orchards. The dominant species, *Xylothrips flavipes*, in the durian orchards was uncommon in rubberwood, whilst most of the abundant species in rubberwood (for example, *Heterobostrychus aequalis* (Waterhouse), *Sinoxylon unidentatum* (Fabricius), *Xylopsocus capucinus* (Sittichaya and Beaver, 2009; Kangkamanee *et al.*, 2011) were rare or absent from the durian orchards. The most notable exception was *Sinoxylon anale* which was the most abundant species in rubberwood sawn timber in southern Thailand (Kangkamanee *et al.,* 2011), and in most of the studied areas in southern and eastern Thailand (Sittichaya and Beaver, 2009) and was also common in the durian orchards (Table 2).

S.anale has a very wide distribution, having been introduced to and become established in a number of tropical and subtropical countries (Sittichaya *et al.*, 2009). It attacks a wide range of host trees; the adults sometimes bore into green shoots and twigs for maturation feeding or hibernation, although breeding occurs in dying or dead wood, including seasoned dry wood (Stebbing, 1914; Beeson and Bhatia, 1937; Ho and Hashim, 1997; Sittichaya and Beaver, 2009). It is regarded as a significant pest species of forest and the forest product industries in Thailand (FAO, 2007). With the exception of *S. anale*, the differences between the rubberwood and orchard bostrichid communities suggest that durian and other fruit tree orchards are not an important reservoir of bostrichid pest species of concern to rubberwood and other seasoned sawn timber.

CONCLUSION

The differences in mean trap catches between the study zones and the cropping system indicated the importance of an availability of food sources on the abundance and population dynamic of the Bostrichidae in agricultural areas. In the monoculture system and study zone 1, there was a higher food supply which supported higher abundance and continued abundance peaks of Bosttrichidae in each community. Although the direct sampling of available wood as feeding material was not investigated in the present study, future investigation is needed to prove this assumption. The present study, several earlier investigations and previous reports indicated that the flash powder post beetle should be grouped into two feeding guilds, one group associated with the fresher and high moisture wood such as is found in stressed trees or newly dead wood material and the other group associated with rather dry wood material. Further investigation on this issue is required.

LITERATURE CITED

Beeson, C.F.C. and B.M. Bhatia. 1937. On the biology of the Bostrychidae (Coleopt.). **Indian For. Rec. (N.S.) Ent.** 2: 223–323.

Borgemeister, C., N. Holst and R.J. Hodges. 2003. Biological control and other options for larger grain borer *Prostephanus truncates*, pp. 311–328. *In* P. Neuenschwander, C. Borgemeister and J. Langewald, (eds.). **Biological Control in IPM Systems in Africa.** CABI Publishing. Wallingford, UK.

Borgemeister, C., W.G. Meikle, D. Scholz, C. Adda, P. Degbey and R.H. Markham. 1997. Seasonal and weather factors influencing the annual flight cycle of Prostephanus truncatus (Coleoptera: Bostrichidae) and its predator *Teretriosoma nigrescens* (Coleoptera: Histeridae) in Benin. **Bull. Entomol. Res.** 87: 239–246.

Borowski, J. and S. Mazur. 2001. Contribution to the knowledge of the Bostrichidae and associated Histeridae (Insecta, Coleoptera). **Atti Mus. Civ. Stor. Nat. Morbegno** 12: 69–75.

Chao, A., R.L. Chazdon, R.K. Colwell and T.J. Shen. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. **Ecol. Lett.** 8: 148–159.

Colwell, R.K. 2005. **EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples.** [Available from: http://www.purl.oclc.org/estimates]. [Sourced: 01 January 2012]

Colwell, R.K., C.X. Mao and J. Chang. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. **Ecology** 85: 2717–2727.

Creffield, J.W. 1991. **Wood Destroying Insects, Wood Borers and Termites.** CSIRO Publications. Melbourne, Vic, Australia. 44 pp.

Dall'Oglio, O.T. and F.O. Peres. 1997. Levantamento e flutuação populacional de coleobrocas em plantios homogêneos de seringueira em Itiquira – MT. **Scientia. Forestal.** 51: 49–58.

Delobel, A. and M. Tran. 1993. **Les Coléoptères des Denrées Alimentaires Entreposées dans les Régions Chaudes.** ORSTOM. Paris, France. 425 pp. [in French]

Dial, R. and J. Roughgarden. 1995. Experimental removal of insectivores from rain forest canopy: direct and indirect effects. **Ecology** 76: 1821–1834.

Edde, P.A. and T.W. Phillips. 2006 Potential host affinities for the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae): behavioral responses to host odours and pheromones and reproductive ability on nongrain hosts. **Entomol. Exp. Appl.** 119: 255–263.

Food and Agriculure Organization (FAO). 2007. **Overview of Forest Pests, Thailand Working Paper FBS/32E.** Forest Resources Development Service, FAO. Rome, Italy. 22 pp.

Gerberg, E.J. 1957. A revision of the New World species of powder-post beetles belonging to the family Lyctidae. **U.S. Dept. Agr. Tech. Bull.** 1157: 1–55.

Gordh, G. and L. Moczar. 1990. A catalog of the world Bethylidae (Hymenoptera: Aculeata). **Mem. Am. Entomol. Inst.** 46: 1–364.

Gumovsky, A.V. 2010. A record of Sinoxylon anale Lesne in Ukraine with notes on false powder post beetles (Coleoptera: Bostrichidae) and their chalcidoid parasitoids (Hymenoptera). **Ukrainska ento.** 1: 1–8.

Haojie, W., H. Wang, R.V. Varma and T. Xiu. 1998. **Insect Pests of Bamboos in Asia: An Illustrated Manual.** International Network for Bamboo and Rattan. Beijing, China. 200 pp.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.J. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. **Adv. Ecol. Res.** 15: 133–299.

Hill, M.G., F.L. Nang'ayo and J. Wright. 2003. Biological control of the larger grain borer *Prostephanus truncatus* (Coleoptera: Bostrichidae) in Kenya using a predatory beetle *Teretrius nigrescens* (Coleoptera: Histeridae). **Bull. Entomol. Res.** 93: 299–306.

Ho, Y.F. and S. Hashim. 1997. Wood-boring beetles of rubberwood sawn timber. **J. Trop. For. Pro.** 3: 15–19.

Hodges, R.J., S. Addo and L. Birkinshaw. 2003 Can observation of climatic variables be used to predict the flight dispersal rates of *Prostephanus truncatus*? **Agric. For. Entomol.** 5: 123–135.

Hodges, R.J., W.R. Dunstan, I. Magazini and P. Golob. 1983. An outbreak of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in East Africa. **Protect. Ecol.** 5: 183–194.

Hutacharern, C. and S. Choldumrongkul. 1989. A note on the insect pests of multipurpose tree species in Thailand. **J. Trop. Forest Sci.** 2: 81–84.

Jia, F., M.D. Toews, J.F. Campbell and S.B. Ramaswamy. 2008. Survival and reproduction of lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on flora associated with native habitats in Kansas. **J. Stored. Prod.** 44: 366–372.

Kangkamanee, T., W. Sittichaya, A. Ngampongsai, S. Permkam and R.A. Beaver. 2011. Wood boring beetles (Coleoptera: Bostrichidae, Curculionidae; Platypodinae and Scolytinae) infesting rubberwood sawn timber in Southern Thailand. **J. For. Res.** 16: 302–308.

Krüger, O. and G.C. McGavin. 2001. Predator-prey ratio and guild constancy in a tropical insect community. **J. Zool.** 253, 265–273.

Lachat, T., P. Nagel, Y. Cakpo, S. Attignon, G. Goergen, B. Sinsin and R. Peveling. 2006. Dead wood and saproxylic beetle assemblages in a semi-deciduous forest in Southern Benin. **Forest Ecol. Manage.** 225: 27–38.

Makihara, H., H. Kinuura, K. Yahiro and C. Soeyamto. 2000. The effect of droughts and fires on coleopteran insects in lowland dipterocarp forests in Bukit Soeharto, East Kalimantan, pp. 154-163. *In* E. Guhardja, M. Fatawi, M. Sutiona, T. Mori and S. Ohta, (eds.). **Rainforest Ecosystems of East kalimantan: El Niño, Drought, Fires and Human Impacts**. Springer-Verlag. Tokyo, Japan.

Meikle, W.G., D. Rees and R.H. Markham. 2002. Biological control of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). **Integrated Pest Manag. Rev.** 7: 123–138.

Nair, K.S.S. 2007. **Tropical Forest Insect Pests: Ecology, Impact, and Management.** Cambridge University Press. Cambridge, UK. 404 pp.

Nang'ayo, F.L.O., M.G. Hill, E.A. Chandi, C.T. Chiro, D.N. Nzeve and J. Obiero. 1993. The natural environment as a reservoir for the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Kenya. **African Crop. Sci. J.** 1: 39–47.

Nansen, C., S. Korie, W.G. Meikle and N. Holst. 2001. Sensitivity of *Prostephanus truncatus* (Coleoptera: Bostrichidae) flight activity to environmental variables in Benin, **West Africa. Environ. Entomol.** 30: 1135–1143.

Peters, B.C., J.W. Creffield and R.H. Eldridge. 2002. Lyctine (Coleoptera: Bostrichidae) pests of timber in Australia: A literature review and susceptibility testing protocol. **Aust For.** 65: 107–119.

Roberts, H. 1969. Forest insects of Nigeria with notes on their biology and distribution. **Commonw. For. Inst.** 44: 1–206.

Rubber Research Institute of Thailand. 2006. **Thai Rubber Statistics, Rubber Plantation Area of Thailand.** Rubber Research Institute of Thailand, Bangkok. [Available from: http://www.rubberthai.com/]. [Sourced: 03 September 2008].

Scholz, D., C. Borgemeister and H-M. Poehling. 1998. EAG and behavioural responses of the larger grain borer, *Prostephanus truncatus*, and its predator, *Teretriosoma nigrescens*, to the borer-produced aggregation pheromone. **Physiol. Entomol.** 23: 265–273.

Sen-Sarma, P.K. 1977. Insect pests and their control in rural housing. **Indian J. Entom.** 39: 284-288.

Sittichaya, W. and A. Ngampongsai. 2009. **Survey and Study on the Effect of Rubber Clones on Breeding Biology of an Important Rubber Wood Borer in Southern Thailand.** Research report, Prince of Songkla University. Thailand. 109 pp. [in Thai with English summary]

Sittichaya, W. and R.A. Beaver. 2009. Rubberwood-destroying beetles in the eastern and gulf areas of Thailand (Coleoptera: Bostrichidae, Curculionidae: Scolytinae and Platypodinae). **Songklanakarin J. Sci. Technol.** 31: 381–387.

Sittichaya, W., R.A. Beaver, L-Y. Liu and A. Ngampongsai. 2009. An illustrated key to powder post beetles (Coleoptera, Bostrichidae) associated with rubberwood in Thailand, with new records and a checklist of species found in southern Thailand. **Zookeys** 26: 33–51.

Stebbing, E.P. 1914. **Indian Forest Insects of Economic Importance: Coleoptera.** Eyre and Spottiswoode. UK. 648 pp.

Wagner, M.R., J.R. Cobbinah and P.P. Bosu. 2008. **Forest Entomology in West Tropical Africa: Forest Insects of Ghana.** Springer. Houton, the Netherlands. 244 pp.

Zar, J.H. 1999. **Biostatistical Analysis.** 4th ed. Prentice-Hall. Upper Saddle River, NJ, USA. 663 pp.