2 — Silk moths inventory in their natural *tapia* forest habitat (Madagascar): diversity, population dynamics and host plants

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Endemic silk moths (Lepidoptera: Lasiocampidae) in Madagascar have been collected and exploited for centuries by local populations either for food or as a source of silk cocoons from which textiles are made. Moth natural forest habitat has also been degraded, leading to a drastic decrease in silk moth populations. However, very few scientific reports highlighted these observations well known by the local people. We have inventoried silk moths species in *tapia* (*Uapaca bojeri* Baill.) forests located in the central Highlands of Madagascar. Inventories have been conducted during one year from August 2009 to July 2010 by sampling transects in Imamo forests. Three species of Lasiocampidae belonging to two genera were found: *Borocera cajani* Vinson, *Borocera marginepunctata* Guérin-Méneville and *Europtera punctillata* Guenée. These three silk moth species are endemic to Madagascar but only one *(B. cajani)* is commercially exploited in the silk industry. The habitat, host plants, abundance, life cycle and feeding behaviour of these species in their natural habitat are described.

Inventaire des vers à soie endémiques de Madagascar au sein des forêts de *tapia* : diversité, dynamique des populations et plantes hôtes

Les vers à soie endémiques de Madagascar (Lepidoptera : Lasoicampidae) ont été collectés et exploités depuis des centaines d'années par les populations locales, soit pour leur soie, soit en tant que biens de consommation. Leur habitat naturel, les forêts de *tapia*, se dégrade également, conduisant à une baisse drastique du nombre de papillons. Cependant, très peu d'études rapportent ces observations qui sont pourtant bien connues par les populations locales. Nous avons inventorié l'ensemble des espèces de papillons producteurs de soie dans les forêts de *tapia* de l'Imamo entre août 2009 et juillet 2010. Trois espèces de Lasiocampidae appartenant à deux genres différents ont été observés : *Borocera cajani* Vinson, *Borocera marginepunctata* Guérin-Méneville et *Europtera punctillata* Guenée. Ces trois papillons sont endémiques à Madagascar mais seulement un (*B. cajani*) est exploité pour sa soie. Les habitats, les plantes hôtes, l'abondance, le cycle de vie et les habitudes alimentaires de ces trois espèces sont décrites.

2.1. INTRODUCTION

Madagascar Island is one of the most important centres of world biodiversity with a high level of endemicity (around 90%) (Mittermeier et al., 2004). Many of its species are forest dwel-

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ling (Myers, 1988). This biodiversity includes in particular wild silk moths. Silk moths produce cocoons that are collected, processed, spun and the silk is used to weave textiles. The domesticated silkworm, *Bombyx mori* L. (Bombycidae) is reared in Madagascar (CAPFIDA, 2008), but beside this species, indigenous wild silk moths have been collected in their natural habitat and exploited for thousands of years (Peigler, 1993). Most wild silk moth species belong to the family Lasiocampidae, subfamily Gonometinae. All these species encountered in the Island are endemic. Only one of them, *Borocera cajani* Vinson, locally named as *landibe*, has been used by the local populations for silk production (De Lajonquière, 1972; Peigler, 1993; 2004). It mainly develops in the locally named *tapia* forests situated in the central Highlands zones, including the Imamo (Arivonimamo, Itasy, elevation 1,200 - 1,400 m), Itremo (Ambatofinandrahana, elevation 1,300 - 1,500 m), Col des Tapia (Elevation 1,400 - 1,600 m) and Isalo zones of southwest Madagascar (elevation 830 - 1,000 m) (De Lajonquière, 1972; Gade, 1985; Kull et al., 2005) (**Figure 2.1**).

Today, local markets present silk products (clothes and fabrics) produced from either domesticated or wild silk moths. Fewer people work in the silk industry than in the mid-20th century. But cocoon collection in the forest still remains an alternative source of income to the poorest and most disadvantaged people living close to the *tapia* forest especially during lean periods (Kull et al., 2005; Razafimanantsoa et al., 2012, chapter 1). Malagasy people in the Highlands prefer shrouds made of silk produced by wild silk moths rather than domesticated moths for their traditional party of exhumation. Moreover, the silk industry constitutes the basis of a new ecotourism activity on the island. Beside the silk it provides, the pupae *B. cajani* are also a preferred delicacy (Decary, 1937; Gade, 1985; Guigou, 1989; Kull et al., 2005).

Understanding the natural history and habitat of Lepidoptera is crucial to their conservation (Turner et al., 2009), especially *B. cajani*, because of its endemicity, its economic importance and traditional use in the Malagasy culture.
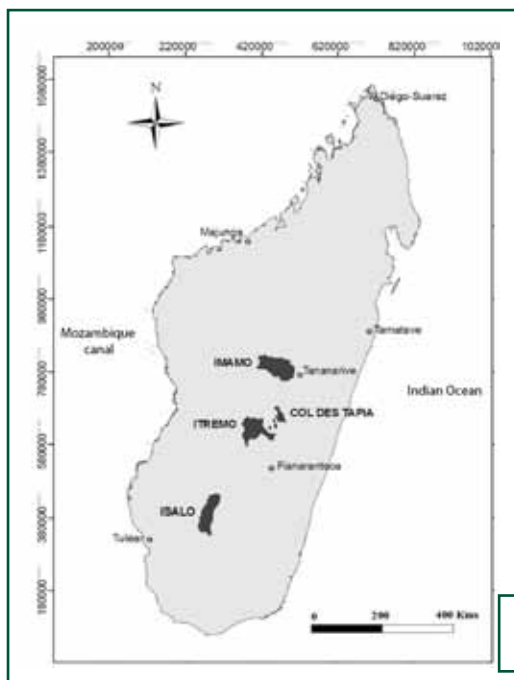
The historical importance of this species has encouraged investigations on its biology and the sustainability of the industry (Paulian, 1953). A better knowledge of *B. cajani* biology has been provided thanks to rearing studies (Razafimanantsoa et al., 2012, chapter 1). Data on its ecology have, however, been largely lacking and this led us to conduct the present study. We have conducted a one-year inventory of silk moths in the *tapia* forests of Imamo, near the city of Arivonimamo, situated in the central Highlands of Madagascar. Information about the habitat, host plants, population density, life cycle and behaviour of the silk moths were inventoried.

Figure 2.1. Location of *tapia* forests in Madagascar (Rakotondrasoa et al., 2012).

2.2. METHODS

2.2.1. Study area

Field inventories were conducted from August 2009 to July 2010, in the sclerophyllous forest of Imamo, located in the central Highlands of Madagascar (**Figure 2.1**). The site was situated close to the city of Arivonimamo, about 50 km west of Antananarivo, 47°11'E 18° 58'S, and elevation between 1,200 m and 1,400 m.

2.2.2. Inventories

For sampling, six 100-m-long and 10-m-wide linear transects were defined. Each transect was separated from the next by a minimum of 700 m and a maximum of 4,000 m. The position of the transects in the investigated *tapia* forest were randomly chosen, ensuring, however, that trees were present in the 100 m of length. Altitude inside one single transect was kept equal, and variations of elevation between all transects was less than 100 m.

In each transect, before the first silk moth sampling, all trees (>2 m of height) and bushes were identified and counted and all shrubs were identified to species level in order to provide botanical information about the silk moth habitat.

The inventory was based only on visual observations. Transects were visually observed twice a month from August 2009 to July 2010. Observations included the immature stages of all silk moths (eggs, larvae and cocoons). Sampling of adult *Borocera* species is very difficult because they are not attracted to light traps (Razafimanantosoa et al., 2006). Each transect was divided into 10 square plots (10 m × 10 m) to facilitate the inventory. Each 100 m² plot was observed for 30 minutes by two experienced observers (i.e. 300 minutes per transect). Only one transect was inventoried per day. The number, developmental stages, name of the host plant and position of the individual on the plant (trunk, leaf or branch) were noted for all observed silk moths. *Borocera cajani* larval stages were easily identified *in situ*, while other species were identified after rearing in the laboratory.

The mean relative abundance of each species (MRSA) belonging to the Gonometinae community was estimated by dividing the number of individuals belonging to a particular species by the number of all individuals belonging to the Gonometinae community. This abundance was then qualified as follow: MRSA≥80%: abundant species; 50≤MRSA<80%: common species; 25≤MRSA<50%: frequent species; 15≤MRSA<25%: occasional species; 5 ≤MRSA < 15%: rare species; MRSA<5%: very rare species (Raselimanana et al., 2007). Mean relative abundance shows the importance of each species relative to all species present in the area (Dajoz, 1985).

2.3. RESULTS AND DISCUSSION

2.3.1. Botanical composition of the *tapia* forest habitat

A list of all plant species observed in the insect-inventoried transects is presented in **table 2.1.** Over-all, trees inventoried in the study transect, 97.8% belonged to the species *Uapaca bojeri*, the remaining 2.2% are composed by *Pinus* sp. and *Eucalyptus torquata* Leuhm. The average density of *U. bojeri* tree is 653 ± 19 (average ± S.E.) per ha. The emergent trees reached a

height of 8 m. Shrub stage is composed mainly by young *U. bojeri* and *Aphloia theiformis* (Vahl) Benn. The herbaceous stage is less than 1 m in height and composed by many species belonging to several families including *Leptolaena bojeriana* (Baill.) Cavaco; *Vaccinium secundiflorum* Hook; *Saccharum viguieri* (A. Camus) Clayton; *Loudetia madagascariensis* Baker; *Aristida rufescens* Steud. and *Imperata cylindrica* (L.) P. Beauv.

Table 2.1. List of plant species inventoried in the transects.

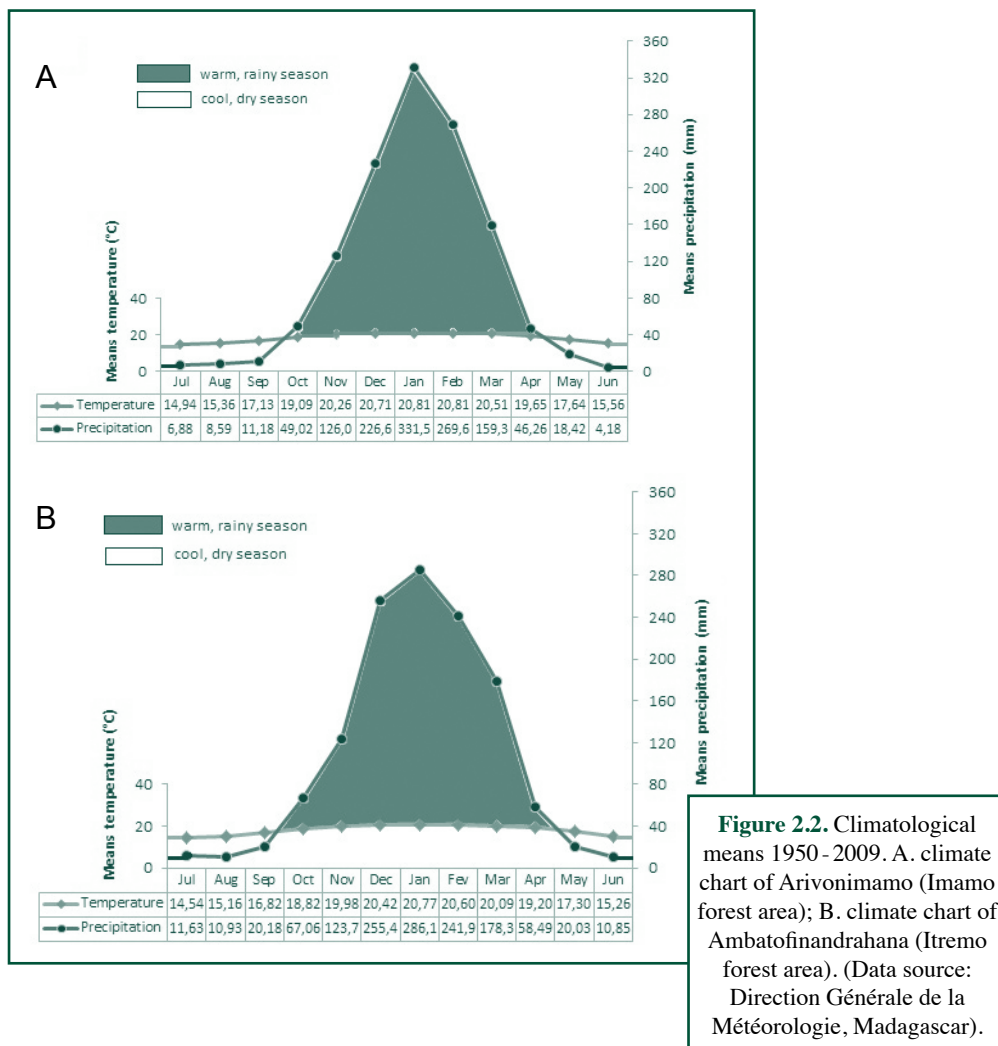| Species	Family	Stratum	Species	Family	Stratum
Agave rigida Mill.	Agavaceae	Shrub	*Vernonia pseudoappendiculata* Humbert	Asteraceae	Shrub
Aloe capitata var. *capitata*	Aloaceae	Herbaceous	*Vernonia trinervis* (Bojer ex DC.) Drake	Asteraceae	Shrub
Aphloia theiformis (Vahl) Benn.	Aphloiaceae	Shrub	*Commelina lyallii* (C.B.Clarke) H. Perrier	Commelinaceae	Herbaceous
Asclepias fruticosa L.	Apocynaceae	Herbaceous	*Commelina madagascarica* C.B.Clarke	Commelinaceae	Herbaceous
Secamone tenuifolia Decne.	Apocynaceae	Herbaceous	*Carex elatior* Boeck.	Cyperaceae	Herbaceous
Schefflera bojeri (Seem.) R.Vig.	Araliaceae	Shrub	*Carex pyramidalis* Kük.	Cyperaceae	Herbaceous
Dipcadi heterocuspe Baker	Apocynaceae	Herbaceous	*Cyperus amabilis* Vahl	Cyperaceae	Herbaceous
Acanthospermum hispidum DC.	Apocynaceae	Herbaceous	*Cyperus impubes* Steud.	Cyperaceae	Herbaceous
Ageratum conyzoides L.	Asteraceae	Herbaceous	*Cyperus obtusiflorus* Vahl	Cyperaceae	Herbaceous
Aspilia bojeri DC.	Asteraceae	Herbaceous	*Kyllinga bulbosa* P.Beauv.	Cyperaceae	Herbaceous
Bidens bipinnata L.	Asteraceae	Herbaceous	*Scleria foliosa* Hochst. ex A.Rich.	Cyperaceae	Herbaceous
Bidens pilosa L.	Asteraceae	Herbaceous	*Pteridium aquilinum* (L.) Kuhn	Dennstaedtia-ceae	Herbaceous
Crassocephalum sarcobasis (DC.) S.Moore	Asteraceae	Herbaceous	*Erica baroniana* Dorr & E.G.H.Oliv.	Ericaceae	Shrub
Elephantopus scaber L.	Asteraceae	Herbaceous	*Erica bosseri* Dorr	Ericaceae	Shrub
Emilia graminea DC.	Asteraceae	Herbaceous	*Vaccinium secundiflorum* Hook.	Ericaceae	Shrub
Ethulia conyzoides L. f.	Asteraceae	Herbaceous	*Euphorbia hirta* L.	Euphorbiaceae	Herbaceous
Helichrysum faradifani Scott-Elliot	Asteraceae	Herbaceous	*Acacia dealbata* Link	Fabaceae	Tree
Helichrysum gymnocephalum (DC.) Humber	Asteraceae	Herbaceous	*Chamaecrista mimosoides* (L.) Greene	Fabaceae	Herbaceous
Helichrysum triplinerve DC.	Asteraceae	Herbaceous	*Crotalaria ibityensis* R.Vig. & Humbert	Fabaceae	Herbaceous
Laggera alata (D. Don) Sch. Bip. ex Oliv.	Asteraceae	Herbaceous	*Eriosema procumbens* Benth. ex Baker	Fabaceae	Herbaceous
Launea pauciflora (Baker) Humbert & Boulos	Asteraceae	Herbaceous	*Indigofera pedunculata* Hilsenberg & Bojer ex Baker	Fabaceae	Shrub
Psiadia altissima (DC.) Drake	Asteraceae	Shrub	*Indigofera stenosepala* Baker	Fabaceae	Shrub
Senecio longiscapus Bojer ex DC.	Asteraceae	Herbaceous	*Kotschya strigosa* (Benth.) Dewit & P.A.Duvign.	Fabaceae	Shrub
Vernonia appendiculata Less.	Asteraceae	Shrub	*Stylosanthes guianensis* (Aubl.) Sw.A	Fabaceae	Herbaceous
Vernonia polygalifolia Less.	Asteraceae	Shrub			

Table 2.1. Continued.

Species	Family	Stratum	Species	Family	Stratum
Zornia puberula Mohlenbr	Fabaceae	Herbaceous	*Loudetia simplex* (Nees) C.E. Hubb.	Poaceae	Herbaceous
Dicranopteris linearis (Burm. f.) Underw.	Gleichemia-ceae	Herbaceous	*Melinis minutiflora* P. Beauv.	Poaceae	Herbaceous
Gladiolus dalenii Van Geel	Iridaceae	Herbaceous	*Pennisetum polystachion* (L.) Schult.	Poaceae	Herbaceous
Hyptis pectinata (L.) Poit.	Lamiaceae	Herbaceous	*Saccharum vieguieri* (A. Camus) Clayton	Poaceae	Herbaceous
Hyptis spicigera Lam.	Lamiaceae	Herbaceous	*Setaria pallide-fusca* (Schumach.) Stapf & C.E. Hubb.	Poaceae	Herbaceous
Lilium longiflorum Thunb.	Liliaceae	Herbaceous	*Trachypogon spicatus* (L. f.) Kuntze	Poaceae	Herbaceous
Lycopodium cernuum L.	Lycopodiaceae	Shrub			
Sida urens L.	Malvaceae	Herbaceous	*Maesa lanceolata* Forssk.	Primulaceae	Shrub
Triumfetta rhomboidea Jacq.	Malvaceae	Herbaceous	*Clematis mauritiana* Lam.	Ranuncula-ceae	Liana
Antherotoma naudinii Hook. f.	Melastomata-ceae	Herbaceous	*Rubus rosifolius* Sm.	Rosaceae	Shrub
Melia azedarach L.	Meliaceae	Tree	*Anthospermum emirnense* Baker	Rubiaceae	Shrub
Ficus rubra Vahl	Moraceae	Tree	*Mussaenda arcuata* Lam. ex Poir.	Rubiaceae	Shrub
Eucalyptus torquata Luehm.	Myrtaceae	Tree	*Oldenlandia herbacea* (L.) Roxb.	Rubiaceae	Herbaceous
Alectra sessiliflora (Vahl) Kuntze	Orobanchaceae	Herbaceous	*Otiophora scabra* Zucc.	Rubiaceae	Herbaceous
Striga asiatica (L.)	Orobanchaceae	Herbaceous	*Psychotria retiphlebia* Baker	Rubiaceae	Shrub
Biophytum umbraculum Welw.	Oxalidaceae	Herbaceous	*Richardia brasiliensis* Gomes	Rubiaceae	Herbaceous
Oxalis corniculata L.	Oxalidaceae	Herbaceous	*Spermacoce pusilla* Wall.	Rubiaceae	Herbaceous
Phyllanthus casticum Willemet	Phyllanthaceae	Tree	*Dodonaea madagascariensis* Radlk.	Sapindaceae	Shrub
Uapaca bojeri Baill.	Phyllanthaceae	Tree	*Leptolaena bojeriana* (Baill.) Cavaco	Sarcolaena-ceae	Herbaceous
Pinus khasya Royle ex Hook. f.	Pinaceae	Tree	*Buddleja madagascariensis* Lam.	Scrophularia-ceae	Shrub
Andropogon gayanus Kunth	Poaceae	Herbaceous	*Hybanthus heterophyllus* (Vent.) Baill.	Violaceae	Herbaceous
Ctenium concinnum Nees	Poaceae	Herbaceous			
Cymbopogon plicatus Stapf	Poaceae	Herbaceous	*Dianella ensifolia* (L.) DC.	Xanthorrhoea-ceae	Herbaceous
Digitaria minutiflora Stapf	Poaceae	Herbaceous			
Eragrostis curvula (Schrad.) Nees	Poaceae	Herbaceous			
Loudetia madagasca-riensis (Baker) Bosser	Poaceae	Herbaceous			

This forest is an open formation, classified as woodland by some authors and mainly composed of a single tree species: *Uapaca bojeri* Baill. (locally named *tapia*, Phyllanthaceae) (Koechlin et al., 1974; Kull et al., 2005; Rakotoniaina, 2010; Vignal, 1963). *Tapia* trees are found in several widely scattered clusters (Kull, 2002). This species is resistant to bush fires (Gade, 1985). As a result it forms monodominant stands in the central Highlands (Hoffmann et al., 2003). It is the most xerophytic evergreen forest tree of Madagascar (Kull, 2003).

Tapia trees grow slowly and reach a maximum height of 8-12 m (Kull, 2002). Up to 60 cm in diameter, the shaft of the tree may be straight or very irregular and tortuous with a crown shaped like a ball, and has a thick bark, up to 2.5 cm (Kull, 2003; Kull et al., 2005).

The annual temperature in this region ranges between 17 °C and 22 °C (Kull, 2002; 2003; UPDR, 2003). The Imamo region experiences two seasons during the year: a warm, rainy season from November to March and a long cool and dry season during the rest of the year (**Figure 2.2**). The mean annual rainfall is 1,350 mm (Blanc-Pamard, 1995; Kull, 2003).

A

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Temperature	14,94	15,36	17,13	19,09	20,26	20,71	20,81	20,81	20,51	19,65	17,64	15,56
Precipitation	6,88	8,59	11,18	49,02	126,0	226,6	331,5	269,6	159,3	46,26	18,42	4,18

B

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Fev	Mar	Apr	May	Jun
Temperature	14,54	15,16	16,82	18,82	19,98	20,42	20,77	20,60	20,09	19,20	17,30	15,26
Precipitation	11,63	10,93	20,18	67,06	123,7	255,4	286,1	241,9	178,3	58,49	20,03	10,85

Figure 2.2. Climatological means 1950 - 2009. A. climate chart of Arivonimamo (Imamo forest area); B. climate chart of Ambatofinandrahana (Itremo forest area). (Data source: Direction Générale de la Météorologie, Madagascar).

2.3.2. Silk moths species identified

Three species of Gonometinae were observed in the *tapia* forest: *Borocera cajani* Vinson, *Borocera marginepunctata* Guérin-Meneville and *Europtera punctillata* Saalmüller (**Figure 2.3**, see color section). Neither *B. marginepunctata* nor *E. punctillata* have been used

for silk textiles in Madagascar. *B. marginepunctata* is not of economic interest because of its low populations and poor silk quality (Paulian, 1953). *E. punctillata*, despite its small size, is sometimes collected for its silk which can be mixed with *B. cajani* silk. A single adult of a fourth Gonometinae moth species, *Anchirithra insignis* Butler, has been once observed in the same forest while using light trapping (unpubl. results).

2.3.3. Silk moths abundance

Borocera marginepunctata was the rarest species with only seven individuals per ha at the sites where the study was conducted (**Table 2.2**). *Uapaca bojeri* might not be its preferred host plant. The species is abundant in the edge of the altitudinal humid forest of Ranomafana with its multiple host plants including *Psidium guyava* L. (Myrtaceae), *Terminalia* spp., *Psiadia altissima* (DC.) Drake (Asteraceae), *Harungana madagascariensis* Lam. ex Poir. (Hypericaceae), *Nuxia* spp. (Stilbaceae), *Weinmannia rutenbergii* Engl. (Cunoniaceae) (Razafimanantsoa, unpubl.).

Table 2.2. Mean annual abundance and classification of the three silk moth species (all stages included) (mean ± SE).

	MAA (ha^{-1})	MRSA (%)	Species Classification
Borocera cajani	119.6 ± 17.9	49.4 ± 0.1	Frequent
Borocera marginepunctata	6.9 ± 2.8	3.6 ± 0.1	Very rare
Europtera punctillata	105.5 ± 14.2	47.0 ± 0.1	Frequent

MAA = mean annual abundance; MRSA = mean relative species abundance

Borocera cajani and *E. punctillata* were the most abundant but their densities did not exceed 120 individuals per ha throughout the year at the study site. Considering the number of trees in the inventoried transects, only one individual of *B. cajani* per five trees was observed. Although this number seems very low, it is hardly comparable as the present study is the first to evaluate *B. cajani* abundance in its natural habitats. *B. cajani* populations in the Imamo area are therefore far from what the forest could accommodate. Many authors have mentioned the decline of this species in this area, which was previously classified amongst the most important silk-producing areas (Paulian, 1953; Kull et al., 2005; CITE/BOSS Corporation, 2009). One might explain the reduced density of cocoons by the destruction of the forest habitats through bushfires (Paulian, 1953), overharvesting of cocoons (Razafimanantsoa et al., 2006), invasion of introduced species such as *Eucalyptus* spp. and *Pinus* spp. (Kull, 2003; Kull et al., 2005), diseases and predators (Grangeon, 1910). It may also be that quality characteristics of host plants at this site have declined due to all of these perturbations (Veldtman et al., 2007; White, 2008). The significant occurrence of *E. punctillata* may cause this decline of *B. cajani*. Grangeon (1906) and Paulian (1953) found two Limacodidae encountered in the *tapia* forest along with *B. cajani*. Our results show that *B. cajani* and *E. punctillata* are classified as frequent species in the *tapia* forest of Imamo. These two species are observed along the year and can therefore be considered as constant species of the *tapia* forest.

Anthropogenic pressures and threats currently affecting *tapia* forests may jeopardize the continuity and maintenance of all roles of this area: survival and reproduction of the species living in it will not be ensured. Therefore, the management and protection of the *tapia* forest

are essential. This management, which can be partly handled by the local community, must be based on rational exploitation of the forest. This would improve, on the one hand, the well being of the local population of the forest (*e.g.* through the revival of the silk industry) and, on the other hand, the conservation of biodiversity (including that of silk moths).

2.3.4. Population dynamics of the three silk moth species

Borocera cajani and *E. punctillata* are bivoltine and their life cycles are synchronous (**Figure 2.4**) at the study site. Similar voltinism have been observed for *B. cajani* under laboratory experiments (Paulian, 1953; Rakotoniaina, 2010; Razafimanantsoa et al., 2012, chapter 1), but no research has ever been conducted on the biology of *E. punctillata*. Because *B. marginepunctata* is very rare at the study locality, the number of generations per year could not be determined. Paulian (1953) suggested that this is a trivoltine species without pupal diapause. Additional research are clearly needed to confirm this hypothesis.

At our study site, the first generation of *B. cajani* was observed in early November, with first presence of eggs. It correlates with the period of high precipitation (**Figure 2.2**). In the southern Highlands of Itremo *tapia* forest (**Figure 2.1**), at a distance of approximately 300 km from Imamo forests, Paulian (1953) reported that the first generation of *B. cajani* is observed to start in September (confirmed in 2011 by pers. obs.). The life cycle of *B. cajani* therefore seems not to be synchronous in the different regions. However, climate charts of the two regions (1950-2009) (**Figure 2.2**) show that the Imamo zone is slightly warmer and wetter than the Itremo area throughout the year. While the rainy season in Ambatofinandrahana (Itremo area) starts in September to reach maximum precipitation in October, at our study site (Imamo area) the rainy season effectively starts in November. Both sites are at the same elevation. It seems therefore that adult emergence correlates with the rainy season period.

Eggs of *B. cajani* and *E. punctillata* were found from November to January for the first generation and from March to April for the second generation (**Figure 2.4A**). The peaks of abundance are observed in November (with up to 232 and 98 eggs/ha, for *B. cajani* and *E. punctillata*, respectively) and in March (with up to 225 and 24 eggs/ha, for *B. cajani* and *E. punctillata*, respectively). *E. punctillata* eggs were observed less than those of *B. cajani*, probably because they are laid singly while those of *B. cajani* are laid in clusters. *B. cajani* may also simply produce more eggs than *E. punctillata*. *B. cajani* and *E. punctillata* eggs occur only during the warm and rainy season. Rain triggers moth emergence (Houri et al., 2006). *B. marginepunctata* eggs were only observed in July.

Larvae of *B. cajani* and *E. punctillata* were observed two times from November to February and from March to June/July (**Figure 2.4B**). The number of first-generation larvae of both species peak in January (with up to 80 and 276 larvae/ha, for *B. cajani* and *E. punctillata*, respectively). For the second generation, *B. cajani* abundance peaks in April (with up to 175 eggs/ha) and in early June for *E. punctillata* larvae (with up to 227 eggs/ha). *B. cajani* larval abundance observed during the rainy season was found to be lower than during the dry season ($T_{obs} = 6.23$, $p < 0.0001$). *E. punctillata* larval abundance was found to be higher during the dry season ($T_{obs} = 5.8$, $p < 0.0001$). The differences in observed abundance between both generations of *B. cajani* are apparently not related to female fertility but should rather be connected to differential survival of the larvae. *B. cajani* and *E. punctillata* larvae lasts five weeks and seven weeks, respectively, for the first generation and 10 weeks for the second
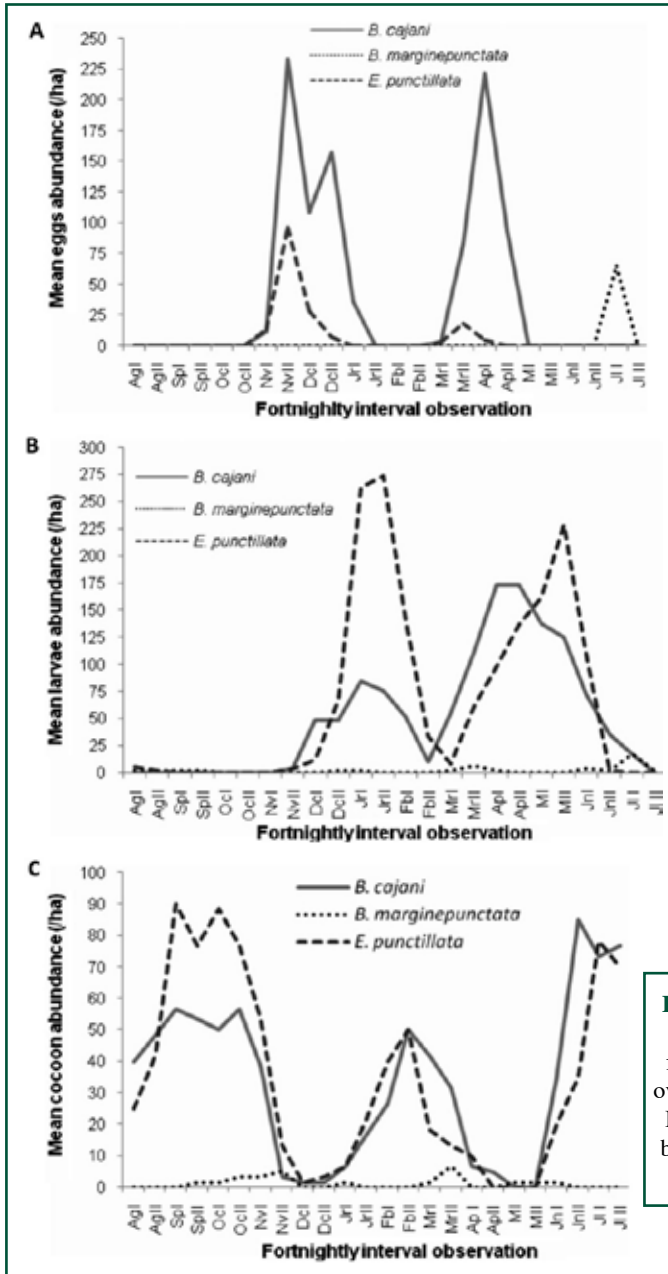
Figure 2.4. Mean abundance (per ha) of the three silk moths, by fortnightly interval observations, over one year of sampling. A. eggs; B. larvae; C. cocoons. Means are based on inventories conducted in six 1,000 m² transects.

generation. First-generation larvae of both silk moths occurs during the rainy season while most of the larval development of the second generation occurs during the cool and dry season. Temperature and humidity clearly positively affect the development of the larvae of both species. *B. marginepunctata* larvae were rarely observed: some larvae were observed at four periods of the year: September, December, March and June/July during the survey.

Chrysalid stages of *B. cajani* and *E. punctillata* reach maximum abundance in February (with up to 51 cocoons/ha for both species) and from July to Septembre (with up to 88 and 90 cocoons/ha, for *B. cajani* and *E. punctillata*, respectively) (**Figure 2.4C**). The few cocoons that were recorded between the peak of abundance, *i.e.* from November to January and from April to May, were all parasitized cocoons or dead ones. Chrysalids of the first generation (from February to March) of *B. cajani* ($T_{obs} = 10.27$, $p < 0.0001$) and *E. punctillata* ($T_{obs} = 9.7$, $p < 0.0001$) are less abundant than those of the second generation, from July to November. The first pupation period lasted 10 weeks for first generation but 22 weeks for the second generation. This difference is probably due to the nymphal diapause occurring during the cool and dry season. Low temperatures during the dry season cause diapause, consequently delaying emergence of *B. cajani* (Paulian, 1953), while higher average temperature and precipitation lead to early adult emergence (Mauchamp, 1988; Mouna, 1989). Ten weeks are probably needed for the nymph development of these Lasiocampidae. The number of cocoons observed during the survey is very low relative to the total number of larvae observed. Several factors may explain this difference including collection of cocoons by the locals and high mortality during the nymphal stage.

2.3.5. Silk moth host plants

Table 2.3 lists 12 host plants on which immature stages of silk moths were observed. *B. cajani* uses eight different host plants and *E. puctillata* uses 11 host plants. *B. marginepunctata* was only found on *U. bojeri* and *Maesa lanceolata* Forssk. **Figure 2.5** illustrates the relative proportion of bushes species used by immature stages of all species of silk moth in the Imamo forest.

Table 2.3. Identified host-plants of the three silk moth species found in Imamo forest.

Family	Genus	Vernacular name	Stratum	B.c	B.m	E.p
Phyllanthaceae	*Uapaca bojeri* Baill.	*tapia*	Tree	+	+	+
Aphloiaceae	*Aphloia theiformis* (Vahl) Benn.	*voafotsy*	Bush	+	-	+
Ericaceae	*Erica baroniana* Dorr & E. G. H. Oliv.	*anjavidy*	Bush	+	-	+
Primulaceae	*Maesa lanceolata* Forssk.	*voarafy*	Bush	-	+	-
Rubiaceae	*Psychotria retiphlebia* Baker	*mahatratranify*	Bush	+	-	+
Asparagaceae	*Agave rigida* Mill.	*taretra*	Bush	-	-	+
Sarcolaenaceae	*Leptolaena bojeriana* (Baill.)	*hatsikana*	Bush	-	-	+
Ericaceae	*Vaccinium secundiflorum* Hook	*voaramontsana*	Bush	-	-	+
Poaceae	*Aristida rufescens* Steud.	*horona*	Herbaceous	+	-	+
Poaceae	*Saccharum viguieri* (A.Camus) Clayton	*haravola*	Herbaceous	+	-	+
Poaceae	*Imperata cylindrica* (L.) P. Beauv.	*tenona*	Herbaceous	+	-	+
Poaceae	*Loudetia madagascariensis* Baker	*tsivongo*	Herbaceous	+	-	+

+ = presence; – = absence; B.c: *Borocera cajani*; B.m: *Borocera marginepunctata*; E.p: *Europtera punctillata*.

Beside the host plants listed in **table 2.3**, different host plant species were mentioned in the literature for *B. cajani*: *Dodonaea madagascariensis* Radlk. (Sapindaceae), *Schizolaena microphylla* H. Perrier (Sarcolaenaceae) and *Sarcolaena oblongifolia* F. Gérard (Sarcolaenaceae) (Rakotoniaina, 2010). The two last plants are only found in the Isalo *tapia* forest, situated in
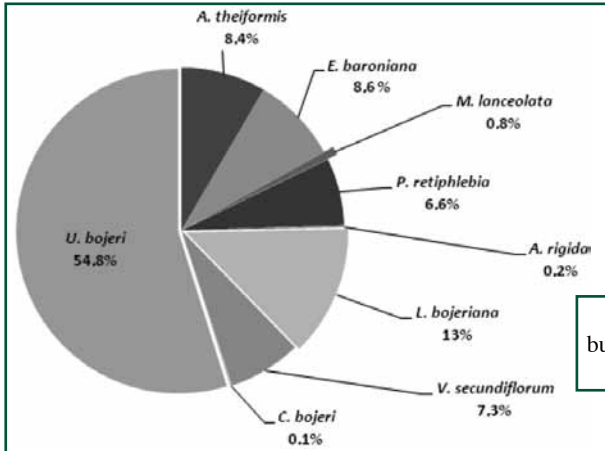
Figure 2.5. Relative proportions of bushes used as silk moth host plants in the *tapia* forest.

the southern region of Madagascar (Kull et al., 2005). Imamo *tapia* forests have, during the last decades, lost a significant proportion of their area. This observation does not match those of Kull et al. (2002; 2003; 2005) indicating either a stability or an increase in terms of *tapia* forest cover. However, their works are based on an analysis of aerial photographs between 1950 and 1990 (Rakotondrasoa et al., 2012, chapter 8). Although the assumption of *tapia* forest area regression deserves further study, degradation and deforestation in the *tapia* forest remain a major concern given its uniqueness and importance. Indeed, Imamo forest has been greatly damaged by bush fire practice and the lower stratum is reduced to trivial Graminaceae (Paulian, 1953, confirmed by pers. obs.). Conservation of *tapia* forest is essential as they have multiple functions: they can be a source of income (production of timber and non-timber forest products), they also play ecosystemic and socio-cultural roles (Rakotondrasoa et al., 2012, chapter 8). The *tapia* forest contributes about 7% of the local economy (Kull et al., 2005). Faced with the continued degradation of this resource, a multifunctional management of forest areas is needed which combines biodiversity conservation, and improvement of the living conditions of local populations.

Eggs of *B. cajani* were observed during very short period of time (**Figure 2.4A**), but were mostly seen on *U. bojeri* (with up to 225 eggs/ha) with very few being observed on *A. theiformis* (<1 egg/ha). Larvae were mostly concentrated on *U. bojeri* (maximal density reaching 112 individuals/ha) and on *A. theiformis* (40 individuals/ha) for the two generations. Most chrysalids were found on *U. bojeri* for both generations. Some chrysalids from the first generation were also observed on *P. retiphlebia*. During the second generation, they were also found on *A. theiformis* and on herbs including *L. madagascariensis*, *S. viguieri*, *A. rufescens*, *I. cylindrical*.

Eggs of *E. punctillata* were mainly deposited on *U. bojeri*. Few eggs were also found on grasses such as *A. rufiscens* and *S. viguieri* as well as on the shrub of *A. theiformis* in the second generation. Larvae and chrysalids of this species have different host habits than that observed in *B. cajani*. Larvae are often found on *U. bojeri* (peak density of 272 individuals/ha). Some individuals were also observed on *A. theiformis* in February. The chrysalid stage is observed on different host plants according to the period of the year. The first generation in March (rainy season individuals) prefers to spin cocoon on *U. bojeri*. However, the second generation of both species in June (dry season individuals) are on several host plants, including *U. bojeri* and herbs such as *L. madagascariensis* and *S. viguieri* as well as shrubs and bushes.

U. bojeri is one of the major tree hosts for the two moth species. The dominance and abundance of this species in the forest is probably the most important factor. Silkworms feed only during larval stage. *U. bojeri* is therefore proposed to be the preferred food source for the three species. However, *B. cajani* also feeds on *A. theiformis*, while *B. marginepunctata* feed on *M. lanceolata*. Observations outside the transect belt and near the villages showed that *B. cajani* also feeds on *Tamarindus indica* L., *Acacia dealbata* Link, *Psiadia altissima*. Both *B. marginepunctata* and *B. cajani* are observed on *Psidium guajava* L., *E. torquata*. *E. punctillata* is also considered as a pest devastating *Pinus* spp. (Raharizonina, 1974). The non-constant presence of *B. cajani* and *E. punctillata* larvae on other plants is the result of the female's oviposition behaviour. In addition, the tendency to oviposit on plants that cannot support larval growth is common among phytophagous insects (Krainacker et al., 1987).

2.3.6. Location on the host plant

The location of the eggs, larvae and cocoons on their host plant has been classified into three parts: the upper part with leaves and branches, the middle part corresponding to the trunk of the host plant, and the bottom part that corresponds to the base of the plant, the tufts of grass, litter and soil. Because too few *B. marginepunctata* were found, only data for *B. cajani* and *E. punctillata* are reported in **table 2.4.**

Table 2.4. *Brocera cajani* and *Europtera punctillata* location frequencies on their host plants.

	Stage	Generation	Frequencies (%)				
				Upper part		Middle part	Bottom Part
			Branch	B-LCx	Leaf	Trunk	Trunk at ground level
B. cajani	Eggs	1	72.1	0	27.9	0	0
		2	19.6	0	55.4	25.0	0
	Larvae	1	82.7	3.5	13.5	0.3	0
		2	81.0	4.9	10.9	2.5	0.7
	Cocoons	1	23.9	15.7	57.2	2.0	1.2
		2	23.9	0.4	45.2	19.2	11.3
E. punctillata	Eggs	1	91.7	0	0	0	8.3
		2	11.1	0	77.8	0	11.1
	Larvae	1	57.1	10.6	13.1	18.7	0.5
		2	81.5	5.5	0.5	10.3	2.2
	Cocoons	1	15.4	0	0	55.5	29.1
		2	13.4	0	0	33.1	53.5

B-LCx = branch-leaf complex.
Generations 1 and 2 correspond to the period when each stage of the species appeared until they disappeared. For the egg stage, generations 1 and 2 are successively November until December and March to May. Larval stage generation 1 is November to March and February to July for generation 2. Cocoons stage generation 1 and 2 is January to April and May to November.

Spherical eggs are deposited in a small cluster or as a mass (8-56) by *B. cajani* females and singly by *E. punctillata* either on the leaves, branches and trunks. They are stuck on different surfaces with the micropyle located on the lateral side. *B. cajani* eggs are mostly found on the upper part of their host plant for the two generations. They were observed exclusively on

branches (72.1%) and leaves (27.9%) during the first generation. For the second generation, 25% of the eggs were observed on the trunk of their host plant. The majority of *E. punctillata* eggs are laid on leaves during the first (91.7%) and second (77.8%) generation. Eggs were also found in the lower part on stems of herbs (11.1%), for the second generation.

Borocera cajani larvae were observed predominantly on branches of their host plants with high frequency (>80%). Larvae could also be observed on leaves (13.5% and 10.9% for the first and second generations). Low percentages were observed on the trunks (<3%). *E. punctillata* larvae were encountered on different parts of their host plants but they were frequently observed on branches (57.1% for the first generation and 81.5% for the second generation). In January and May, larvae stick on the point of attachment of the leaf on the branch, which in **table 2.4** is called 'branch-leaf complex'. Larvae are more easily detectable at that time.

Cocoons are preferentially found on leaves (57.2% and 45.2% for the first and second generation of *B. cajani*, respectively). Cocoons of the second generation of *B. cajani* were found in the middle and bottom part of the host plant. No cocoon of *E. punctillata* was found on leaves for both generations. The species prefers to spin cocoons on branches, trunks and bases of trunk at ground level. Caterpillars of the second generation move in the bottom part of their host plant to pupate. *B. cajani* and *E. punctillata* preferentially spin cocoons in small holes caused by the breaking of branches but also within the trunk.

Grangeon (1906) stated that most *B. cajani* larvae leave their food tree to spin their cocoons on neighbouring plants. In contrast, Paulian (1953) maintained that *B. cajani* larvae rarely leave their host plant for cocoon spinning. During the dry season, we found that some larvae migrate to spin their cocoons in tufts of grass. First-generation larvae of *E. punctillata* remain on their host plants but spin their cocoons in other plant stratum, especially tufts of grass. *E. punctillata* cocoons are hidden in the tufts of grass and the larvae incorporate soil and vegetation into the cocoon surface. This behaviour (preferring spinning cocoon on the lower part of the plant) is probably brought about by the lower temperature and humidity during the dry season.

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