Canopy arthropod biodiversity: a chronology of sampling techniques and results

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RESUMEN

ERWIN T.L. 1989. Biodiversidad de artrópodos en copas de árboles: cronología y resultados de las técnicas de muestreo. Rev. per. Ent. 32.—Se han desarrollado varios métodos para llegar a las copas de los árboles y efectuar muestras de artrópodos, teniendo el convencimiento que en los bosques tropicales en dicho hábitat se encuentra un inmenso número de especies nuevas para la ciencia, lo mismo que tantos procesos ecológicos que necesitan ser estudiados. Se hace una revisión cronológica de la literatura al respecto y se dan recomendaciones para los estudios de artrópodos de las copas de árboles, que están en sus comienzos. Se incluyen observaciones sobre la fauna de la copa de los árboles y debajo de ella, efectuadas por la técnica de la nebulización.

Palabras clave: Artrópodos de las copas de los árboles, artrópodos de los bosques, técnicas para coleción de artrópodos en árboles.

SUMMARY

ERWIN T. L. 1989. Canopy arthropod biodiversity: a chronology of sampling techniques and results. Rev. per. Ent. 32.—Following the recognition that the tropical forest canopy held untold numbers of species new to science and ecological processes that needed to be studied, various forms of sampling and canopy access have been developed. The literature on these is reviewed chronologically and recommendations are given for those beginning canopy arthropod studies. Observations on canopy fauna of canopy and undercanopy sampled by the fogging technique are given.

Key words: Canopy arthropods, forest arthropods, techniques to collect canopies’ arthropods.

INTRODUCTION

Henry Walter Bates clearly understood insect radiation in the tropical forest canopy during his 11 years in the Amazon (1832–1843). He wrote of Agaia (Bates 1884) the following: “...this remarkable genus, in which the arboreal type of the family Carabidae reaches its highest development...their head quarters are the great forests near the equator in South America, the numbers diminishing on approaching the tropical limits north and south”. William Beebe (1917) was also attracted to the ‘unknown’ of the tree tops and built platforms to observe jungle life there. Though Bates pondered canopy life from the ground and Beebe ascended to watch vertebrates, it was more than half a century later that serious studies began on arthropod life in the last biotic frontier (Erwin 1983a).

Only in the last three decades has collecting arboreal species or sampling them for various types of ecological studies been other than felling of trees or the use of malaise and sticky traps hoisted into the treetops with ropes. Martin (1966) used hydraulic spraying to sample the insect fauna of pine trees in Canada, and Kikuzawan and Shidei (1966) used “smoking” techniques on a Japanese forest, thus opening an era in which further canopy exploration revealed unanticipated numbers of species, most of them new to science (Erwin 1982).

In the last 15 years, it has become abundantly clear that tropical tree canopies are extremely rich in insect and related arthropod species (Roberts 1973, Wolda 1979, Erwin and Scott 1980, Erwin 1981, 1982, 1983; Stork 1987a, 1987b; Farrell and Erwin 1988, Noyes 1989). Erwin and Scott (1980) and Erwin (1981) first reported on the incredible numbers of coleopterous species found in tropical canopies based on sampling of the tree species Luehea semianulata Titiina and Planche (Tiliaceae) in 1974 in Panama and Wolda (1979) reported on the richness of Homoptera in these same trees. Subsequent papers by Stork (1987a), Farrell and Erwin (1988 in press), and Kay and Miller (in prep) report on various aspects of tropical canopy insect species using fogging methods refined by Erwin (figs. 1, 2, 3); however, thus far only Erwin (1983) documented the methodology underpinning this technique, though until now only partially so, and Adis et al. (1984) and Stork (1988) have

offered critiques the method. Gayne (1979) and Southwood et al. (1982b) have documented hydraulic spraying techniques and Hijii (1983, 1989) provides an extensive bibliography on Japanese efforts at canopy studies using the “smoking” technique. Although the hydraulic spraying and smoking methods are similar to true fogg ing techniques in that they disperse insecticide into the canopy, they have severe limitations in acquiring anywhere near the total fauna even with cumbersome aids (Afreh-Nuamah and Thornhill 1988, Hijii 1986). In tropical forest situations, they are not at all useful because of crown architecture, overlapping branches of different tree species, and density of epiphytes. Hydraulic spraying does not penetrate well all the niches and crevices nor even the center of densely foliated trees, and “smoking” is only good for small, densely-leaved trees such as conifers, and as Hijii (1986) has shown it works better with tented trees, a technique impossible to use in tropical forests with 55 to 70 m high trees, usually interdigitated with others.

The purpose of this paper then is to detail the true fogging method and its history, in addition to reviewing other methods that have been used for sampling arboreal arthropods in both the tropical and temperate zones. I also provide observations on the composition of the general tropical forest canopy insect fauna and its behavior when collected with true fogging methods, as well as documenting uses to which the material from canopy samples have been put, or might be put.

METHODS OF SAMPLING CANOPY ARTHROPODS: A CHRONOLOGY

Collecting from tree canopies previous to Martin’s work mostly involved arboreal traps or destructive techniques, including felling of trees. On the other hand, Stecker (19xx) built an elevator on the side of a Giant Sequoia in California and worked inside the canopy to study insect biology associated with the tree, foreshadowing Perry’s tree-climbing techniques in Costa Rica by xx years.

In order to assess the flight patterns of pathogene carrying bark beetles, Merrill and Skelly (1968) sent a modified window flight trap (Chapman and Kinghorn 1955) above the main canopy of an oak-pine forest in Pennsylvania with ropes and pulleys. Eighteen families of Coleoptera were collected; other material was discarded. In 1981, Novak et al., reported their use of suction traps and human bait located on a canopy-elevation tower in a forest in Indiana to sample mosquitoes. Their work was proceeded by others who invented or improved the suction traps (Taylor 1951, Johnson and Taylor 1955, Horsfall 1961) and continued a tradition of studies of vertical stratification of mosquitoes using other means (Bates 1944, Snow 1955, 1975; Love and Smith 1958, Scholl et al. 1979). Removal of parts of the forest canopy to assay the insect species has been used by several investigators, for example climbing and pruning (Ohmart et al. 1983), pole pruning after aerial spraying of insecticide (Martinat et al. 1988), general pruning (Hunter 1987, Verghese et al. 1988), clipping shoots in lower canopy (Kidd and Tozer 1983), or just picking leaves with miners (Wanjala 19xx). Beating sheets used under lower canopy leaves (Futuyama and Gould 1979) and accumulated debris in lower branches is a common collecting technique of many collectors, but Salman and Lowman (1983) restricted their beating to Antarctic Beech buds at night for a study of leaf beetle biology in a rainforest of New South Wales, Australia.

J L Martin (1966) and Gagne and Martin (1968) studied insect ecology in red pine plantations of Ontario, Canada. Their samples were obtained through the use of a hydraulic sprayer using pyrethrum insecticide. Martin seems to be the first to systematically study an intact forest canopy arthropod fauna. Cunningham and Harper (1977) applied insecticide to the canopy from an airplane and used suspended funnel traps for sampling the fallout.

SAMPLING WITH INSECTICIDAL FOGGING TECHNIQUES

A brief history of the fogg ing method is given in Erwin (1983a) and those aspects will not be repeated here. Roberts (1973) was the first to use a machine (1966 and 1967) which dispersed a true insecticidal fog (droplets of 5 microns in diameter of dichlorvos [DDVP] with great penetration powers. Knowing that many tropical Acrididae (Orthoptera) are arboreal, Roberts collected by using a small Aero-Dyne fogger to disperse insecticide into the tropical forest canopy on the Osa Peninsula of Costa Rica by pulling the machine up on rope with a pulley fastened in a tree. Many Orthoptera were collected and noted by Roberts, but the rest of the material was discarded or not labelled adequately for retrieval as canopy-derived specimens. In 1971, Gagne used a Dynafogger with pyrethrum synergized with piperonyl butoxide to capture Hawaiian forest arthropods in cloth funnels. His pioneering work was not reported until later in Gagne (1979). The problems associated with fogging tropical canopies through 1984 for ecological studies were associated with an inability to acquire samples from individual tree species. However, this was
FIG. 1: The Dynafogger used from the ground at dawn puts fog into the tops of 30 m high trees regularly due to the warmth of the insecticide and cool temperature near the ground.

FIG. 2: The use of pulleys and ropes in the past allowed fogging of trees higher than 30 m, but control of the fogger was difficult.

FIG. 3: Cloth trays suspended from ropes tied between trees were used in studies in southeastern Peru.

not the purpose of the studies in Tambopata, Peru, the most ambitious undertaking thus far using the fogging technique (Erwin 1983). Because the samples were not made in a way that species restricted to specific plant species could be detected, their use for analysis is limited, that is they are similar to undercanopy or field sweep samples (Janzen, pers. comm.). In attempting to analyze the data from those studies, it became clear that statements about the fauna and its relationships with the environment were going to be limited, but generally useful (Farrell and Erwin 1988, Farrell and Erwin, in press) for faunal descriptions. Earlier attempts to fog single tree species (for example, in 1974, Lubin and Montgomery's fogging of *Luehea seemannii* (see Erwin and Scott 1980, Wolda 1979) were difficult to control for specimens from leaves of other trees because of the use of large plastic sheets suspended near the ground that collected general insect rain. Interdigitated branches of *Luehea* and other trees likely yielded mixed samples. Erwin and Farrell (in prep.) eliminated this problem with newly designed sampling funnels and careful placement of these under branches of target species which did not interdigitate with other trees nor have epiphytes (see below and fig. 1). Thus, enough pure samples for several tropical tree species were obtained and these can be treated statistically.

Another problem faced by canopy researchers has been accessibility to high canopies and super-emergents such as *Ceiba, Clarisia, Calophyllum*, and *Bertoletia*. Stork (1987), using the pulley methods of Erwin in Peru (fig. 2), collected from the tops of high Dipterocarps in Suluwesi, but problems of breezes drifting the insecticide and mixed samples from epiphytes with the trees remained a problem. Erwin, Farrell and Tobin eliminated this problem in 1989 at Pakitza, Peru, by establishing climbing ropes in emergent trees, climbing the ropes and dispersing the fog from within the upper canopy itself at dawn (fig. 4, and see below) and later at Pacaya-Samiria National Reserve, Peru during the day. With the use of the funnel collectors described below and rope-climbing techniques, it is possible to collect samples from the leaves, branches, and trunks of
any tree and have virtually uncontaminated samples. In this way, host specificity of insects can be ascertained with certainty given a rigorous research plan and sufficient samples. Rope-climbing techniques even provide access for habitat manipulation experiments such as continuous removal of arthropod faunae from single branches, but not adjacent ones. A combination of good canopy access and directed fog dispersal must be combined with efficient collecting trays.

Collecting Trays

Peterson (1934), Connola et al. (1966), and Southwood (1966) all described drop traps for use in collecting arthropods. The evolution of collecting surfaces for fogging began with Gagne’s cloth funnels in 1971, but plastic sheets laid out on the ground were used by Roberts (1973) and the same, tied with strings to trees, by Lubin and Montgomery (cf. Wolda 1979, Erwin and Scott 1981). Subsequently, suspended funnel traps were designed (Cunningham and Harper 1977, Erwin 1983) and these evolved to maximize efficiency and minimize hazards to the specimens collected. Several generations of suspended tray design and tests have past (see also Kay and Miller, in prep). The present system used by Erwin and Farrell (fig. 5) employs aluminum sheets cut so they can be folded into funnels with a collecting area of 0.25 m²; they are also pre-drilled so that a three string harness can be tied on for suspension over water for sampling flooded forests (e.g. fig. 3, although the tray in the photo is of an earlier design). After folding the aluminum sheet funnel-form and interlocking the edges, a nalgene bottle cap with the center bored out is attached to the neck. These funnels are easily stacked and carried in 10’s into the forest site where trees have been selected for sampling. For installation, plastic stakes with flat beads are center-drilled and a plastic cup is attached with a screw. This cup fits the nalgene bottle attached to the bottom of the funnel. These stakes are hammered or pushed into the ground at desired locations. Just before fogging, nonneck bottles are attached to the funnels, filled to one third with 70% ethanol using a garden pressure sprayer, and the bottle with funnel is inserted into the cup on the stake (fig. 5). If dry material is desired, an egg carton (24 egg type) can be laid across the mouth of the funnel (Pogue, per comm; fig. 5). After the usual 2 hours of drop time, desired dry specimens are taken off the egg carton with forceps or putter, the rest dumped into the funnel. Funneis are then washed down with the garden sprayer (70% ethanol) and the bottles detached and capped for study in the lab. This method results in specimens appropriate both for the ecologist and the taxonomist leaving the specimens in excellent condition for museum collections at the termination of the study.

Insecticides

The number and types of insecticides used by canopy researchers in nearly as numerous as the studies, however, except for experimental studies (e.g. Martina et al. 1988, Afreh-Nuamah and Thornhill 1988), collectors and ecologists have used pyrethroid-based chemicals with knock
down agents. Pure pyrethrum with piperonyl butoxide as a knock down agent was used by Roberts (1973), Gagne (1979), Erwin and Scott (1981), Erwin (1983b), Adams et al. (1984). In my studies, begun in Peru in 1981 (Erwin 1983), a change was made to use the cheaper and highly effective synthetic pyrethroid chemical, Resmethrin, or “Cross Fire” trademark (now called “Respond”). Stork (1987) and Paarman and Stork (1987) used Reslin E, similar to Resmethrin, but with high knock down and low kill properties. They even recovered and bred fogged specimens. Observations from field tests in Peru between the two versions of synthetic pyrethroid sprayed on adjacent trees at the same time on the same day indicated that Resmethrin was the more effective of the two chemicals and more reliable for extracting canopy fauna.

TABLE I. Total numbers in rank order of selected taxonomic groupings and percentages of a sample of Arthropods from an isolated canopy of Hirtella triandra (Chrysobalanaceae) and Matina cordata (Bombacaceae) with 11 unidentified lianas (size classes of stems = 0.02 to 0.09 cm dbh) reaching the intertwined tree crowns. No epiphytes were visible from the ground with a 5×8 binoculars. Approximately 2/3 of the total catch are reported in this table.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Number of specimens</th>
<th>% of total</th>
</tr>
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<tbody>
<tr>
<td>Formicidae</td>
<td>57,322</td>
<td>69.6</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>7,523</td>
<td>9.1</td>
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<tr>
<td>Psocoptera</td>
<td>3,314</td>
<td>4.0</td>
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<td>Diptera</td>
<td>2,062</td>
<td>2.5</td>
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<tr>
<td>Collembola</td>
<td>1,839</td>
<td>2.2</td>
</tr>
<tr>
<td>Araneae</td>
<td>1,647</td>
<td>2.0</td>
</tr>
<tr>
<td>Homoptera</td>
<td>1,581</td>
<td>1.9</td>
</tr>
<tr>
<td>Acari</td>
<td>1,405</td>
<td>1.7</td>
</tr>
<tr>
<td>Orthoptera</td>
<td>1,285</td>
<td>1.6</td>
</tr>
<tr>
<td>other Hemiptera</td>
<td>1,207</td>
<td>1.5</td>
</tr>
<tr>
<td>all larvae (not nymphs)</td>
<td>805</td>
<td>1.0</td>
</tr>
<tr>
<td>Hemiptera</td>
<td>770</td>
<td>0.9</td>
</tr>
<tr>
<td>Thysanoptera</td>
<td>704</td>
<td>0.9</td>
</tr>
<tr>
<td>Pseudoscorpiones</td>
<td>614</td>
<td>0.7</td>
</tr>
<tr>
<td>Lepidoptera</td>
<td>147</td>
<td>0.2</td>
</tr>
<tr>
<td>Neoptera</td>
<td>51</td>
<td>0.06</td>
</tr>
<tr>
<td>Myriapoda</td>
<td>30</td>
<td>0.04</td>
</tr>
<tr>
<td>Dermaptera</td>
<td>26</td>
<td>0.03</td>
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<tr>
<td>Scorpiones</td>
<td>15</td>
<td>0.018</td>
</tr>
<tr>
<td>Embioptera</td>
<td>14</td>
<td>0.016</td>
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<tr>
<td>Isoperta</td>
<td>14</td>
<td>0.016</td>
</tr>
<tr>
<td>Thysanura</td>
<td>11</td>
<td>0.013</td>
</tr>
<tr>
<td>Tricoptera</td>
<td>4</td>
<td>0.003</td>
</tr>
<tr>
<td>Odonata</td>
<td>2</td>
<td>0.002</td>
</tr>
<tr>
<td>Total</td>
<td>82,391</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Based on many years of fogging experience, I offer here observations of a general nature on the canopy arthropod fauna that might be useful to those planning to use such techniques in the tropics.

As noted by Roberts (1973), wind currents are an important factor in the effect of insecticide on the canopy fauna. It is necessary to fog at dawn, when there is usually no air movement, for effective penetration of all parts of the canopy and consistently reliable results. Near rivers or on ridges, however, even at dawn there can be problems. In 1990, in Pacaya-Samiria National Reserve, I made effective use of the fogger at all times of the day and before dawn in the lower canopy, but only with tree climbing techniques was I able to fog high canopies during the day. On cold mornings, I have put fog into tree crowns up to 55 m from the ground, but microclimate is fickle. This is not recommended as a usual method of sampling.

Immediately after the fog strikes the leaves or trunk area, ants begin to drop, as they are highly affected by “Respond.” Carabidae and other beetles drop over a period of 30-45 minutes, larger Orthoptera usually take longer to succumb to this insecticide. After two hours, there is virtually no arthropod left in the fogged area. In Tambopata (1982-1885), various follow-up tests were made (branch shaking, refogging, second two hour drop collections, etc) and almost nothing was recovered by any tests. Therefore I conclude that the two hour effectiveness of the insecticide as advertised is in effect in tropical faunas as well as temperature. Interestingly, both at Tambopata and Pacaya-Samiria, refogging after 10-30 days resulted in as big an insect rain as the original fogging (12 tests of large trees, 5 tests of suspended dry leaves in the undercanopy). My conclusion is that the arboreal fauna is highly mobile, at least on a local level, and the canopy and subcanopy are virtual horizontal highways across which mass daily movement takes place.

All groups of insects fall using “Respond” with the noted exception of female scale insects (Coccidae). The nature of the tropical beetle fauna has been characterized by me elsewhere and need not be repeated here (see above). Adams et al. (1984) and Stork (1987) have contributed information also on the general nature of tropical canopy arthropod fauna. Through seasonal sampling regimes it is possible to register species normally living inside the wood or bark because at some point in time they disperse and lay eggs on the surface. Large butterflies are uncommon in dawn foggings of the canopy and for years I thought they were escaping the fog. With recent undercanopy fogging experience in Pacaya-
Samiria, it can now be stated that large butterflies do not escape the fog, rather they roost in the undercanopy at night and are not subjected to canopy fogging at dawn. This is not true for Lyscaenidae, which are common in dawn fogging samples from the canopy.

Myrmecophilous insects are plentiful in all tree sampled which had large ant populations; fogging is a recommended method for obtaining these. Arthropods which occur in bromeliads are also easily obtained; the action of the insecticide kills by interrupting synapses and the spams during this process virtually drive the dying arthropod up and out of the leaf axil. This seems to be true for all crack and crevice arthropods in the canopy too. Table I shows percentages of arthropods collected from an entire canopy footprint (1000 sq feet) of a single isolated canopy (two tree crowns interdigitated with 11 lianas at height of 33 m and a diameter of 11 m) at Pakitza, Peru (Erwin, in prep). It is clear that all expected groups were sampled. Further analysis of this material and others will indicate whether or not faunal balance is consistent among communities of different species and different individuals of the same species (Erwin and Farrell, in prep.).

Certainly, when compared with faunae of the mid-Amazonian igapo near Manaus, where various taxa annually migrate into tree canopies from flooded soils (Adis 1988), dominance of groups varies considerably from site to site.

In all studies to date, it has become abundantly clear that biodiversity is far more than a list of species. Patterns of occurrence and dominance even on a local level are highly variable. Many areas need to be sampled before we will have estimates within an order of magnitude of arthropod biodiversity on this planet. However, current modern methods of canopy sampling will aid greatly in this endeavor, as the canopy is clearly where maximum tropical biodiversity occurs.

Acknowledgements

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Literature cited


