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CANOPY FOGGING OF AN OVERSTORY TREE – RECOMMENDATIONS FOR STANDARDIZATION

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Abstract. Recommendations are given for canopy fogging of a single, 'regular' overstory tree in the middle of a forest with respect to (1) the tree, (2) the fogging set-up, (3) the fogging machine, (4) the insecticide, (5) the collecting set-up, (6) the collecting trays, (7) the fogging procedure, and (8) the collecting procedure. *Accepted 27 July 1998.*

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CANOPY FOGGING: A SHORT REVIEW

Sampling of canopy arthropods with an insecticidal fogging machine was first attempted by Roberts (1973) in Costa Rica and by Gagné (1979) in Hawaii. A history of insecticidal fogging was given by Erwin (1983, 1989). Studies within the last 25 years focussed first on faunal composition and species richness of insects in the canopy of tropical forests and on the estimation of species numbers worldwide (cf. Erwin 1982, Stork 1988). Recent investigations are aimed, for example, at community structure, faunal similarity, species turnover, host specifity, recolonization dynamics, species loss and mechanisms which maintain tropical diversity. An overview of some field projects and methods applied are found in Erwin (1995) and Stork *et al.* (1997a). The commercial fogging machines currently in use are: Dyna-Fog/USA (e.g., Erwin 1983), SN11 Swing Fog/UK (Jaydon Engineering, Sutton/Surrey; e.g., Stork & Hammond 1997) and Swingfog SN50/Germany (Montan Swingtec, Isny; e.g., Adis *et al.* 1997). Fumigation, mist and smoking techniques were employed by Kitching *et al.* (1993), Kikuzawa & Shidey (1966), and Watanabe (1977). A variety of insecticides have been used and their knockdown potential is mostly unknown (cf. Erwin 1989, 1995; Adis *et al.* 1997, Floren & Linsenmair 1997). The widely utilized but expensive 'pure' or 'natural' pyrethrum with piperonylbutoxide as a synergist (cf. Kitching *et al.* 1993) has been replaced by cheaper synthetic pyrethroid chemicals which are now available (e.g., 'Resmithrin' (also called 'Respond'), Reslin E; cf. Erwin 1989, Stork 1991). The use of natural pyrethrum without synergist enables collection of live arthropods from tree canopies and makes habitat manipulation experiments possible (Paarmann 1994, Paarmann & Kerck 1997). Tree canopies were either fogged from the ground (cf. Erwin 1989), by hoisting the fogging machine with a rope and pulley system into the tree crown (cf. Erwin 1983, Basset 1995, Basset *et al.* 1996), by climbing into the tree crown (cf. Erwin 1989, Floren & Linsenmair 1997) or the insecticide was sprayed from the air by plane or helicopter (cf. Cunningham & Harper 1977, Watanabe 1997). Falling arthropods were intercepted by plastic sheets laid out on the ground (e.g., Roberts 1973), by bed sheets, plastic trays, cloth or nylon funnels suspended on ropes between tree trunks near the ground and by dismountable aluminum funnels placed on the ground (on top stakes) and into the canopy (e.g., Erwin 1983, 1989; Adis *et al.* 1984, Stork & Hammond 1997). Drop time of falling arthropods varied between one and three hours. In conclusion, most research groups developed their 'own' methodology,

* Dedicated to Dr. Hans Klinge on the occasion of his 70th birthday.

FIG. 1. A cloud of natural pyrethrum fog is produced by a fogging machine at dawn and rises through the canopy of a 45 m high *Goupia glabra* Aubl. (Celastraceae) in a primary upland forest of Central Amazonia near Manaus, Brazil. Photo J. Adis.

therefore the comparison of data is difficult and standardization of canopy fogging is required (cf. Stork & Best 1994, Erwin 1995).

RECOMMENDATIONS FOR STANDARDIZED FOGGING OF AN OVERSTORY TREE

Canopy fogging procedures have to be designed around the basic and/or applied research question aimed at, e.g., prey-predator interactions, recolonization patterns, faunal structure with regard to contrasting tree phenologies (in full flush, flowering, with fruits), the diversity of the arboreal system, etc. (see also Stork *et al.* 1997b). Fogging procedures also have to be adjusted to the type of canopy being investigated, e.g., several trees or tree species, one single tree, its branches, the upper or lower canopy, shrubs, etc. (see also Erwin 1989, 1995). According to Erwin (pers. comm.), fogging is simply a specimen/data gathering device. As with any other sampling method, first ask your research question, design your protocol, lay out your analysis method (replications, statistical procedures) and then collect and process your data (cf. Erwin 1997).

The premises for this paper, set during a workshop on 'Protocols and Data Processing' of the ESF Scientific Programme on Tropical Canopy Research (Sant Feliu de Guixols/Spain, December 1996) was to elaborate recommendations for standardized canopy fogging of a single, 'regular' overstory tree in the middle of a forest.

What to do.

The tree. Select a single overstory tree of a common species (to enable replications) in the middle of the study area with leaves, no flowers, no fruits, few epiphytes/liana and the crown barely overlapping with neighboring trees. Measure the diameter of the trunk at breast height (dbh) and of the crown, estimate the height of trunk and crown (clinometer, ballons, measuring rod). Give as many details as possible on the tree selected, e.g. at what height ramification starts, the amount of old/new leaves and of dead wood in the crown, the structure of bark, color and odor of wood, viscosity of resin/latex, etc.

The fogging set-up. Select a high branch in the tree crown and shoot a fine, resistant nylon (fishing) line over it. Use a line-throwing gun ('E-Z Liner', Specialty Products Company, Box 398B, Queenstown, MD 21658/USA), crossbow, bow and arrow or sling with a lead weight. Attach a strong nylon rope (diameter 10-12 mm) to the end of the nylon line and pull it back over the branch. Attach a pulley to the end of the nylon rope ('pulley line') and run a second strong nylon rope ('fogger line') through the pulley. Secure both ends of the fogger line, pull both fogger and pulley line into the canopy and tie their ends to tree trunks. Use the fogging line to hoist the fogging machine into the canopy. Set up a second rope and pulley system at a different spot in the tree crown (cf. Erwin 1983). For better orientation and control of the set-up, climb into the tree several days before fogging.

The fogging machine. Use a commercial fogging machine (see above; also enquire with local malaria

control agencies) and install a radio control to enable release of the insecticide in the crown from the ground.

The insecticide. Use a 1.0% solution of natural pyrethrum without synergist diluted in a highly refined white oil (e.g., Shell Ondina or Risella, Essobayol 82; cf. Floren & Linsenmair 1997, Paarmann & Kerck 1997).

The collecting set-up. Put up a 'spider web' of nylon ropes (diameter 8–10 mm) tied about head-height under the tree crown several days before fogging (only moderate cutting of understorey plants where necessary). Try to cover ≥75% of the canopy leaf area and place at least 18 (+2 spare) collecting trays on the ropes, secured by clothes-pegs, up to several meters distance from the tree trunk (cf. Adis *et al.* 1997), avoiding crown gaps (non-random distribution). To monitor possible wind drifts, set up additional ropes in each of the four compass directions from the tree trunk and place two trays on each rope twice and three times as far from your 'spider web'. Make a scale drawing of the tray arrangement under the canopy and note the distance of each tray from the tree trunk. Mark the position of each tray on the rope with a sticky tape, remove all trays and store them on the study site (protected from rain) until the day of fogging (cf. Adis *et al.* 1997, Stork & Hammond 1997).

The collecting trays. Use funnel-shaped trays (1m² in area) made of a smooth, tough, silicon-coated nylon (parachute) fabric which is held by a ring of dismountable aluminum tubing. Tie three nylon cords to the aluminum ring and their other ends to a knot which holds a detachable plastic clip or wire hook for tray suspension from the 'spider web' rope. Attach a numbered polyethylene bottle (500 ml, opening diameter: 4–5 cm) filled about one third with 70% ethylene alcohol (or with textile gauze in case of biomass studies) to the funnel outlet. Screw the bottle into its hollow plastic lid (centre disk removed) which is tightly fixed at the funnel outlet with a PVC tension-strip and screws. Permit overflow of accidental alcohol or rainwater by a fine nylon gauze (200 mm, 6 x 3 cm) sewn into the funnel fabric near its outlet (cf. Stork & Hammond 1997).

FIG. 2. Funnel-shaped collecting trays are suspended from a 'spider web' of nylon ropes under the tree crown of *Goupia glabra* Aubl. (Celastraceae) in a primary upland forest of Central Amazonia near Manaus, Brazil. Photo J. Adis.

Fogging procedure. Start to set up your trays on the experimental site and prepare the fogging machine at least one hour before fogging (normally at dawn). Recheck the strength of your fogging lines. Make sure that all trays are clean and dry shortly before fogging. Start and hoist the fogging machine into the tree crown with your rope and pulley system (normally as soon as the upper canopy becomes visible from the ground at dawn). Release the fog for 10 minutes in the lower canopy region (radio control). Direct the fog to all parts of the tree crown by rotating the fogging machine 180° by the rope from which it is supended (or by a hand-held line attached to the exhaust end of the machine). If the ascending fog (chimney effect) does not reach most parts of the canopy, stop fogging after 5 minutes and use the second fogging line installed in the tree crown to continue fogging for the remaining 5 minutes. Note down the hour when you started and finished releasing the fog, how your machine worked (strong/weak fog) and wind conditions (cf. Appendix in Stork & Hamond 1997). Measure the temperature and humidity of the air near the ground before and after fogging. Use a respirator during canopy fogging and take a shower afterwards.

Collecting procedure. Control all nylon ropes of your collecting set-up after fogging to avoid immigration of arthropods from the ground and tree trunks (ants, termites) into your trays. Allow a drop time of 2 hours. Tap the side of each tray gently to aid the drop of arthropods into the plastic bottle before you wash the remaining specimens down the funnel wall with 70% alcohol using a mechanical garden sprayer. Remove the numbered bottles and transfer the arthropods to fresh alcohol in the laboratory. In case of biomass studies, kill and store your living specimens in a freezer.

What not to do.

(1) Never fog a tree which covers a dense understory, search for a better site.
(2) Never fog wet leaves (after nightly rainfall, dense haze) or when it is windy.
(3) Never use a non-nylon material as line for the fogging machine.
(4) Never stand directly under your fogging machine while fogging the canopy.
(5) Never use DDT, non-arthropod specific or slow decomposing insecticides as fogging agent.

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