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Sustainable weaver ant (*Oecophylla smaragdina*) farming: harvest yields and effects on worker ant density

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ABSTRACT. The Asian weaver ant *Oecophylla smaragdina* Fabricius is renowned as an efficient biocontrol agent since it preys on a multitude of pest insects. Additionally, this ant is harvested and sold at local and international markets as a delicacy, a prized bird feed and as traditional medicine. We present the first attempt to farm this ant scientifically and test whether the harvest of ant queen brood is compatible with biocontrol, i.e., if worker ant densities are affected by harvest pressure. In a Thai mango (*Mangifera indica* L.) plantation, unfed ants produced fresh mass yields of 114–157 g queen brood tree^{-1} year^{-1}, compared with 258–377 g for ants fed sugar and cat food. The lowest-producing treatment corresponded to a value of THB 22.8 (USD 0.65) tree^{-1} year^{-1}, and the highest to THB 75.4 (USD 2.16). Worker ant densities estimated shortly after the ant harvest did not differ significantly between harvested and unharvested plots, and surprisingly the longer-term effect was a significant increase on harvested trees. We conclude that plantations can, with negligible costs, produce significant (>100 g tree^{-1}) edible high-protein ant biomass, and that this harvest is sustainable and can be combined with ant biocontrol. Further, the yield can be increased several times through appropriate management.

Keywords: ant husbandry, entomophagy, food ecology, food security, biocontrol, sustainable agriculture, Thailand.

INTRODUCTION

Weaver ants belonging to the genus *Oecophylla* can benefit agriculture in two distinctly different ways. As notorious insect predators, the ants are effective biological control agents able to control more than 50 different pest species in at least 12 different tropical crops (Way & Khoo 1992; Peng & Christian 2006). Benefits attributed to *Oecophylla* biocontrol are several. Using ants as a biocontrol agent is both ecologically sound and inexpensive if the ants can be found in surrounding habitats; ant colonies need no external inputs to function, and ant farming only requires simple management techniques. Further, the ants can increase fruit yields and/or fruit quality compared to conventional synthetic insecticide control measures (Way & Khoo 1989; Barzman *et al.* 1996; Peng *et al.* 2004; Peng & Christian 2005; see also review by Van Mele 2008).

A second way of utilizing O*ecophylla* ants is as a food source, which has been practiced in Southeast Asia for centuries (DeFoliart 1999, 2009 and references therein). The ant colonies produce large amounts of queen brood every year which is placed in visible and easily-accessible leaf nests in trees and bushes in disturbed habitats, i.e., close to human populations, and can thus be harvested in vast amounts (Césard 2004; Sribandit *et al.* 2008). The term "queen brood" refers to larvae and pupae destined to become new queens as well as their last stage as imago virgin queens.

These are numerous relative to other brood: in the present study they comprised 86% (± 4.3% SE, *n* = 20 trees) of all brood. The ants (brood and imago workers) are considered delicious in many cultures and constitute an important nutrient source as they contain 48.5 % dry-mass protein (DeFoliart 2009). In Thailand, in particular, ants are harvested in large amounts and consumed as a delicacy. In the Thai province of Nakhon Rachasima, the total value of the yearly ant harvest was calculated as USD 620,000 (Sribandit *et al.* 2008), and frozen ant brood are exported to Asian stores on the European and Japanese markets. Similarly, *Oecophylla* ants constitute a human food resource in a number of other tropical countries, including Vietnam, Borneo, Myanmar, Philippines, India, Cameroon and Congo (Bristowe 1932; Barzman *et al.* 1996; DeFoliart 1999, 2009; Oudhia 2002; Sunil Kumar and Alain Dejean personal communication).

Thus, *Oecophylla* ants not only possess a high potential to indirectly increase crop production and quality by means of pest control, but the ants may also contribute directly to food security (Offenberg & Wiwatwitaya 2009). Among Thai ant collectors and entomologists, commercial markets have generated an increasing interest in *Oecophylla* ant farming and a need for an evaluation of harvest yields (Sribandit *et al.* 2008). If the harvest of ants can be sustainably linked to biocontrol (i.e., if ant biomass can be harvested from plantations without decreasing the ant's biocontrol efficiency), then increased fruit production and production of animal biomass may go hand in hand. In this paper, we estimate ant harvest yields from a Thai mango plantation and test the sustainability and economic viability of integrating ant biocontrol with ant harvest.

MATERIALS AND METHODS

In May 2006, the study was initiated, on 70, 12-year-old mango *Mangifera indica* L. trees (variety: Nam Dok Mai) with a 6 x 6 m spacing in a mango plantation in Wang Nam Khiaow District, North Eastern Thailand (14°26´18´´ N; 101°53´13´´E). We established *Oecophylla smaragdina* Fabricius colonies on all the trees that were not already occupied by these ants and divided the trees randomly into three treatments: (i) trees where ants were fed and ant brood harvested (fed and harvested; *n* = 23 trees and 3 ant colonies), (ii) trees where ants were not fed and ant brood was harvested (unfed and harvested; *n* = 23 trees and 3 colonies), and (iii) trees where ants were fed and not harvested (fed and unharvested; *n* = 18 trees and 2 colonies). Sample size was lower in the fed and unharvested treatment since one colony died in this treatment and was excluded.

Since each ant colony occupied several trees, all individual colonies were spatially limited to a single treatment. To facilitate ant establishment, all trees belonging to the same ant colony were connected with nylon strings (diameter = 7 mm) whereas trees belonging to different colonies were pruned to reduce fights between colonies. On trees where the ants were fed, tuna-based cat food and a 35% sucrose solution was provided 16 times between the first feeding on 18 November 2006, and the last feeding on 24 March 2007 (approximately once per week). At each feeding, one spoonful of wet cat food (22.75 g wet mass / spoon, Tesco brand) was placed on the main trunk and 30 ml sugar solution was offered in two 15 ml plastic test tubes plugged with cotton and placed upside down on a twig approximately 2 m above the ground. Only the *Oecophylla* ants were observed feeding on the cat food and sucrose as both were immediately monopolized by them. The sugar feeders were usually not depleted before the following feeding whereas cat food was removed within one or two days after the feeding.

Feeding costs were tracked and used to calculate the profitability of ant feeding. The rate of return was calculated as $r_{arith} = (V_f - V_i) / V_i$ where r_{arith} equals the arithmetic rate of return, V_f is the increase in income due to ant feeding (mean income from fed colonies minus mean income from unfed colonies) and V_i is the cost of ant feeding. On ant-harvested trees, two local ant collectors were hired to collect queen ant brood using traditional methods (Sribandit *et al.* 2008) twice during the 2007 ant harvesting season (27 February and 2 April). After the ant yield was processed by sorting ant castes and washing the brood in water, the biomass harvested from each tree was weighed (fresh weight) and used for analysis. Mann-Whitney-Wilcoxon tests (Normal Approximation) were used to compare yields between fed and unfed colonies since tests for normality and homogeneity of variances failed. The Thai baht–US dollar (THB–USD) exchange rate (from December 2008) used for conversion was 34.96.

Worker ant densities were estimated on each tree five times during the 2007 ant harvesting season (17 February, 13 March, 29 March, 26 April and 19 May) and twice after the season (5 October 2007 and 8 February 2008), the latest more than 11 months after the first ant brood harvest. Density estimates were never conducted when cat food was present on the trees, since this may increase ant activity and trail densities; however, sugar water was continuously supplied. The method for the most reliable and cost-effective density estimates of *Oecophylla* worker ants (the branch method) has been developed by Peng and Christian (2005) and Van Mele *et al*. (2007). Because of the documented benefits of this method and to allow ant density comparisons between studies, the density estimates used in the present study were based on the branch method. In our study, we increased the resolution of the index. Densities were estimated as the proportion of the main trunks on a tree occupied by *Oecophylla* ant trails, weighted by the density of the trails. The number of main trunks on trees ranged from 4 to 7 with a mean of 5.3 ± 0.09 SE. Trails were categorized into four densities: (i) "trails" without ants (zero density), (ii) trails with 1–9 ants m^{-1} (low density), (iii) trails with 10–50 ants m^{-1} (medium density), and (iv) trails with > 50 ants m^{-1} (high density). We calculated this forager based density index FDI = ((0)(Z)+(L)(1/3)+(Me)(2/3)+(H))/M, where FDI equals the Forager Density Index, M is the total number of main trunks on the tree and Z, L, Me and H are the numbers of zero, low, medium and high density trunks, respectively. Thus, the index varies from 0 to 1, where 1 indicates all the main trunks on a tree carry high density trails. We also estimated ant nest densities by counting ant nests in the trees on 5 June 2006, which was before we developed the FDI and before feeding treatments were initiated. To translate nest density to an ant density index, nests were classified as small, medium or large, since larger nests contain more ants (Offenberg *et al*. 2004). This nest based index NDI = (# of small nests) + (# of medium nests × 2) + (# of large nests × 3). The NDI was only used as a covariate for the analysis of the effect of feeding (see below) since the FDI was not available from the pre-feeding period. The effect on FDI of the feeding and the ant harvest was analysed using one-way analysis of covariance performed for each of the seven sampling dates (starting 17 February 2007). The effect of feeding was tested with harvest treatment (± harvest) and the pre-feeding density (NDI) as co-factors except for the first survey on 17 February; in this case, harvest was not included as a co-factor since the ant harvest started after this date. The effect of harvest was tested with feeding (± feeding) and the pre-harvest density (FDI on 17 February) as co-factors. All statistical tests were performed with the statistical software package JMP 7.0.

RESULTS

Ant yields

The overall (including both fed and unfed colonies) mean amount of ant brood harvested per ant colony within the experimental plot was 1,426 g (± 533 SE, *n* = 6 colonies) fresh mass; however, colony C (fed) and D (unfed) showed very low yields (Table 1). Leaving out these two colonies resulted in average yields of 2,043 g $colony^{-1}$ (± 574 SE, *n* = 4 colonies). The mean yield per tree was 186 g (± 62 SE, *n* = 46 trees) overall, but more than twice as high in fed treatment (mean = 258 ±112 SE, *n* = 23 trees) as in the unfed treatment (mean = 114 ± 54 SE, *n* = 23 trees). Leaving out the two low-producing colonies resulted in an overall mean of 264 g (± 90 SE, *n* = 31 trees) $tree^{-1}$, again with more than double the production in the fed treatment (377 g ± 165 SE, *n* = 15 trees) as in the unfed (157 g ± 75 SE, *n* = 16 trees). Thus, yields ranged between 114 and 377 g ant brood $tree^{-1}$ $year^{-1}$ depending on feeding and the inclusion of the two low-producing colonies, corresponding to values of between 22.8 (USD 0.65) and THB 75.4 (USD 2.16) if using the May 2007 local market price of THB 200 kg fresh $mass^{-1}$ (Sribandit *et al.* 2008) (Table 2). There was no significant difference between treatments, whether all colonies were included (Z = 1.15, *P* = .25, *n* = 46 trees) or whether colony C and D were excluded (Z = 1.17, *P* = .25, *n* = 31 trees). The

Table 1. Yields of ant brood harvested from weaver ant (*Oecophylla smaragdina*) colonies from experimentally manipulated treatments in a mango plantation in Wang Nam Khiaow district, North Eastern Thailand during 2007 and 2008. Yields are given as total and mean +/-SE per tree.

Colony	Food	Total yield (g)	Yield tree^{-1} (g)	n (trees)
A	-	1 091	136 (69)	8
B	+	1 983	331 (172)	6
C	+	275	34 (20)	8
D	-	112	16 (11)	7
E	+	3 674	408 (259)	9
F	-	1 423	178 (139)	8

Table 2. Average ant brood yield and its economic value per mango tree in a Thai plantation in relation to ant management (i.e., ant feeding and the inclusion of low producing non-mature ant colonies, C and D). Ant brood values were calculated using the local market price of THB 200 kg^{-1} fresh weight (price from May 2007) reported by Sribandit *et al.* (2008). Numbers in brackets are the value in USD using an exchange rate of 34.96 (from December 2008).

		+ Food	- Food
Including all colonies	Mass	258 g	114 g
	Value	THB 51.6 (USD 1.48)	THB 22.8 (USD 0.65)
Excluding colonies C and D	Mass	377 g	157 g
	Value	THB 75.4 (USD 2.16)	THB 31.4 (USD 0.90)

increase in income due to ant feeding (V_f) was THB 1,186.4 (total income from fed colonies) minus THB 525.2 (total income from unfed colonies) = THB 661.2. Thus, the overall return (r_{arith}) generated by the feeding of the ants was only 1.5 % (= (661.2 – 651.4)/651.4 THB). However, returns increased to 48 % (V_f = 1,131.4 – 502.8 = 628.6; r_{arith} = (628.6 – 434.8)/424.8 THB) if the two low-producing colonies were excluded.

Worker ant densities

During the first five density surveys in the harvesting season, there were no significant differences between worker ant densities on harvested and unharvested trees. However, six months after the last ant harvest (5 October 2007) and again four months later (8 February 2008), marginally higher and significantly higher densities were observed in harvested compared to unharvested colonies, respectively (Fig. 1 and Table 3). When comparing the average ant densities between the first three surveys, when ant harvest was taking place, and the following four surveys after the ant harvests, there was a 7 % (± 8 SE) increase among harvested trees but a 17 % (± 14 SE) decrease among unharvested trees ($F_{1,47}$ = 2.27, P = .14). When densities were compared between fed and unfed colonies, there were significantly more workers in fed colonies at the two first surveys, when the ant feeding was still taking place; differences became non-significant during the following surveys (Fig. 1 and Table 3). When comparing average ant densities between the two first surveys (within the feeding period) and the last five surveys (after the last feeding), there was a 9 % (± 7 SE) decrease in ant densities among fed colonies, but a 35% (± 10 SE) increase among unfed colonies ($F_{1,47}$ = 14.29, P = .0004).

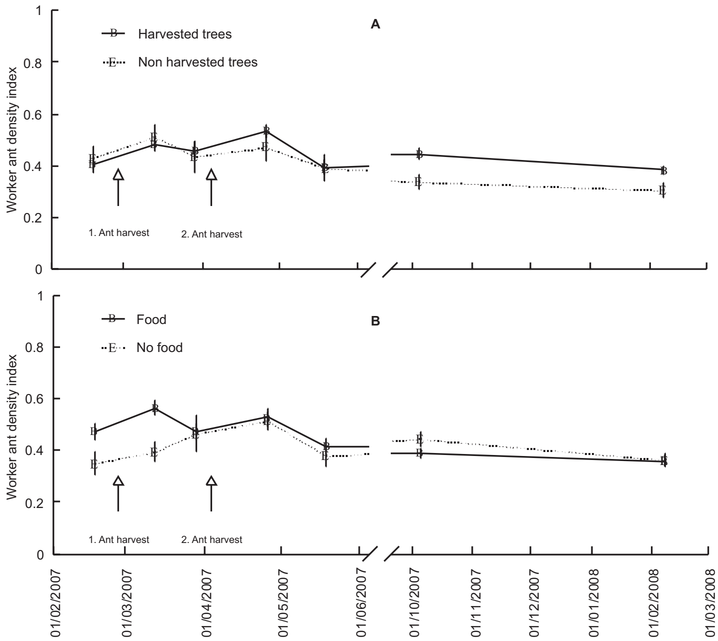

Fig. 1. Worker ant densities by time on mango trees in a plantation in Wang Nam Khiaow District, North Eastern Thailand. The figure shows (**A**) the mean densities (± SE) for trees where ant brood were harvested and trees where ant brood were not harvested ($n_{harvested}$ = 52 trees, $n_{unharvested}$ = 18 trees) and (**B**) where ants were fed and not fed (n_{fed} = 41 trees, n_{unfed} = 23 trees). Arrows indicate the times of harvesting on 27 Feb and 2 Apr 2007. The last feeding was on 24 Mar 2007.

Table 3. Statistical analysis (one-way ANCOVA) of the effect of feeding and ant harvest on weaver ant (*Oecophylla smaragdina*) densities by time on mango trees in a Thai plantation in 2007 and 2008. Feeding led to higher densities during the feeding period (February and March 2007), whereas the harvest of ant brood led to increased ant densities 11 months after (February 2008) the first harvest.

Date	Source	df	F	P
17 Feb	Food	1	5.80	.019*
	-	-	-	-
13 Mar	Food	1	13.37	.0006***
	Harvest	1	0.90	.35
29 Mar	Food	1	0.15	.70
	Harvest	1	0.019	.89
26 Apr	Food	1	0.86	.36
	Harvest	1	1.36	.25
19 May	Food	1	0.87	.36
	Harvest	1	0.12	.73
5 Oct	Food	1	0.077	.78
	Harvest	1	3.40	.070
8 Feb ’08	Food	1	1.01	.32
	Harvest	1	4.20	.045*

DISCUSSION

This study should be considered preliminary since the sample size at the ant colony level was low (*n* = 8 ant colonies) and therefore, trees were used as the experimental replicate unit. This weakens the robustness of the analyses. On the other hand, the study provides important quantitative data on harvest yields and it is safe to conclude that all harvested colonies were alive after one year and that the trend was towards a higher increase in worker ant densities among harvested than unharvested colonies.

Yields

Colony C and D produced only very low yields compared to the other harvested colonies (Table 1). A likely explanation for these low yields is that the colonies had only just reached maturity and therefore, had invested little in production of sexual brood. *Oecophylla smaragdina* colonies do not produce sexual brood until they reach maturity, which is approximately two years after their claustral founding (Vanderplank 1960; Peng *et al.* 2004). After attaining maturity, they may then increase investment in sexuals as the colony grows in population size from year to year. If immature ant colonies cannot be avoided in plantations, and our study is representative of their prevalence, a yield of some 114 g per tree can be expected without feeding them. Our figures suggest the yield may be substantially increased (by 38% in this case) if management can exclude non-mature colonies, and more than doubled again if ant colonies are provided food.

Sribandit *et al.* (2008) found that average annual income for an ant collector household in the same area was THB 67,000. This means that 588 ant-occupied mango trees would be needed to sustain a household if ant colonies are not fed and if colony age is not managed. On the other hand, only 178 trees would be needed if the ants are fed and if young low-producing colonies are excluded (though if ant food must be paid for, more trees would be needed to generate the same net income). Even fewer trees may be needed if harvest and feeding efficiency can be improved as outlined below.

The ant colonies concentrated most of their queen brood in a few large nests in one or a few trees, leaving the remaining trees in their territory with little or no queen brood. This behaviour led to high variation in queen brood yield between trees. Therefore, even though yields more than doubled in the trees where the ants were fed, this increase was not significantly different from trees where ants were unfed. It is likely that a higher sampling size at the ant colony level would detect such an effect.

The feeding of ants was only marginally profitable, with a return of 2 %. However, if non-mature colonies could be avoided, the return on feeding increased to 48 % and active ant farming became lucrative. Therefore, it is a priority to develop techniques that can restrict the feeding to mature colonies producing the higher quantities of sexual brood (although the feeding of non-mature colonies may increase their development rate and shorten their time to reach maturity). Further, returns may be increased via the development of more efficient feeding. The cat food used in this study was expensive compared to alternative food resources. For example, locally caught small fish, chicken intestines or other sorts of kitchen waste are readily eaten by *O. smaragdina* and may be much cheaper or free (Van Mele & Cuc 2007). Another possibility is the use of plant-protein based fish pellets that ants have been observed to accept as food when the season of sexual brood production peaks and the demand for protein is highest. If plant-based protein can be assimilated by the ants, the production of ant biomass may become much cheaper. For example, the farmed catfish *Clarias macrocephalus* raised on fish pellets has a market price of THB 50-60 kg^{-1}, which is 3–4 times lower than the value of ant brood (THB 200 kg^{-1}). Thus, even if the assimilation of fish pellets by ants is only half as efficient as catfish assimilation, the return generated by investment in fish pellets may still be higher on an ant farm compared with a fish farm. However, it remains to be tested how efficiently such food can be assimilated. One study has shown that *O. smaragdina,* under laboratory conditions, have difficulties in utilizing dry food items probably because the larvae only feed via trophallaxis with imago workers, and imagos are only capable of taking up liquid food (Kristine Bollerup, unpublished results). On the other hand, dry cat pellets have re-hydrated in *O. smaragdina* leaf nests, potentially making them appropriate for ant assimilation (Kristine Bollerup, unpublished results). Further research is needed to develop and document the efficiency of cheaper protein foods.

Ant farming also may be improved by a more efficient harvesting schedule. First, it is possible that 1–2 more harvesting events per season would have increased yields. This was suggested by the local ant harvesters after the study. Second, the timing of the harvesting events may be important. Larvae and pupae, compared with virgin imago queens, are easier to shake out of the nests because they are unable to hold to the substrate as they have no legs. Therefore, harvesting primarily at the earlier part of the season when a larger proportion of the ant brood is in the larval/pupal stages may increase harvest efficiency. Also, brood should preferentially be harvested before pupation because metamorphosis is energy-consuming (Mogens Gissel Nielsen, personal communication). Thus, the ant brood cohort loses mass during that stage, causing a reduction in harvestable biomass. Third, if queen production can be triggered artificially, more than one harvest season per year may be achieved. Thus, studies are needed to determine the factor(s) that triggers the production of queen brood. This would substantially increase the yearly income from ant farming and spread the income throughout the year. This study has been a first attempt to quantify *Oecophylla* ant farming. Given developments on lowering feed costs and increasing harvest efficiency, the profitability of ant farming in future attempts may be significantly improved compared to the figures given here.

Worker ant densities

Worker ant densities were higher on trees where ants were fed, but only during the period when ant feeding actually took place during the first two surveys (Fig. 1B, Table 3). On the third density estimate, five days after the last feeding, this difference had ceased and was therefore not likely to have been caused by changes in colony demography. The observed difference, which was based on worker ant activity on the main trunks, was probably a reflection of high recruitment to the sugar feeders that were also placed on the main trunks.

Even though some worker ants were caught in their attempts to protect the queen brood during harvest, the densities of workers were unaffected during the harvest season and in the following one to two months (Fig. 1A, Table 3). Densities even became marginally higher on harvested trees in the October survey, approximately six months after the last harvest, and significantly higher later in the February survey. This result may look surprising at first, but two factors may explain an increased investment in the worker caste in response to harvesting. First, the production of sexuals is seasonal and may therefore not be reinitiated if interrupted. Thus, if sexual brood is removed from the colony before its maturation and the colony has successfully optimized its production of mature sexuals to predicted resources, then a surplus of these resources will accumulate which can only be invested in worker production. Second, harvested colonies may have perceived an increased predation risk, based on the loss of their brood, and responded by increasing their investment in major workers that protect the colony. The two explanations are mutually compatible and both may explain the observed delayed increases in worker densities, as the production of imago workers takes approximately 30 days, with additional time needed before these workers will be foraging outside the nests and thus be included in the density estimates. Since it is the activities of worker ants that are responsible for colony survival, colony maintenance, and capturing and deterring other insects, harvest pressure is unlikely to affect either colony survival or predation pressure on prey populations.

It follows from these results that the harvest of ants, or active ant farming via the feeding of ants, is compatible with weaver ant biocontrol. Plantations accommodating ants for protection may function as “substrates” for ant farming. The ants then not only protect crops against pests, but additionally add an extra asset by producing animal biomass. In this way, yield of more than 114 g edible high protein animal biomass can be produced per mango tree without interventions or investments, but with the prevailing insects in the plantation as the primary raw material. In other words, integrating *Oecophylla* ant farming and *Oecophylla* biocontrol creates an agricultural system where ants convert harmful pest biomass into valuable ant brood. Moreover, our study suggests that ant biomass and biocontrol functions may be considerably increased via appropriate management actions.

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