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Article

When the beetles hit the fan. The *fan-trap*, an inexpensive, light and scalable insect trap under a *Creative Commons* License, for monitoring and experimental use

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Simple Summary: There is a need for cheap, easily deployed traps for insect pest monitoring. Here we propose the design of an inexpensive *fan-trap*, under a Creative Commons BY-SA License. Using the blueprint we provide, anyone could laser-cut their own traps from a sheet of polypropylene or have this done commercially by a contractor. As they are flat when unfolded, the fan-traps ship easily. When mounted, they are easy to transport in the field in a backpack. The blueprint can also be modified in order to re-size the traps to adapt them for different purposes.

Abstract: Monitoring is an important component of pest management, to prevent or mitigate outbreaks of native pests, and to check for quarantine organisms. Surveys often rely on trapping, especially when the target species respond to semiochemicals. Many traps are available for this purpose, but they are bulky in most cases, which raises transportation and deployment issues, and they are expensive, which limits the size and accuracy of any network. To overpass these difficulties, entomologists have used recycled material, such as modified plastic bottles, producing cheap and reliable traps but at the cost of recurrent handywork, not necessarily possible for all end-users (e.g., for national plant protection organizations). These *bottle-traps* have allowed very large surveys which would have been impossible with standard commercial traps, and we illustrate this approach with a few examples. Here we present, under a *Creative Commons* BY-SA License, the blueprint of a *fan-trap*, a foldable model, laser-cut from a sheet of polypropylene, that can rapidly be produced in large numbers, and could be transported and deployed in the field with very little efforts. Our first field comparisons show that *fan-traps* are as efficient as *bottle-traps*, and we describe two cases where they are being used for monitoring.

Keywords: Traps; beetles; monitoring; surveys; spatial distribution

1. Introduction

Surveys are necessary at different spatial scales to determine the extent and magnitude of native pest populations, forecast outbreaks, delimit critical areas, and assess the success of control operations. Surveys also allow population assessments and spread measurements in biological and ecological research.

Non-native, invasive pests expanding their distribution range on their own by flight or moving with travelers or with commercial goods (e. g. unprocessed roundwood, or live plants for planting), with wood packaging material or as hitchhikers in vehicles or containers, also create a need for cheap and easy to handle monitoring tools.

In many countries, the inspection services of national plant protection organizations (NPPOs) monitor high risk locations (ports, airports, road, railway hubs, commercial nurseries, companies importing stones or machinery in wood packaging material). Surveys can be operated visually, but the large amount of incoming goods makes this very difficult and unreliable. Recently, in March 2021, the public at large came to realise the magnitude of the problem when the 400 m-long giant container ship *Ever Given* blocked Egypt's Suez Canal during almost one week. This ship carries 20,400 6 m-long cargo containers. Presently, there are even larger ships, carrying 24,000 containers. Although all containers do not contain material at risk, the extent of commercial movements makes visual inspections extremely inefficient. In addition to visual inspections, when chemical or visual attractants are available, inspectors can also deploy traps in entry points and in their vicinity ([1-7]). This raises the technical and commercial issues of traps – they should be at the same time cheap, easy to handle and efficient. Here we present a cheap trap model for surveying beetles (Coleoptera).

1.1. Present state-of-the-art: available commercial traps

A variety of commercial traps are currently on the market and used in the surveys described above. They include *Theysohn* trap, *Witasek* traps, *Ecotraps*; *Lindgren funnel traps*; *Crosstraps* and *Crosstraps Mini*. They are in general very efficient in catching large numbers of beetles (see, e. g., [8, 9]) but they weight several kilograms and are bulky. They cannot be easily transported in large numbers (one person can walk with one or two of them at a time, which makes it uneasy to establish large trap networks offroad, and they take time and manpower for set up (often, two persons are necessary). Also, in many cases, these traps must be fixed on stakes or hanged on ropes attached to two adjacent trees. Their individual prices range from 25 to 50€ (information generally available on the producers' websites).

1.2. A cheap and versatile alternative: bottle-traps

There are many examples in the literature of makeshift traps made out from plastic bottles and used in experimental work. Rieske and Raffa [10] used baited flight traps made from modified gallon-sized milk plastic containers, positioned upside-down with three sides removed for monitoring *Pissodes nemorensis* and *P. strobi* (Coleoptera, Curculionidae). They found that these traps were more effective than baited pitfall traps. Steiniger *et al.* [11] showed that traps improvised from 2 L plastic water bottles, equipped with commercial alcoholic sanitizers, are very efficient and cheap for monitoring invasive ambrosia beetles (Coleoptera, Curculionidae, Scolytinae). Reding et al. [12] used ethanol-baited bottle traps to monitor *Xylosandrus crassiusculus*, *Xylosandrus germanus*. Olenici et al. [13] monitored *X. germanus* in Romania with similar traps.

Bottle traps have been used since the early 2000s in our own research in Belgium, France, and Britain. They consist each in a 2 L commercial transparent PET bottle, cut longitudinally and turned upside-down so that it forms a 21 x 13 cm interception pane, the inverted bottleneck serving as a collecting funnel connected to a 50-ml clear polystyrene collecting tube filled with propylene glycol as a preservative. Franklin et al. [14] and Franklin and Grégoire [15] used them for release-recapture experiments with *Ips typographus* (Coleoptera, Curculionidae, Scolytinae) in Belgium; Grégoire et al. [16] monitored the presence and abundance of various potentially harmful Scolytinae in the Forêt de Soignes, near Brussels, with 100 traps spread across 1600 ha; Meurisse et al. [17] used bottle traps for monitoring and release-recaptures of *Rhizophagus grandis* (Coleoptera, Monotomidae) in Belgium and France; Piel et al. [18-19] monitored *I. typographus* in the city of Brussels and *Ips duplicatus* in Liège; Warzée et al. [20] surveyed *Thanasimus formicarius* (Coleoptera, Cleridae) in the Vosges, France. The Observatoire Wallon de la Santé des Forêts maintains since 2012 a permanent network of 50 bottle traps across Wallonia for the monitoring of *I. typographus* [21].

A review of interception traps (including bottle traps) was provided by the late Simon Leather [22].

Other studies (Grégoire et al., unpublished to date) involved networks of 460 traps in Wallonia (2005-2006), and of 300 traps in a transect from Wallonia to the Champagne area in France. Bottle-traps were also used in large numbers (20-45 traps/tree) for passive interception to monitor random landing of bark beetles on already attacked and healthy spruce trees in a stand colonized by *Dendroctonus micans* in Lozère (France). Inward et al. (in preparation) used an extensive network of 185 and 250 traps in 2021 and 2022, respectively, in France and England to measure the expansion into England of the French and Belgian *I. typographus* populations.

These cheap and efficient traps are much easier to transport and use than the commercial models available so far. At least thirty traps can be transported together in a backpack, and each trap can be fixed to a range of standing objects (trees, electricity posts, public lighting) with staples or nylon binders. One problem, though, is that, because they are three-dimensional, they are still bulky in large shipments. But the major difficulty is that empty plastic bottles must be found or bought, and the traps must be handmade, which is not practical for many potential end users, such as NPPOs. This led to designing of the *fan-traps*.

2. The *fan-trap* – a description

The fan-traps are described under a Creative Common BY-SA licence[1]. The full description and blueprint files are available at the following sites: https://ebe.ulb.ac.be/ebe/Fan-trap.html; https://spell.ulb.be/fan-trap_description.zip.

A *fan-trap* (figures 1 and 2) consists in an arrow shaped polypropylene sheet that can be folded into a funnel by fitting lugs on one side of the "arrowhead" into corresponding slots on the other side. The bottom of the funnel is inserted into a circular hole, 2.5cm in diameter, cut into the screw cap of a collecting container, either kept dry or partly filled with a preservative liquid (e. g., polypropylene glycol). The cap is maintained attached to the trap by pre-cut wedges at the bottom of the funnel, bent outwards. When visiting the traps, the containers can be unscrewed, tightly closed with unperforated caps, and replaced by fresh material. Different sizes of collection containers can be used depending on the expected catches. When folded, the traps can be attached to trees or any other support (e. g., electrical posts) with plastic ties or strings pulled through pre-cut fixation holes, or with staples. Additional fixation holes can be added to attach the lures (see supplementary information). For added performances, the traps could be painted and/or sprayed with polytetrafluoroethylene (PTFE).

The traps used in our experiments were cut out of a 0,8mm thick polypropylene sheet using a Metaquip MQ1590 laser cutter driven by the RDWorks 8.0 software (https://rdworks.software.informer.com/8.0/). Previous tests showed that thicker sheets (maximum 1 mm) could be used as well. Polypropylene was chosen due to its affordable price, flexibility, and resistance, allowing to fold and unfold the traps for multiple successive uses. The traps are machine-washable and tolerate high temperatures up to 135-165°C depending on the polymer [23].

A more detailed description of the traps, including a detailed blueprint and practical details of trap manufacturing with a laser cutter could be found in the S1 file of the Supplementary Material.

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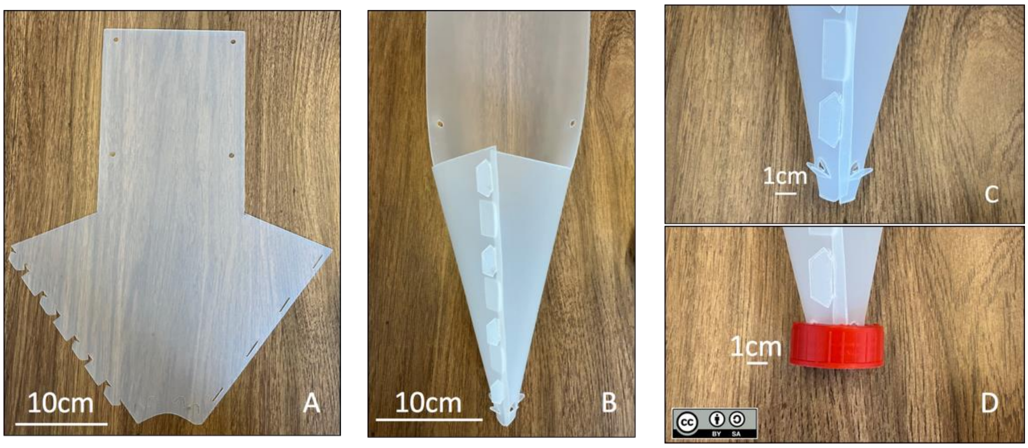

Figure 1. An unfolded and an assembled *fan-trap*. Details of the collecting-container cap fixation. **A** – The flat design; **B** – Folded trap; **C** – Pre-cut wedges to fix the collecting container's cap; **D** – Cap attached to the bottom of the trap

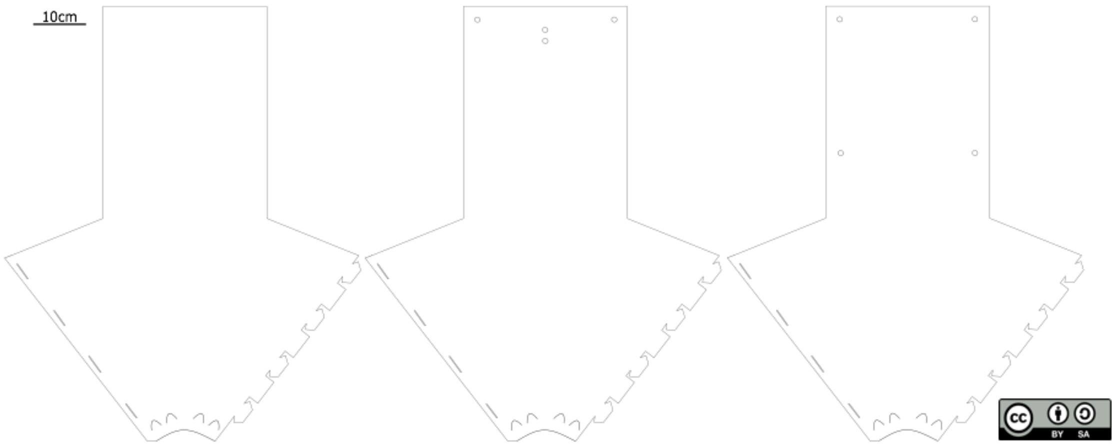

Figure 2. Blueprint of the *fan-trap* with various fixation holes

3. Experimental support

3.1. Material and Methods

3.1.1. Comparisons with bottle-traps

An experiment was set up in the Vosges mountains, département du Bas-Rhin, massif du Donon (48.4403, 7.1091) in 2005, at a time when the area was still a hotspot of *I. typographus* activity after the Lothar storm in December 1999. Fifteen blocks were spread out in a meadow bordering spruce stands. Each block comprised one fan-trap (size of the trapping panel: width = 15 cm; height = 20 cm) and one bottle-trap (19 x 17 cm), stapled to a broadleaf tree or a fir, facing East and distant from each other by ca. 5 m. The blocks were distant from each other by ca. 15 m. Each trap was baited with a Pheroprax lure (BASF), replaced monthly. The traps were set up on May 5, 2005, visited on June 1, July 6, August 10, and September 16.

3.1.2. Comparisons with bottle traps and commercial trap models

This experiment was run in 2005 in Wellin, province of Luxembourg, Belgium (50.0581, 5.1214) in a clear-cut area adjacent to mature spruce stands with sporadic attacks. The traps compared there were *fan-traps*, *bottle traps*, *Theysohn* (W x L: 60 x 50 cm) and *Intercept* traps (15 x 70 cm). They were baited from April 4 to May 12, 2005, with lineatin (Witasek, Feldkirchen in Kärnten, Austria) and ethanol (97.1% ethanol, 2.9% ether; diffusion rate ca 1.2 g/d) and also visited on April 4. From May12 to June 10, 2005, the traps were baited with Pheroprax, and also visited on May 27. The lures were renewed at each visit. The lineatin-ethanol-baited traps were aimed at xylomycetophagous Scolytinae (*Trypodendron* spp. and *Anisandrus dispar*), the pheroprax-baited traps were deployed to catch *Ips typographus.* There were two parallel lines distant by 20 m and comprising each twenty traps (five replicates of the four trap models, fixed on wooden stakes) placed randomly at 20 m from each other. The order of the traps within each line was modified randomly at each visit.

3.2. Results

3.2.1. Comparisons with bottle-traps

The detailed results are available as Supplementary Material (file S-3), and a summary is provided in Table 1.

Table 1. Total catches per trap over the whole trapping period for each of the two groups of Scolytinae (the "xylomycetophagous" species, i.e., *Trypodendron lineatum*, *T. domesticum*, *T. signatum*, and *Ips typographus*). For each species, the traps are listed in decreasing order according to trapping results.

Species	Trap	N	Mean	Std. Dev.	SEM
Ips typographus	Intercept	10	2106.70	1035.17	327.35
	Theysohn	10	1965.70	874.26	276.46
	Bottle-traps	10	252.30	107.77	34.08
	Fan-traps	10	229.80	128.92	40.77
Trypodendron domesticum	Intercept	10	30.60	16.85	5.33
	Theysohn	10	22.70	13.85	4.38
	Bottle-traps	10	7.10	3.81	1.21
	Fan-traps	10	6.40	3.37	1.07
T. signatum	Intercept	10	292.90	230.47	72.88
	Theysohn	10	166.90	58.54	18.51
	Fan-traps	10	115.20	34.26	10.83
	Bottle-traps	10	100.50	27.66	8.75
T. lineatum	Intercept	10	111.70	88.81	28.09
	Theysohn	10	50.10	13.88	4.39
	Fan-traps	10	35.20	12.57	3.97
	Bottle-traps	10	32.30	14.38	4.55
Anisandrus dispar	Theysohn	10	77.20	62.12	19.64
	Fan-traps	10	59.80	52.49	16.60
	Intercept	10	45.00	23.86	7.54
	Bottle-traps	10	39.50	38.27	12.10

After a log(n+1) transformation needed to stabilize the variances, a one-way analysis of variance was applied on the total catches per species for each trap model. There were no significant differences between traps for *A. dispar* ($F_{3,36}$ = 1.849; p=0.156). For all the other species, the four traps performed differently: *I. typographus* ($F_{3,36}$ = 80.787; p<0.001); *T. domesticum* ($F_{3,36}$ = 19.931; p<0.001); *T. signatum* ($F_{3,36}$ = 10.246; p<0.001); *T. lineatum* ($F_{3,36}$ = 13.016; p<0.001.

For *I. typographus*, and *T. domesticum*, Student-Neuman-Keuls post-hoc tests (α=0.05) separated two homogeneous categories: the *bottle-traps* and *fan-traps* on the one hand, and the *Intercept* and *Theysohn* traps on the other hand. Roughly, the two latter traps caught on the average ten times more *I. typographus* than the first two trap models. The differences were not as wide for *T. domesticum*. For *T. signatum*, there was no significant difference between the *bottle-* and *fan-traps*, and between the *fan-* and *Theysohn* traps. The *Intercept* traps performed significantly better than the other three models. For *T. lineatum*, there were no significant difference between the *bottle-*, *fan-* and *Theysohn* traps and, again, the *Intercept* traps performed significantly better than the other three models.

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4. Discussion

Individually, as seen above with *I. typographus*, but depending on the target species, the *fan-traps* might catch much less insects than commercially available traps. This however does not necessarily mean that they are less efficient collectively, considering that their price and easiness to handle allow many more of them to be deployed. At this point, it could prove fruitful to distinguish between the possible uses of trapping networks. Two different objectives can be considered: i) monitoring for still absent or rare species (surveys for potentially incoming non-native species); ii) measuring population trends (e.g., phenology, spread or density changes) among established, often abundant species (in particular, native pests).

1. For monitoring potentially incoming non-native species, one needs to reach a high probability (sometimes prescribed by the national regulatory agencies, see e.g. [24-27]) to detect an unwanted organism above a certain level of prevalence. Up to a certain limit, the larger the trap, the more likely it is to catch the targets. Byers et al. [28] report a positive link between catches and the diameter of sticky cylindrical pheromone traps, up to a 30 cm radius. However, another limitation here is the attraction radius of the lure in the trap, i.e., the radius around the trap within which randomly flying beetles perceive the lure. For many beetles, these attraction radii are comparatively short. Byers [29] calculated a radius of 1.4 to 16 m for *I. typographus*, but Franklin and Grégoire [15] provide a slightly larger estimate (at least 50 m). From a network of Multifunnel traps baited with frontalin and turpentine, Turchin and Odendaal [30] calculated that a trap attraction range for *Dendroctonus frontalis* is about 0.1 ha. Jactel et al. [31] calculated a 92-123 m radius for *Monochamus galloprovincialis*, whilst Torres-Vila et al. [32] report a 50 m radius for the same species. These rather short distances mean that, for maximum monitoring accuracy, traps should be deployed at densities high enough to avoid gaps between their respective areas of attractiveness. For example, *D. frontalis* should be monitored with traps positioned 20 m from each other. This would plead in favour of deploying many cheaper but less efficient traps. However, because they are scalable, a still better option could be to increase the size of the *fan-traps*, considering that further research with *fan-traps* of increasing sizes is still needed to establish optimal trap dimensions for any given species. The easiness of modifying the original blueprint towards larger models should facilitate this type of approach.
2. For measuring population trends in well-established species, the trapping results are compared to each other, e. g., against time to measure phenology or density changes, or against space to measure population expansion. The trapping data in this case are relative (one trap against the others) and even small catches could be compared to each other.

The *fan-traps* were successfully tested so far only with small (<1 cm) or medium-sized (1 – 2 cm) Coleoptera: Scolytinae and Buprestidae, respectively. Their capacity to catch larger beetles must still be tested. Other taxa, e. g. Lepidoptera or Diptera, are not very likely targets, because they could probably veer off, or land, when hitting the vertical panel. The proportionally large wings of the moths and butterflies might also prevent them to fall into the collecting pots.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Supplementary_S1_fantrap_description: practical information for constructing the fan-traps; Supplementary_S2_Table_S2: detailed results of the experiment described in section 3.2.1. (Comparisons with bottle-traps); Supplementary_S3_Table_S3: detailed results of the experiment described in section 3.2.2. (Comparisons with bottle traps and two commercial trap models); Supplementary_S4_fantrap_Blueprint_Fantrap1: blueprint; Supplementary_S5_fantrap_Blueprint_Fantrap2: blueprint; Supplementary_S4_fantrap_Blueprint_fantrap3: blueprint; Supplementary_S6_fantrap_Blueprint_fantrap3nested: example of a nested blueprint.

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and S.H.; data curation, J.-C.G., E.C. and S.H.; writing—original draft preparation, J.-C.G.; writing—review and editing, J.-C.G., E.C., S.H., J.-M.M. and S.W.; funding acquisition, J.-C.G. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: All data are available in the Supplementary Materials.

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