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Sampling forest canopy arthropod biodiversity with three novel minimal-cost trap designs

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Abstract Sampling arthropods in the upper canopy of tall trees presents a range of challenges associated with portability, cost, placement, replication and collection. Detailed schematics and instructions are presented here for three trap designs: sticky CD cases, plastic bottle hanging flight-intercept traps and drink bottleneck funnel crawl traps. By using simple and salvageable materials such as plastic drink bottles and compact disc cases, the financial cost of an arthropod sampling regime in the crowns of old-growth Tasmanian stringybark trees *Eucalyptus obliqua* (L'Herit) was kept to a minimum. The traps collected comparatively diverse communities: the sticky traps catching high levels of Diptera, Hymenoptera and Coleoptera; the funnel traps catching Diptera, Hemiptera and Coleoptera; and the hanging traps catching Diptera, Coleoptera and Lepidoptera. The sticky traps were ranked best, and the funnels worst, when integrating relative merits of cost, transport, durability, construction, placement, retrieval, sorting and arthropod condition.

Key words bark sampling, *Eucalyptus obliqua*, malaise flight-intercept trap, sticky trap, trunk crawl trap.

INTRODUCTION

The composition of arthropods associated with forest canopies is of concern and interest to scientists studying global biodiversity (Stork *et al*. 1997; Basset *et al*. 2003). However, sampling the insect fauna associated with tall trees presents a range of challenges associated with access, efficacy, financial cost, transport and replication. An emerging trend in canopy studies is the use of multiple sampling methods (Hosking 1979; Basset *et al*. 1997). A variety of passive traps which integrate samples of the fauna over time have been widely used and specific strengths and weaknesses are associated with each (Basset *et al*. 1997). There is a need for improved, low-cost, portable traps which can be secured and retrieved efficiently, in order to generate useful datasets for comparative studies.

This paper describes three low-cost sampling methods and reports data that demonstrate their comparative efficacy. Novel designs of passive sticky traps (hereafter 'CD traps'), bark surface funnel intercept traps ('funnels') and hanging flight-intercept traps ('hangtraps') are illustrated, along with advice on design goals, plans, transport and placement. We concentrate on the financial and time costs for construction, placement and initial processing of the samples, but not on other (usually much greater) costs such as those associated with canopy access, site transport, taxonomic resolution or personnel retention. All traps were built for less than A$1 per unit using widely available materials. The biodiversity and composition of the collected arthropods from eight ~450-year-old *Eucalyptus obliqua* (L'Herit) is broadly compared between the three designs.

Sticky traps are relatively inexpensive and simple to construct, but are messy and generally yield poor quality specimens (Basset *et al*. 1997). However, they may yield more specimens of Coleoptera than other traps (Chenier & Philogene 1989). Bickel and Tasker (2004) used sticky traps to target Diptera associated with *Eucalyptus* trunks in New South Wales. A compact casing was required to carry a surface painted with sticky coating into the tree crown without allowing the coating to come in contact with other objects, while also allowing protection of the collected specimens during transport to the ground. Sticky traps target animals landing on tree surfaces, as do the flight-intercept traps used by Majer *et al*. (2003).

The funnel crawl traps target animals walking on the tree surface in any direction and are based on the designs of Majer *et al*. (2003) and Hanula and New (1996). Trunk mounted funnels have previously been used to collect animals walking

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upwards (Majer *et al*. 2003) or downwards. The design described here can also be used to capture animals moving horizontally on branches. Hanula and New (1996) found that 'drift fences', or walls, leading into the funnels increased trap yield. Majer *et al*. (2003) used a portable angle grinder to create a mounting groove for a plastic fence. A technique for mounting a drift fence that could be anchored to the irregular stringy bark of *E. obliqua* with a minimum of equipment carried into the tree crown was required.

The hanging flight-intercept trap designs were based on the hanging traps illustrated by Wilkening *et al*. (1981). Unlike sticky traps, or flight-intercept panels mounted parallel to the trunk surface (Majer *et al*. 2003), which are designed to capture animals landing on tree surfaces, these traps sample animals moving through the airspace within the crown.

The wet *Eucalyptus* forests of south eastern Australia include some of the tallest trees in the world (Hickey *et al*. 2000; Mifsud 2003). Access to the crowns of the dominant forest trees may involve climbing above 70 m. In addition, the sclerophyllous evergreen canopies are sparsely foliated and are exposed to high levels of both heat and wind stress. Therefore, we developed lightweight, robust trap designs which can be placed in position efficiently and that may also be useful in other habitats.

Canopy arthropod biodiversity sampling in *Eucalyptus* trees has generally been conducted using insecticide fogging (Majer *et al*. 2000; Bashford *et al*. 2001) or foliage clipping and shaking (Morrow 1977; Yen 1989; Majer *et al*. 1996; Abbott & Wills 2001; Bashford *et al*. 2001). These active collecting techniques were less appropriate for this study than stationary traps because they are more vulnerable to confounding daily, seasonal or climatic factors, or require access to foliage growing at the branch ends (Jacobs 1955).

Passive, non-attractive traps have been used to study arthropods of *Eucalyptus* trees, mostly at ground level. Majer *et al*. (2003) collected animals walking on *Eucalyptus* trunks in Western Australia using bark crawl traps and bidirectional flight-intercept traps. Yee *et al*. (2001) and Grove and Bashford (2003) placed bidirectional flight-intercept traps on fallen logs in Tasmanian forests. Sticky traps have been mounted on tree trunks to collect Diptera in New South Wales (Bickel 2003) and Coleoptera in Tasmania (K. Harrison, unpubl. data 2005).

METHODS

Trial site and trap construction

We compare here the fieldwork and arthropod capture attributes of three trap designs suitable for use in the forest canopy. We do not address the costs associated with arthropod sorting, taxonomic identification or access to trapping locations. The trap designs were used to study the arthropod fauna associated with eight old (~450 years) *E. obliqua* (Bar-Ness *et al*. 2006), the dominant forest tree of wet sclerophyll forests at the Warra Long Term Ecological Research Site in southern Tasmania (Warra LTER, at 43°04′S, 146°40′E, overview by Brown *et al*. (2001)). These trees were the first safely accessible climbing trees found in an uncut region of old-growth forest with two distinct age cohorts of *E. obliqua*. We also conducted equivalent sampling in eight of the nearby 100-year-old *E. obliqua* trees; these results are not analysed in this paper but our experiences with them are included in our methods section. Traps were active for 60 days and placed in spatially distinct zones in the tree crowns using rope techniques for access (Perry 1978; Dial & Tobin 1994; Moffett & Lowman 1995) during the southern summer of 2004. Schematic plans for building each trap design are presented in Figure 1. The knots mentioned in the text are described by Budworth (1999). A graphical representation of their placements within the crown is presented as Figure 2.

CD Sticky traps

A standard compact disc case served as both the sticky surface and carrying case. Older style cases, when the interior CD mounting crown was removed, formed a transparent plastic tray 125 mm × 140 mm × 10 mm. The inside front panel was coated with Tanglefoot™ coating to form a trapping area of 17.5 cm^2. A central hole for anchoring with a nail was melted with a soldering iron. The coated cases were carried into the tree crown, and handled by first labelling the outside of the sticky half, separating the two halves and nailing to the desired location. The uncoated half of the case was retained.

The collection results presented are from one upper crown and one lower crown trap mounted directly on the tree trunk. Traps were retrieved by bringing the retained CD lids into the sampled tree, removing the exposed trap from its retaining nail and recombining the case sections. Labels were checked while at the trap location. Once in the laboratory, animals were removed by soaking the entire trap in a kerosene bath for 2 h, then rinsing the animals off with water. Earlier unsuccessful trials soaking with citrus-based solvent irretrievably entombed the animals in the chemically decomposed plastic case. However, citrus solvents would be preferable for removing specific individual animals or for shorter soaking times.

Funnel crawl traps

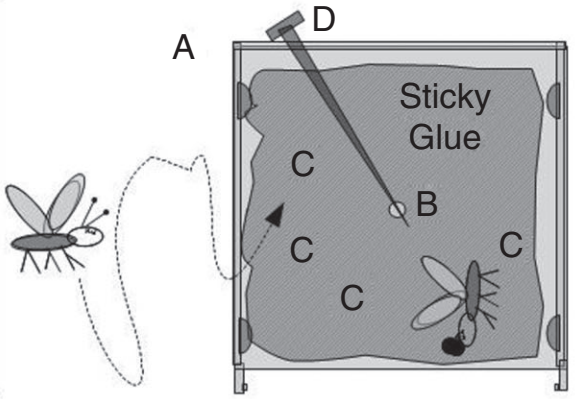
The funnel crawl traps, targeting walking animals, were composed of two foam strips attached to the bark leading towards a collecting funnel. Cut bottlenecks, salvaged from a municipal recycling centre, served as the funnel. Intact bottles (for collection) were filled with 10 mL of salt and 200 mL of 25% diluted ethylene glycol (sold as automotive coolant and antifreeze) and capped for transport. For funnel traps leading upwards, an extra bottle was used as an intermediate 'elbow' chamber. Strips measuring 10 mm × 10 mm of blue closed cell foam (such as used for sleeping mats) were placed on the branch surface as drift fences to guide walking animals towards the trap. Several nails were used to mount the trap assembly on the tree.

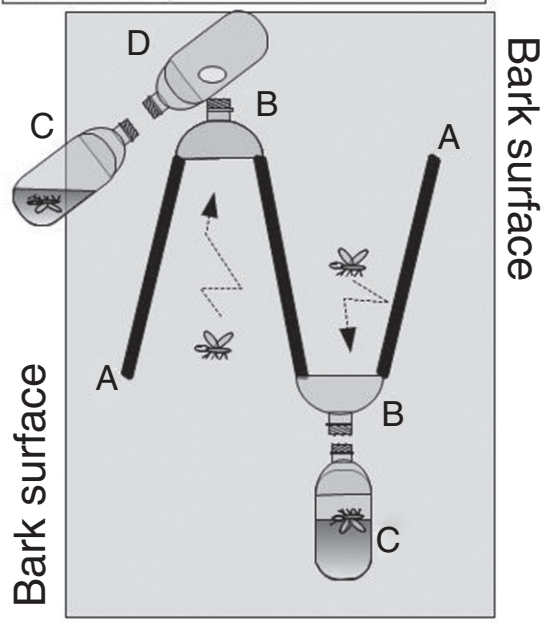
CD Sticky Traps

Components:
A) 'Front booklet' half of CD case
B) Hole melted through for nail
C) Sticky glue paint

Connectors:
D) Nails

Not Shown:
E) 'Back' half of CD case retained for transport
F) 'CD' crown disk mounting insert retained for use in data back-up





Funnel Crawl Traps

Components:
A) Drift fence (closed cell foam, optional)
B) Bottleneck
C) Intact bottle with collecting fluid
D) Elbow chamber bottle (fitted hole drilled inside)

Not Shown:
E) Bottlejoins (duct tape, shrinkwrap or female–female screwmount)
F) Nails to anchor to tree, through drift fence and bottlenecks
G) Bottlecaps for retrieval

-Can be modified for horizontal branches
-Down trap very vulnerable to rain and debris

Hanging Omnidirectional Flight-Intercept Traps

Components:
A) Intercept panels (slotted together)
B) Bottleneck (2 L)
C) Intact bottle with collecting fluid
D) Elbow chamber bottle (fitted hole drilled inside)

Connectors:
E) Cord (clove hitch around bottleneck)
F) Cableties, string, or wire between 'x' points

Not Shown:
G) Bottlejoins (duct tape, shrinkwrap or female–female screwmount)
H) Bottlecaps for retrieval

-Hanging on cord secured to branch in upper canopy
-Ground-servicable

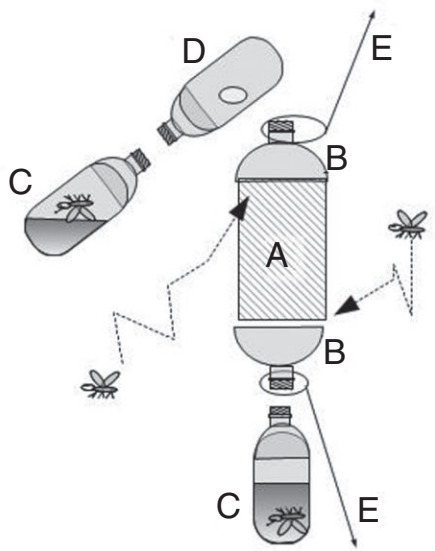


Fig. 1. Design plans for building three minimal-cost trap designs for sampling canopy arthropods (CD sticky traps, funnel crawl traps and hanging flight-intercept traps).

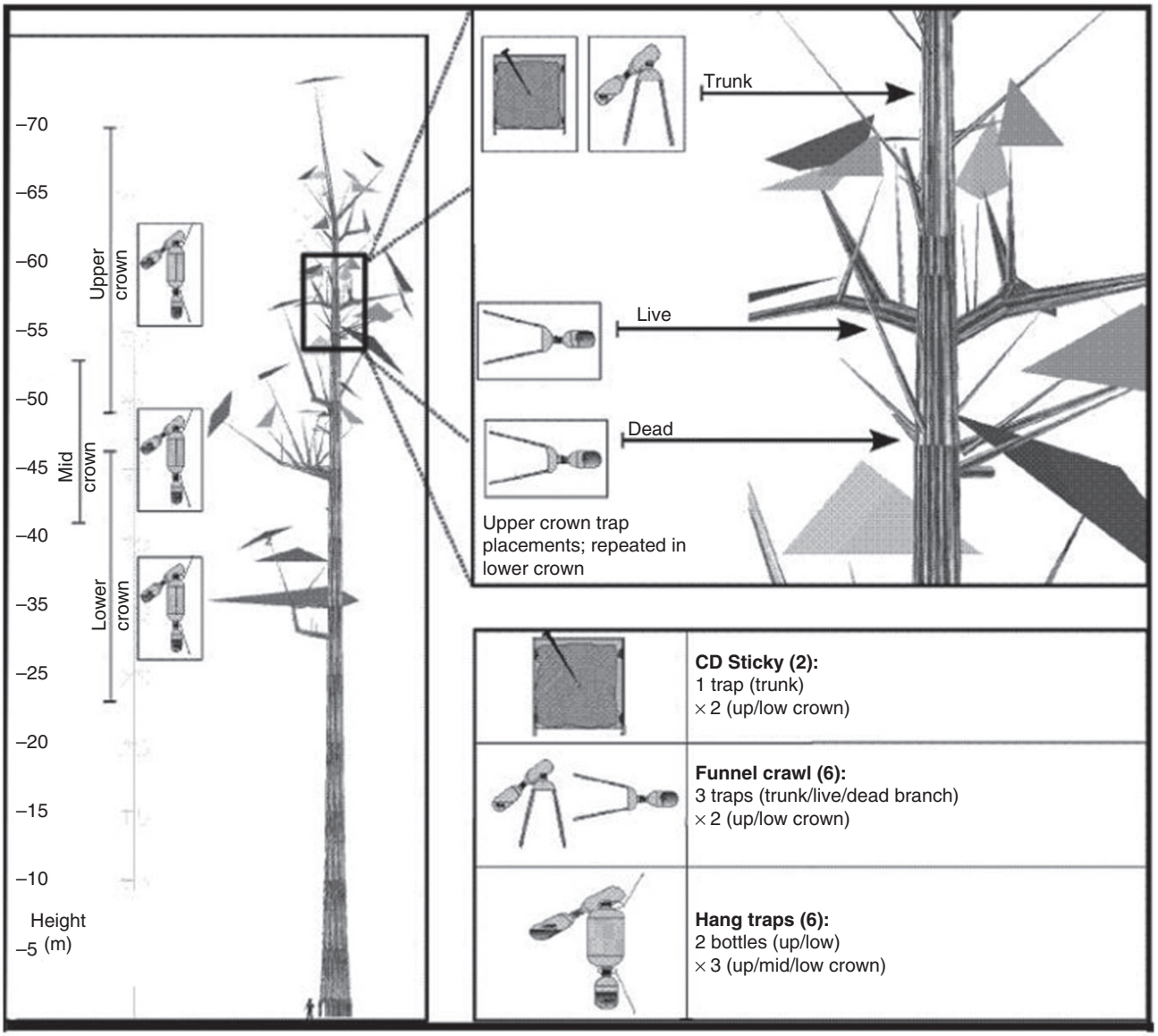


Fig. 2. Placements of three arthropod trap designs (CD sticky traps, funnel crawl traps and hanging flight-intercept traps) used in eight old-growth Tasmanian *Eucalyptus obliqua* trees.

In the tree, the bottleneck funnel was nailed to the trunk or branch in the desired place and direction. The foam was then nailed into position with two strips leading into the funnel. When traps targeting insect movement in opposite directions were adjacent, a foam strip could serve as a fence for both. A label was placed in the collecting bottle, and duct tape was used to carefully join the funnels to the collecting bottles. Downwards facing traps were vulnerable to dilution from rainwater and obstruction from falling debris or spider webs. Because of this, Basset *et al*. (1997) suggests salt water as a dilution-resistant collecting fluid.

Data are from funnel traps targeting upward-walking animals on the upper and lower trunk, and from horizontal traps targeting animals walking inwards on four branches: upper live, lower live, upper dead and lower dead. Traps were retrieved by climbing to the trap location with retained bottle caps, cutting through the duct tape to remove the trap and recapping the bottle

Hanging flight-intercept traps

Two 2 L bottlenecks, joined vertically by intercept panels, led to lower and upper (via an elbow bottle) collecting bottles. An omnidirectional flight-intercept surface was constructed from three 200 mm × 60 mm × 4 mm plastic panels joined by plastic electricians' cable-ties through drilled holes. The panels were arranged in a triple cross-section and cable-tied to the bottlenecks. A cord was set in the uppermost branches of the tree crown by a climber and the traps were connected from the ground. The two legs of the cord were tied together to form

a closed loop and traps raised and lowered by pulling on the other side of the cord. Three traps were placed on each line using a clove hitch around the bottleneck. Care must be taken when raising traps near understorey trees so as to avoid accidental sampling of different trees. Trap placement is limited only by the ability to place cordage and haul traps up through the forest canopy; they may also be mounted directly to the tree.

Results presented are from the three traps hanging within each tree's crown, with the upper and lower collecting chambers treated separately. Traps were spaced equidistantly on the rope with the uppermost trap ~1 m below the highest accessible branch and the lowermost at the bottom of the tree crown. Retrieval of the traps was performed from the ground by lowering them on the cord. The bottle join was removed, bottle caps replaced and the sample relabelled.

Arthropod evaluation

Animals were transferred from CD traps or collection bottles into 70% ethanol and insects were sorted to Recognisable Taxonomic Units (RTU, e.g. morphospecies). Coleoptera were pinned and identified using the Tasmanian Forest Insect Collection at Forestry Tasmania, Hobart. Acarina, Araneae, Formicidae, very small insects (<1 mm) and larval hexapods were counted as such but not sorted.

Results are presented at either a 'placement' comparison level (in which all traps of a single design and position are treated separately, replicated in eight old-growth trees) or at a 'design' comparison level (in which all traps of a single design are pooled together, replicated in eight old-growth trees). Note that the design level is subject to confounding by any differences in arthropod biodiversity that may exist between (1) the upper and lower canopy, (2) trunk, live branch and dead branch funnel traps, or (3) by the pooling of upper and lower chambers in the hanging traps.

Abundances, richness and a quantitative index of diversity were tabulated at a placement level and a design level for all arthropods and separately for the five most abundant taxa: Coleoptera, Diptera, Hemiptera, Hymenoptera (excluding Formicidae) and Lepidoptera. To measure diversity (reflecting richness and evenness), we calculated (–ln(Simpson's D)) as recommended by Magurran (2004), wherein a higher value represents a more diverse community. For the tabulation by trap design, mean collections per tree were compared between the three designs using ANOVA with Tukey's *post hoc* comparison.

An estimate of true species richness for each trap type, Chao 1, was generated using EstimateS software (Chao 1984; Colwell 2004) by resampling the community structure of each trap processed. This value is calculated using the number of morphospecies represented by just one individual arthropod and those represented by only two individuals, following the concept that a sampling effort is complete when two individuals have been collected from each morphospecies. Sampling completeness was calculated by presenting the number of morphospecies actually collected in our fieldwork as a percentage of Chao 1. The composition of arthropods collected was compared first by illustrating RTU overlap using an interlocking circles graph, and second by non-metric multidimensional scaling ordination (NMS) using PC-ORD software (McCune & Grace 2002).

RESULTS

Experiences with construction, placement and processing of each trap design are presented with approximate time and monetary investment (in Australian dollars) in Table 1. A ranking of traps, calibrated to relative advantages following our experience, is provided as Table 2. The CD traps were ranked first for cost, transport, durability and effort of construction and placement, but last for pre-sorting effort and sample condition. The hangtraps ranked best for durability, retrieval, pre-sorting and conditions, but were the most expensive, least portable and most complicated to place. The funnel traps' performance was midway between the other two designs, except in durability and retrieval effort, where they performed worst.

Almost a quarter (60 of 256) of the exposed CD traps could not be collected, and were presumably lost to strong winds. Forest detritus accumulated on the CD traps, making extraction of intact animals in the lab more difficult. A large proportion of collected mass was arthropod fragments, leading to underestimates of the true collection totals. Winged animals had often lost their wings, and were generally in worse condition than those in the liquid collection chambers of the other traps. More than a quarter (28 of 96) of the exposed funnel traps failed, overwhelmingly due to failure of the duct tape bottle join. Animals were generally in excellent condition and required very little sorting from debris. For the hangtraps, less than 5% of trap bottles failed (5 of 96 bottles in 48 traps), mostly upon retrieval when the upper elbow chamber bottle caught on understorey foliage. Animals were in excellent condition and free from debris.

Of the 92 processed traps sampling the crowns of eight old-growth *E. obliqua*, a total of 3005 arthropods representing 250 RTU were collected. Results for each trap design's total capture are presented in Table 3. Comparing the total trapping regime (regardless of tree) between trap types, the hanging trap regime caught more than twice as many arthropod individuals and RTU as the CD traps (1281:596 individuals and 170:81 RTU, respectively). The funnel traps caught almost as many individuals (1128) but fewer RTU (110) than the hanging traps. The diversity index for the total collection funnel traps (3.22) was higher than that of the CD (2.59) or hang (2.36) traps.

Sampling completeness was the highest, at 72%, for the hangtraps (170 observed of 235 estimated species), the lowest for the CD traps at 39% (80 of 205) and midway at 65% for the funnel traps (110 of 169). Pooled, these three trap designs collected 71%, or 250 of 353 estimated species, with an additional 103 unencountered 'cryptic' species predicted by the Chao 1 estimator.

Table 1 Comparison of construction, transport and processing efforts associated with three minimal-cost traps for sampling canopy arthropods

	Sticky CD case	Funnel crawl	Hanging flight intercepts
Target	Fliers in tree airspace, jumpers	Bark walkers, hoppers, skimmers, close fliers	Fliers in tree airspace
Ranking of five most abundant taxa (first is most abundant)	Diptera, Hymenoptera, Coleoptera, Hemiptera, Isoptera	Diptera, Hemiptera, Coleoptera, Hymenoptera, Blattodea	Diptera, Coleoptera, Lepidoptera, Hymenoptera, Araneae
Potential confounds	Wind blowing in aerial plankton, bark debris	Funnel not fixed closely enough to trap surface – animals walk right under, down traps are vulnerable to rainfall and debris	Trap hanging in canopy of neighbouring plants
Specimen conditions	Medium, wings often lost	Fine	Fine
Portability into field	Compact, can use commercial music CD carriers	Bulky, but light. Most difficult component is pre-filled collecting bottle	Bulky, but light. Most difficult component is pre-filled collecting bottle
Total time effort (minute:second per trap)	7:25	15:30	15:00
Construction Time (minute:second per trap)	From intact CD case: removing crown and painting coating ~20; melting anchor hole ~5 s	Washing and cutting funnels; washing and filling collecting bottles; cutting of foam drift fences (optional); ~30 s	Cutting and combining of intercept panels; washing and cutting funnels and elbow chambers; washing and filling collecting bottles; attachment of two funnels to intercept trap ~7 min
Placement time (minute:second per trap)	Once at branch, nailing into branch or trunk ~2 min	Once at branch, nailing drift fence ~5 min; nail funnels and join bottles ~5 min	Once line is in place, ~3 min to clove hitch to cord
Processing time (minute:second per trap)	Trap dissolving and specimen washing, ~20 min; sorting animals from debris, ~5 min	Sorting animals from debris, ~5 min	Sorting animals from debris, ~5 min
Label considerations	Can label plastic directly with permanent marker or scratch, at risk of being lost in coating solvent	Can place final label in collecting bottle. Best done after placement to avoid difficulty if a trap is dropped	Can place final label in collecting bottle. Best done after placement to avoid difficulty if a trap is dropped
Tools required	Access to treetop, carrying bag, hammer with nail pouch, marker or nailscratch to label trap. Must retain lid.	Access to treetop, carrying bag, hammer with nail pouch, marker or pencil and paper to label trap. Duct tape for bottlejoins. Knife or hands to cut foam to size. Must retain bottlecap	Cord rigged in canopy, knowledge of clove hitch, marker or pencil and paper to label trap. Duct tape for bottlejoins. Must retain bottlecap
Total cost ($A per trap)	$0.41	$0.67	$0.95 plus cordage
Materials and cost ($A per trap)	CD case ~$0.35	Foam drift fence ~$0.20	Intercept panels ~$0.50
	Nail ~$0.01	Bottlenecks, collecting bottle, elbow chamber bottle, bottlecaps ~$0.0	Collecting bottle, elbow chamber bottle, bottlecaps ~$0.0
	Sticky coating ~$0.05	Six nails ~$0.06	Cableties ~$0.05
		Duct tape bottlejoins ~$0.20	Duct tape bottlejoins ~$0.20
		200 mL collecting fluid ~$0.20	200 mL collecting fluid ~$0.20
			Cordage variable with tree height

Examining mean values per tree (Table 3), the abundance of Hemiptera captured by the funnels was significantly higher than the other designs. The total richness collected by the hangtraps was significantly higher than the CD traps, as was that of the Coleoptera catch only. For Diptera richness, the hangtrap catch was significantly higher than that of the funnels; for Hemiptera the funnel catch diversity was higher than that of the CDs; and for Lepidoptera richness the

Table 2 Ranking of three minimal-cost trap designs for sampling canopy arthropods

		CD sticky	Crawl funnel	Hangtraps
Monetary cost	Per individual trap	1	2	3
Transport	Difficulty of carrying trap into field and into position	1	2	3
Durability	During both placement and retrieval	2	3	1
Construction effort	Both into field and into position	1	2	3
Placement effort	At trapping position	1	2	3
Retrieval effort	At trapping position (or ground*) and exiting field	2	3	1*
Pre-sorting effort	Transfer of animals into sorting trays	3	2	1
Arthropod condition	Intactness of specimens	3	2	1
Total rankings	(Lower number is better)	14	18	16

hangtraps were caught significantly more than the other trap designs. There was no significant difference in Hymenoptera catch richness between the three traps.

Mean diversity levels (–ln(Simpson's D)) per tree for all arthropods were higher in the funnel traps as compared with the CD traps, and for Coleoptera and Diptera, significantly lower in the hangtraps than the other designs. However, the diversity of Lepidoptera was significantly greater in the hangtraps than in the CD traps. For the Hemiptera, significant differences between all the three designs were observed: hangtraps caught the most diverse fauna, and CDs the least. No significant differences between designs were found in the Hymenopteran diversity.

The number of shared RTU (Fig. 3) was the lowest between the CD and the funnel traps (37 in common) and the highest between the funnels and hanging traps (73 in common). An ordination by non-metric multidimensional scaling (Fig. 4) indicates a distinct fauna collected by the hangtraps, and a much more variable fauna collected by the funnel traps. The position of funnel traps (live, dead or trunk) appears to be a stronger determinant of composition than the vertical crown zone. Trunk funnel traps were more similar to the trunk CD traps than to the branch funnel trap. There was a distinction between upper and lower collecting bottles of the hangtraps that was more prominent than the distinction between upper, middle or lower crown.

DISCUSSION

The traps described here represent a contribution to reducing the sampling costs that are recognised as a limiting factor in biodiversity studies (Oliver & Beattie 1996). While we draw exclusively on our experience in the *Eucalyptus* forest canopy, the techniques may be of service and value in other environments. By making extensive use of common discarded materials (bottles and CD cases), more resources can be devoted to other aspects of the biodiversity survey.

The loss of traps to weather or gravity was significant, with approximately a quarter of the CD and funnel traps lost. Our trapping regime was imbalanced by the small numbers of CD traps processed. The damaged condition of animals collected by these traps likely caused an underestimate of the actual species richness sampled: many animals were unrecognisable or entrapped in coating. Because of this poor-quality material, we chose to process less of the placed traps and therefore had fewer data on trap positional differences. However, they were exceptionally promising for portability and installation. Use of these traps would be especially suited to studies with a high need for replication within the tree crown.

The live and dead branch funnel traps caught low numbers of RTU, but the trunk traps caught a more rich and diverse fauna. The funnel traps provided specimens in excellent condition and valuable information about positional differences in arthropod biodiversity. Their major detraction was the failure of the bottle connection – a problem that could be remedied by using different materials than tape. In trees like *E. obliqua*, the large amounts of stringy bark material falling from the tree surfaces can block the opening of a trap aimed at downwards travelling insects. If more frequent processing of traps is possible, the use of other collecting agents besides ethylene glycol may result in arthropods collected in less brittle condition.

The hangtrap regime caught the widest range of arthropods, but not always the most diverse. The hanging traps were the most complicated to transport and set in the field, but had the overarching advantage of being serviceable from the ground. While we only conducted one sampling round, researchers could use the hanging traps to collect throughout the year. We found that the relatively open Tasmanian rainforest canopy was sufficiently sparse for us to pull the traps up without them getting entangled; however, this may not be true for other forests. Additional cordage could be used to more securely attach the intermediate elbow chamber to the intercept section, reinforcing the most likely point of failure.

Our sampling was conducted over only a 60-day period of time. Longer sampling times may alter the relative merits between these trap designs. For example, our CD sticky traps, with only 39% (of 205 estimated species) sampling completeness, may outperform the funnel traps (65% of 169 estimated species) in richness of RTU over a longer period of time. Additionally, the funnel traps and CD traps would likely become more difficult to process as they collected more drifting material (e.g. bark, leaves), making the hangtraps more effective by comparison.

All trap designs collected a plurality of Diptera, and Coleoptera additionally were well represented in each. The sticky CD cases performed well for catching flying insects including Hymenoptera and Isoptera, the funnel traps for

Table 3 Mean arthropod abundance, richness and diversity (–ln(Simpson's D)) compared with ANOVA at a design level between three trap designs sampling the canopy arthropod biodiversity of eight old-growth Tasmanian *Eucalyptus obliqua*

Design	No. of traps	(All trees)	All Arthropods	Coleoptera	Diptera	Hemiptera	Hymenoptera	Lepidoptera
					Abundance per tree: mean (SD)			
CD total	13	596	85.14 (34.80)	9.71 (7.13)	53.43 (22.18)	4.29 (2.81)	13.14 (7.42)	1.25 (0.50)
Funnel total	35	1128	141.00 (127.50)	18.25 (20.65)	35.00 (37.20)	32.43 (27.77)	24.63 (22.89)	9.50 (10.40)
Hangtrap total	44	1281	160.13 (80.55)	20.75 (9.45)	88.38 (53.86)	7.63 (4.10)	9.29 (7.70)	12.13 (10.00)
All traps pooled	92	3005	375.00 (165.00)	47.50 (19.80)	170.13 (69.43)	39.75 (30.94)	46.38 (29.56)	19.88 (18.04)
						$P = 0.007$ f/hc		
					Richness per tree: mean (SD)			
CD total	13	81	24.00 (6.85)	5.29 (2.13)	8.57 (2.22)	2.43 (1.51)	4.57 (1.51)	0.14 (0.38)
Funnel total	35	110	35.13 (20.54)	7.75 (5.33)	4.88 (2.80)	6.71 (3.82)	6.50 (4.24)	1.50 (1.07)
Hangtrap total	44	170	47.50 (10.87)	12.13 (4.80)	12.25 (3.53)	5.63 (2.38)	6.38 (2.92)	4.75 (2.12)
All traps pooled	92	250	83.40 (18.06)	21.13 (5.14)	17.75 (4.39)	11.75 (4.39)	14.00 (5.39)	6.13 (2.16)
			$P = 0.006$ hf/fc	$P = 0.016$ hf/fc	$P = 0.001$ hc/cf	$P = 0.022$ fh/hc		$P < 0.001$ h/fc
					Diversity per tree: mean (SD)			
CD total	13	2.59	1.272 (0.03)	2.592 (0.07)	2.515 (0.05)	0.906 (0.19)	1.079 (0.08)	0.173 (0.35)
Funnel total	35	3.22	1.293 (0.08)	2.598 (0.11)	2.460 (0.08)	1.097 (0.14)	0.985 (0.17)	0.483 (0.35)
Hangtrap total	44	2.36	1.285 (0.04)	1.835 (0.03)	1.108 (0.08)	1.102 (0.13)	1.089 (0.18)	0.873 (0.23)
All traps pooled	92	2.34	1.347 (0.01)	1.293 (0.07)	1.250 (0.03)	1.224 (0.07)	1.238 (0.05)	1.110 (0.11)
			$P = 0.026$ fh/hc	$P < 0.001$ fc/h	$P < 0.001$ cf/h	$P = 0.038$ c/f/h		$P = 0.004$ hf/fc

Grouped initial letters (c, CD sticky; f, funnel; h, hangtrap) following the *P*-value indicate designs between which no significant differences were detected (Tukey's *post hoc*). For example, hf/fc means that the only significant difference detected was between hangtraps and funnels, whereas no difference was found between hangtraps and funnels, or between funnels and CD sticky traps.

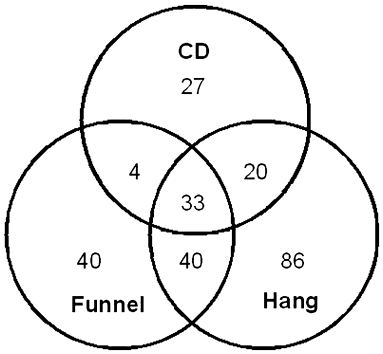


Fig. 3. Overlap in Recognisable Taxonomic Units (morphospecies) composition in collection from three trap designs (CD sticky traps, funnel crawl traps and hanging flight-intercept traps) sampling canopy arthropods in eight old-growth Tasmanian *Eucalyptus obliqua.*

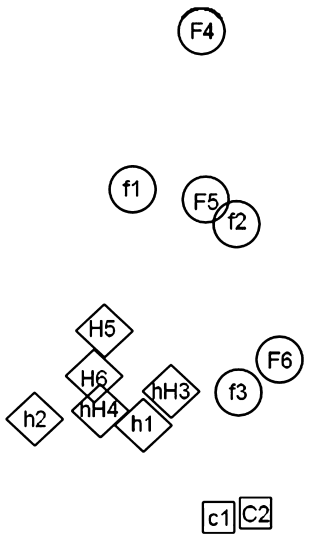


Fig. 4. Non-metric multidimensional scaling ordination of the arthropod composition collected by 14 trap positions in eight old-growth Tasmanian *Eucalyptus obliqua* trees. 2-d stress = 12.61. Uppercase letters indicate upper crown placements. Legend: c1 = CD trap lower trunk; C2 = CD trap upper trunk; f1 = funnel lower dead branch; f2 = funnel lower live branch; f3 = funnel lower trunk; F4 = funnel upper dead branch; F5 = funnel upper live branch; F6 = funnel upper trunk; h1 = hang lower crown bottom bottle; h2 = hang lower crown top bottle; hH3 = hang mid-crown bottom bottle; hH4 = hang mid-crown top bottle; H5 = hang upper crown bottom bottle; H6 = hang upper crown top bottle.

walking animals Hemiptera, Hymenoptera and Blattodea, and the hanging traps for flying Lepidoptera and walking Araneae and Hymenoptera.

For researchers that wish to study specific habitats, the funnel traps and CD traps offer portability, and small-scale directionality. These traps would be more appropriate for studies of tree hollow or saproxylic invertebrates, whereas the hangtraps would be better suited for catching mobile phytophagous insects.

Independent of their construction and placement efforts, the hangtraps performed best of the three. The plastic bottle design, as presented here, is inexpensive, durable and made of ubiquitous materials.

For placement efforts and ease of transport, the CD sticky traps were the best. Despite the declining availability of CD jewel-box cases, these effectively isolate the tremendously sticky trap surface for both placement and collection.

A concerted effort to manage waste is vital to minimise the impact of studies, especially in a long-term research site such as Warra LTER. In addition to the resources associated with time, materials and effort, there were also considerations of waste management and minimal impact to the study site. The entire removal of the foam drift fence for the funnel traps proved difficult as it often disintegrated while being removed. Collecting bottles and CD cases were removed in their entirety, but trap installations were left intact in the tree in the hope of being used in the future for additional samples. Where this is not appropriate, the efforts in dismantling and transport must be considered.

Furthermore, accidents and breakages could create further hazards and litter, possibly including plastic fragments, nails, foam and collecting agents. Trap components and installation materials which fell out of the tree were often impossible to retrieve, having been caught in mid-canopy trees.

As an ensemble, these traps can help meet the needs of entomologists who routinely sample forest insects with a variety of traps (Hosking 1979; Basset *et al*. 1997), and potentially complement the widespread method of canopy fogging used in *Eucalyptus* and other forests (Chey *et al*. 1998; Floren & Linsenmair 2001; Majer *et al*. 2002). These trap designs are well suited for studies that require highly replicated, inexpensive regimes of passive traps that cannot be attended continuously for long periods of time. Therefore, these designs are recommended for canopy biologists surveying arthropods in the treetops, with difficult access conditions and stringent requirements for transport and durability.

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