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The development of a multipurpose trap (the Nzi) for tsetse and other biting flies

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Abstract

New trap designs for tsetse (Glossinidae), stable flies (Muscidae: Stomoxyinae), and horse flies (Tabanidae) were tested in Kenya to develop a multipurpose trap for biting flies. Many configurations and colour/fabric combinations were compared to a simplified, blue-black triangular trap to identify features of design and materials that result in equitable catches. New designs were tested against conventional traps, with a focus on *Glossina pallidipes* Austen and *G. longipennis* Corti, *Stomoxys niger* Macquart, and *Atylotus agrestis* (Wiedemann). A simple design based on minimal blue and black rectangular panels, for attraction and contrast, with a trap body consisting of an innovative configuration of netting, proved best. This 'Nzi' trap (Swahili for fly) caught as many or significantly more tsetse and biting flies than any conventional trap. The Nzi trap represents a major improvement for Stomoxyinae, including the cosmopolitan species *S. calcitrans* (Linnaeus), with up to eight times the catch for key African *Stomoxys* spp. relative to the best trap for this group (the Vavoua). Catches of many genera of Tabanidae, including species almost never caught in traps (*Philoliche* Wiedemann), are excellent, and are similar to those of larger traps designed for this purpose (the Canopy). Improvements in capturing biting flies were achieved without compromising efficiency for the savannah tsetse species *G. pallidipes*. Catches of *fusca* tsetse (*G. longipennis* and *G. brevipalpis* Newstead) were higher or were the same as catches in good traps for these species (NG2G, Siamese). Altogether, the objective of developing a simple, economical trap with harmonized efficiency was achieved.

Introduction

Numerous traps for tsetse (Glossinidae, *Glossina* spp.) and other large biting flies (Tabanidae or horse flies, Muscidae: Stomoxyinae or stable flies) have been developed by researchers studying different species on different continents. In Africa, the transmission of pathogenic trypanosomes prompted the early development of many efficient devices (Cuisance, 1989) and baits (Green, 1994) for both the sampling and control of tsetse as vectors. Only minimal effort was devoted to biting flies (Ryan & Molyneux, 1982; Vale, 1982). Outside Africa, researchers have designed many traps for biting insects (Muirhead-Thomson, 1991), but detailed behavioural studies are few (Allan *et al*., 1987), and there are only rare examples of their use for control (Foil & Hogsette, 1994). Hence, much of what is known about host and trap-oriented behaviour is derived from studies of tsetse (Gibson & Torr, 1999).

Until the development of a practical cloth trap (biconical) for riverine tsetse in West Africa (Challier *et al*., 1977), tsetse and other biting flies were often collected with cumbersome traps resembling animals (Swynnerton, 1933; Morris, 1963), or were collected manually with nets (Glasgow, 1946; Kangwagye, 1974). After the refinement of the blue-black format of the biconical trap, similar compact square (F3) or triangular (Epsilon) cloth traps were refined for savannah tsetse in Zimbabwe (Flint, 1985; Hargrove & Langley, 1990). These designs also caught biting flies, but were used mostly for tsetse. In Kenya, the triangular format was eventually adapted to a more practical, economical design (NG2G) for use in community-based tsetse control (Brightwell *et al*., 1987, 1991). Parallel improvements occurred for riverine tsetse, with the development of simpler traps (pyramidal, Vavoua)

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for large-scale use in vector control in East and West Africa (Gouteux & Lancien, 1986; Laveissière & Grébaut, 1990). Efforts to develop traps for tsetse have continued to date, with occasional new designs for specific fauna (Mhindurwa, 1994; Ndegwa & Mihok, 1999; Kappmeier & Nevill, 2000).

Outside Africa, traps for biting flies have remained relatively unchanged since the development of practical designs in the 1960s and 1970s in North America. For sampling tabanids, researchers typically use Canopy or Malaise traps (Roberts, 1976; Schreck *et al.*, 1993) derived from older designs, such as the Manitoba horse fly trap (Thorsteinson *et al.*, 1965). Tabanid traps have been refined for certain species (French & Hagan, 1995), but there are few examples of their use for control (Ailes *et al.*, 1992). For stable flies, researchers have relied on objects coated with sticky materials, rather than traps in the conventional sense. The first widely-adopted stable fly trap was a small cross made from translucent Alsynite® fibreglass panels coated with adhesive (Williams, 1973). Modern sticky traps have changed little since 1973, except for the use of a cylindrical format (Broce, 1988; Cilek, 1999). In Africa, researchers have only recently tested many trap styles against stable flies (Holloway & Phelps, 1991; Mihok *et al.*, 1995, 1996a,b) and tabanids (Phelps & Holloway, 1992; Amsler *et al.*, 1994).

Owing to the geographic separation of both researchers and target insects, there has never been a concerted effort to harmonize trap designs for all biting flies. There are a bewildering variety of traps, each with major idiosyncrasies in capture efficiency. This technical detail has limited the adoption of traps for vector and/or nuisance fly control by the public, leaving traps in the domain of academic researchers. This study undertook to compare the basic features of traps in a comprehensive and systematic fashion. The objective was to develop a simple, non-technical and economical trap, with minimal bias in efficiency, for as many groups of biting flies as reasonably achievable. The outcome is a practical cloth trap (the Nzi), based on extensive studies conducted in East Africa.

Materials and methods

Study areas

Experiments were conducted at eight locations in Kenya, mostly during, or shortly after rainy seasons, in order to sample tsetse and biting flies simultaneously. About 70% of the effort (trap-days) was carried out at Nguruman in the southwest Rift Valley (Dransfield *et al.*, 1990), an area with high year-round populations of *Glossina pallidipes* Austen and *G. longipennis* Corti, and seasonally-high populations of *Stomoxys niger* Macquart (Muscidae) and tabanids, especially *Atylotus agrestis* (Wiedemann). Other areas with tsetse included Shimba Hills National Reserve south of Mombasa (*G. pallidipes*, *G. brevipalpis* Newstead, *G. austeni* Newstead) (Kyorku *et al.*, 1995), Ruma National Park in the Lambwe Valley (*G. pallidipes)* (Wellde *et al.*, 1989), the shores of Lake Victoria near Mbita Point (*G. fuscipes fuscipes* Newstead) (Mwangelwa *et al.*, 1990) and the Ewaso Ngiro River Valley south of Maralal near Kirimun (*G. longipennis*). A few trials were conducted in areas with no tsetse, but with many Stomoxyinae (Mihok *et al.*, 1995, 1996a): Nairobi National Park, the International Centre of Insect Physiology and Ecology (ICIPE) large animal facility, and a residential Nairobi garden (bordering a partially-forested river valley).

Trapping

Unless stated otherwise, the blue and black components of traps were made from the same new cotton fabric. To avoid the effects of weathering, traps were reused once or twice only. Except for the last experiment, blue and black cotton came from a single lot from Mount Kenya Textiles, Nanyuki, Kenya. This local 'Jinja' cotton is manufactured in East Africa to a 90 cm width. It is only semi-opaque, with a crude matt finish and a plain weave. It shrinks about 10% during exposure to sun and rain. Trap cones were made from stiff, white polyester mosquito netting from one source (formerly Ace/Tigra Knit, Nairobi). Tests of 100% polyester blues, blacks and a new texturized netting were conducted with experimental fabrics supplied by Vestergaard Frandsen A/S (abbreviated as VF, Kolding, Denmark). Full details are given with descriptions of each experiment, with a summary in appendix 1.

A new standard trap (STD) was included in the first series of experiments to guide the design process (fig. 1). It had a triangular shape with dimensions of 90 cm to a side, following the example of the NG2F (Brightwell *et al.*, 1991). The back portion under the netting cone was all black. The body was closed by a blue top front shelf, providing a 90 × 45 cm bottom front entrance. The front entrance was flanked by two blue 'wings', 45 cm wide. The STD trap was inspired by the suggestion that the best format for a target for *G. pallidipes* would be a 1-m piece of black cloth flanked by 0.5-m panels of blue (Vale, 1993).

Conventional traps were included in most experiments to test and then validate design modifications for specific groups of flies, based on catch expectations in different areas and seasons. The traps were: NG2G, a triangular, one-winged trap designed for *G. pallidipes* and *G. longipennis* in Kenya (Kyorku *et al.*, 1990; Brightwell *et al.*, 1991; Baylis & Nambiro, 1993), also a good trap for Tabanidae (Amsler *et al.*, 1994); a modified Epsilon, a triangular trap with a recessed cone designed for *G. pallidipes* and *G. morsitans morsitans* Westwood in Zimbabwe (Hargrove & Langley, 1990); M3, a triangular trap with multiple entrances for the same species in Zimbabwe (Mhindurwa, 1994); Siamese, a cuboidal trap with two entrances and a central partition designed for *G. pallidipes* and *G. brevipalpis* in Kenya (Kyorku *et al.*, 1995); Biconical, a compact trap with small oval entrances for riverine tsetse (Challier *et al.*, 1977); Vavoua, a monoconical trap with an open bottom for riverine tsetse, also an excellent trap for Stomoxyinae and other muscids (Laveissière & Grébaut, 1990; Mihok *et al.*, 1995, 1996a); Écran-piège, originally a target for riverine tsetse (Gouteux & Noireau, 1986), modified to a trap format for tabanids in Burkina Faso (Amsler *et al.*, 1994); Sticky-cross, small wooden panels in blue and black in the shape of a cross covered in polybutene (type XTBuBl), formerly used in South Africa to sample *G. austeni* (Vreysen *et al.*, 1998); Manitoba, a slightly-modified version of the original Canadian horse fly trap consisting of a shiny black ball suspended under a pentahedral plastic canopy (Hansens *et al.*, 1971); and Canopy, a modern horse fly trap with a very large cone and a lower band of black cloth (Hribar *et al.*, 1991).

Traps were normally baited with industrial-grade acetone, Maasai zebu cow urine aged for two to three weeks, and research-grade 1-octen-3-ol (octenol). The baits were dispensed at high rates from bottles with appropriate aperture sizes placed at the base of traps (Mihok *et al.*, 1995, 1996b). This combination of attractants was chosen to mimic the baits used by Maasai pastoralists for the control of tsetse

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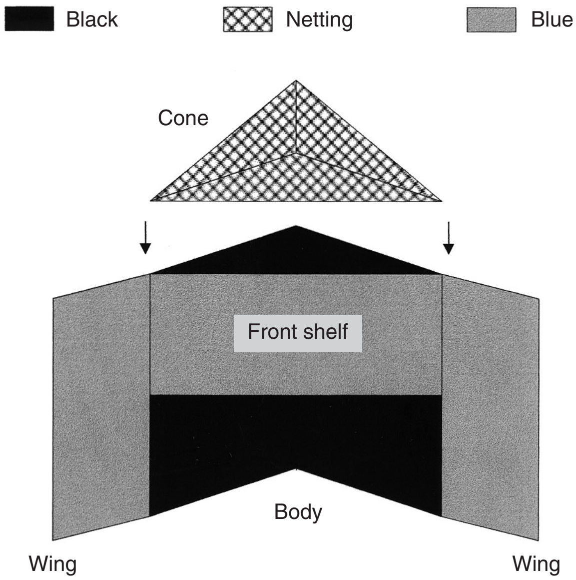

Fig. 1. Schematic view of the standard triangular trap (STD) used in experiments 1–12 in series 1. The body of the trap is in the shape of an equilateral triangle, 90 cm along each side, with a blue front, a black back and a lower front entrance. It is topped by a tetrahedron 'cone' of white netting.

at Nguruman (Dransfield *et al.*, 1990). In areas without tsetse, traps were either not baited, or were baited with octenol (1–2 mg h^{-1}); octenol is a useful bait for African Stomoxyinae (Mihok *et al.*, 1995, 1996a).

Experimental designs

Most experiments were Latin-square designs where the number of sites and days was equal to the number of traps tested (Perry *et al.*, 1980). The two most common designs were thrice-replicated 7 × 7 or 8 × 8 Latin squares (11 of 23 trials). At the ICIPE large animal facility and at the Nairobi garden site, three experiments were conducted using a randomized blocks design at one site, rotating traps among sequential days. Each complete rotation among days represented a statistical block (Mihok *et al.*, 1995).

Statistical analyses were done with log(n + 1)-transformed data using analysis of variance (Mihok *et al.*, 1996b). Differences among treatments were tested with the Student-Newman-Keuls test (*SNK* at $P < 0.05$). Statistics were calculated for each major group of flies (tsetse by species, Stomoxyinae, Tabanidae, non-biting Muscinae). When sample sizes warranted, analyses were repeated at the lowest possible taxonomic level (genus, species, sex). Due to the massive amount of information generated, only data of relevance to trap development are presented in detail. Results are summarized in terms of a Catch Index relative to a standard trap in each major series of experiments (ratio of backtransformed treatment mean to the backtransformed mean of the standard). A comprehensive guide to experiments is given in appendix 2.

Characterization of trap materials

Diffuse reflectance (cloth) or transmittance (netting and plastic) was measured to guide the selection of colour contrasts. Measurements were made between 370 and 790 nm with a Li-Cor 1800 spectroradiometer (Lincoln, Nebraska) equipped with an integrating sphere (Endler, 1990). A single layer was measured in triplicate against a black background (reflectance) or a white background (transmittance) at 1 nm intervals. Pressed barium sulphate was used as a working standard for the calibration of 100% reflectance. Repeatability was ± 1% or better.

For interpretation according to human perception (MacAdam, 1985), colour indices (appendix 1) were calculated, based on a Commission Internationale de l'Éclairage (CIE) 1931 standard 2° observer for illuminant D_{65} (average daylight at the correlated colour temperature of 6500°K). By convention, colour is characterized through three indices: Y, the tristimulus value corresponding to luminous reflectance/transmittance relative to a white, perfectly-reflecting surface; and x and y, the normalized trichromaticity coordinates representing the combined spectral energy and visual response functions in the red (x) and green (y) regions. The trichromaticity coordinates define Excitation purity, the purity relative to a monochromatic spectral colour of 100% purity at the indicated dominant wavelength. The complimentary dominant wavelength is given for purples (denoted with the subscript c). As insect vision differs from human vision, particularly in terms of heightened sensitivity in the ultraviolet (Young *et al.*, 1987), and lack of sensitivity to red, average reflectance or transmittance between 370 and 400 nm (appendix 1) was also calculated. The integrating sphere detector of the Li-Cor 1800 cannot measure reflectance quantitatively below 370 nm; however, none of the fabrics had substantial reflectance below this wavelength.

Experiments and Results

Series 1: improving the triangular trap

Effects of colour substitutions at the front of the trap

Experiments 1–3 were thrice-replicated 7 × 7 Latin squares, set within the tsetse suppression zone of Nguruman during the short rainy season of 1993 (November–December). The objective was to test the standard trap in a limited number of attractive colours (Green, 1986; Torr, 1989) against a selection of conventional traps (NG2G, Siamese, Vavoua), keeping the back of the trap either blue or black. Contrasting reds and purples were chosen to investigate suggestive correlations between tsetse trap catches and red reflectance (Green & Flint, 1986). A dark green and a bright turquoise were also chosen to mimic the effects of contrasting vegetation (colour statistics are summarized in appendix 1). In experiment 1, the back of the trap was black (colour 0); in experiment 2 it was blue (colour 1); in both experiments, only the colour of the front was varied (wings and shelf). In experiment 3, one colour was retested (dark red front, with the back either blue or black) along with two colour variations of the Siamese trap (dark red or bright turquoise substituted for blue). Experiment 4 was a repeat of experiment 3, with the coloured versions of the Siamese trap dropped from the design (5 × 5 Latin squares). Experiment 4 was conducted in Ruma Park in the Lambwe Valley in March, just at the start of the rainy season.

Initial colour trials produced mostly non-significant results and few clear patterns; all four experiments are therefore summarized in table 1. Only substitutions with

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Table 1. Catch indices (ratio of backtransformed means) for traps in experiments 1–4 relative to the STD trap.

Expt	Trap details	*Glossina pallidipes*	*G. longipennis*	Tabanidae
	Back of trap is BLACK, Wings/Shelf are			
1	Dark red no. 3	1.13	1.54	0.82
3	Dark red no. 3	0.91	**1.86***	**0.54***
4	Dark red no. 3	0.84	ND	1.12
1	Dark reddish purple no. 6	0.85	1.01	0.71
1	Dark bluish purple no. 5	0.89	0.88	0.97
1	Dark green no. 8	0.71	0.90	0.76
1	Bright turquoise no. 9	0.82	0.79	1.04
	Back of trap is BLUE, Wings/Shelf are			
2	Dark red no. 3	0.69	1.62	0.62
3	Dark red no. 3	0.91	1.08	**0.65***
4	Dark red no. 3	1.12	ND	1.17
2	Bright red no. 4	0.71	1.46	0.75
2	Dark reddish purple no. 6	0.70	1.38	0.82
2	Dark green no. 8	**0.54***	1.55	0.89
2	Bright turquoise no. 9	0.63	1.24	1.06
	Conventional traps			
1	Vavoua	**0.49***	**0.74***	**0.18***
3	NG2G	1.08	1.64	**0.53***
4	NG2G	1.16	ND	0.81
2	Siamese	**0.33***	**0.69***	0.66
3	Siamese	**0.61***	1.11	**0.65***
4	Siamese	0.68	ND	**0.64***
3	Siamese dark reddish purple no. 7	0.65	1.36	**0.50***
3	Siamese bright turquoise no. 9	**0.53***	0.85	0.78

Expt, experiment; ND, no data (*G. longipennis* is not in Ruma Park). Catches that differed significantly from those in the STD trap are marked in bold face with an asterisk ($P < 0.05$, *SNK* test). Colour variations are sorted in descending order according to the degree of redness (value of CIE index x in appendix 1).

pure reds showed potential for trap improvement. In four of five tests, catches of *G. longipennis* were increased by about 50% with red panels, once significantly so by 86%. Improvements in catch with red panels were accompanied by significant reductions in the catch of Tabanidae, which were caught in particularly large numbers in experiment 3 (97% of these were *A. agrestis*). The STD trap performed as well as, or significantly better than, the three conventional traps.

Performance of some red, blue and black traps

The possibility of using red panels to increase the catch of *G. longipennis* was examined further in experiments 5 and 6 in thrice-replicated 7 × 7 Latin squares, set during and shortly after the long rainy season of 1994 at Nguruman (May–June). Experiments were relocated to Shompole north of Lake Natron, where no tsetse suppression was taking place. The timing and location of these experiments ensured substantial catches of all species. A medium red Jinja cotton (colour 15, appendix 1) was chosen as a replacement for the polyester/cotton fabrics used previously. All-red, all-black or all-blue traps were first compared to red-blue, red-black and black-blue (front-back) traps in experiment 5. Red-blue, blue-red and black-blue traps were compared to NG2G, Vavoua and Manitoba traps in experiment 6. All-red, all-blue and all-black traps were then compared to blue-red, blue-red/black and Vavoua traps in experiment 7. Experiment 7 was conducted in an area with a different fauna at Shimba Hills, during the short rainy season in October 1994.

As in previous experiments, modifying the STD trap by interchanging blue, black and red panels showed little promise (table 2). Traps of a single colour caught the same number of flies or statistically fewer flies than the STD trap with no apparent pattern. The single exception was the puzzling trend for an increase in the catch of *G. longipennis* (45%, 36%) in configurations where red was used for the back of the trap (now with an exact match in materials). No increase in catch with red was noted for the other *fusca* tsetse, *G. brevipalpis*. Altogether, four species of tsetse and many genera and species of biting flies were sampled in these experiments, some at quite high density (appendix 2). As before, the STD trap performed as well as or better than the NG2G and Vavoua traps. The Manitoba trap performed poorly for all flies, including the tabanids *A. agrestis*, *Tabanus taeniola* Palisot de Beauvois, and *T. conformis* Walker. As in previous studies (Mihok *et al*., 1995), the Vavoua trap performed extremely well for Stomoxyinae (92% of which were *Stomoxys niger niger* Macquart).

Modifications to the trap body

As colour substitutions at the front of the trap were not productive, the effect of replacing the black back of the trap with a few select colours was investigated, while keeping the front in an attractive colour (blue). These substitutions were tested at Nguruman at the end of the rainy season in December 1994 to January 1995 in two thrice-replicated 8 × 8 Latin square experiments. The objective was to test 'background' modifications that might focus fly activity

Table 2. Catch indices for traps in experiments 5–7 relative to the STD trap.

Expt	Trap details	*Glossina pallidipes*	*Fusca* tsetse	*G. austeni*	Tabanidae	Stomoxyinae
	Solid colours: Shelf, Wings and Back of trap all in one colour					
5	Blue	0.85	0.68	ND	1.01	1.63
7	Blue	**0.51***	0.64	1.06		
5	Black	1.04	0.94	ND	0.93	**0.44***
7	Black	0.66	0.83	**0.71***		
5	Red	0.72	1.45	ND	0.62	**0.63**
7	Red	**0.57***	0.66	**0.71***		
	Mixed colours: Shelf/Wings – Back					
5	Red–Blue	0.97	0.82	ND	0.90	0.84
6	Red–Blue	1.00	0.77	ND	0.93	1.12
6	Blue–Red	1.00	1.36	ND	0.87	0.90
7	Blue–Red	0.94	0.99	0.81		
5	Red–Black	0.79	0.90	ND	0.73	**0.52***
7	Blue–Red/Black	0.70	**0.51***	0.81		
5	Black–Blue	1.00	0.86	ND	1.25	1.06
6	Black–Blue	0.81	0.86	ND	1.17	0.78
	Conventional traps					
6	NG2G	0.93	1.00	ND	**0.57***	0.51
6	Vavoua	**0.48***	0.96	ND	**0.27***	**3.06***
7	Vavoua	**0.33***	0.72	**0.57***		
6	Manitoba	**0.07***	**0.33***	ND	**0.29***	**0.35***

Expt, experiment; ND, no data (*G. austeni* is not at Nguruman). *Fusca* tsetse – *G. longipennis* in experiments 5 and 6, *G. brevipalpis* in experiment 7. Red is colour no. 15 (appendix 1). Catches that differed significantly from those in the STD trap are marked in bold face with an asterisk ($P < 0.05$, *SNK* test). Empty cells reflect catches too low for analysis.

towards the front blue surfaces, and hence the trap entrance (Green, 1993a). In experiment 8, bright violet, dark bluish purple, bright turquoise, light green and medium red cloth (all identical Jinja cotton, appendix 1), and transparent plastic, were substituted for the back of the trap. A modified Epsilon trap was also tested. The modification (removal of the front horizontal blue shelf, substitution of white netting for the dark netting used in Zimbabwe) allowed for a clearer comparison of the Epsilon design relative to the STD trap. It now had only two unique features: a low cone and a blue/black back relative to the high cone and the all-black back of the STD trap. In the next experiment (no. 9), six versions of a trap with a blue front, with half of the all-black back replaced with white netting (fig. 2) were tested. The Vavoua trap was included to provide a comparison with an optimal trap for *Stomoxys* spp.

Replacing the back of the trap with transparent plastic resulted in large increases in the catch of Stomoxyinae (3.42×, table 3) and non-biting Muscinae (2.54×, data not shown) relative to the STD trap, with no significant change in the catch of tabanids (1.27×, data not shown), and *G. longipennis* (0.65×, table 3). This increase in catch was consistent for the three *Stomoxys* spp. captured at high numbers (*S. niger bilineatus* Grünberg, *S. niger niger*, *S. taeniatus* Bigot). Unfortunately, major improvements in the catch of both biting and non-biting Muscidae coincided with a reduced catch of a critical tsetse species, *G. pallidipes* (0.41×). Colour substitutions mostly decreased the catch of *G. pallidipes*, but did not affect the catch of other flies. There was no indication of an increase in catch of *G. longipennis* with red. The modified Epsilon trap performed poorly for both tsetse.

In experiment 9, all configurations of white netting and black panels at the back of the trap (fig. 2) resulted in promising, but non-significant ($P = 0.06$), increases in the catch of Stomoxyinae (93% of which were *S. niger bilineatus*), with no significant change in the catch of *G. longipennis* (table 3), or tabanids (data not shown). As before, catches of *G. pallidipes* were reduced significantly, with the smallest reduction in the Edge configuration. The Edge trap caught many *G. longipennis* and Stomoxyinae relative to both the Vavoua and the STD trap; it was therefore retained as the basis for further design modifications.

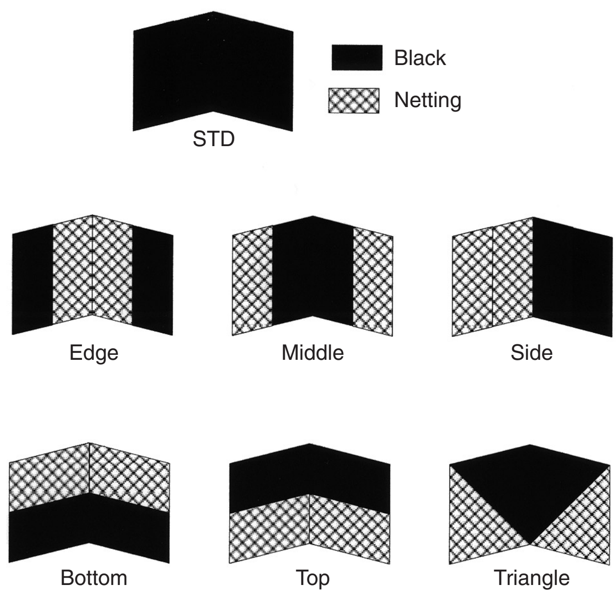

Fig. 2. Configurations of black cloth and white netting in the back of traps in experiment 9 (wings, shelf and cone are constant and are not shown).

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Table 3. Catch indices for traps in experiments 8–9 relative to the STD trap.

Expt	Trap details	*Glossina pallidipes*	*G. longipennis*	Stomoxyinae
8	Front is BLUE, Back is			
	Bright violet no. 10	**0.58***	0.73	1.22
	Dark bluish purple no. 11	0.86	1.28	1.48
	Bright turquoise no. 12	**0.64***	0.96	1.23
	Light green no. 13	**0.61***	0.74	1.14
	Transparent plastic no. 14	**0.41***	0.65	**3.42***
	Medium red no. 15	1.14	0.83	1.32
9	Front is BLUE, Back is netting and black with configuration as in fig. 2			
	Edge	**0.67***	1.25	1.88
	Middle	**0.50***	1.18	2.18
	Side	**0.45***	0.73	1.63
	Bottom	**0.52***	1.14	2.11
	Top	**0.59***	0.65	1.31
	Triangle	**0.59***	0.70	1.42
	Conventional traps			
8	Modified Epsilon	**0.15***	**0.16***	1.57
9	Vavoua	**0.42***	0.98	2.54

Expt, experiment. Catches that differed significantly from those in the STD trap are marked in bold face with an asterisk ($P < 0.05$, *SNK* test).

Prior to designing a complex field experiment, the performance of the Edge trap was validated for peridomestic Muscidae relative to an efficient trap for this group (the Vavoua) at the ICIPE large animal facility during the dry season of February–March, 1995. The main objective was to confirm that the cosmopolitan species *S. calcitrans* (Linnaeus) would respond to transparent panels at the back of the trap in the same fashion as other *Stomoxys*, before proceeding further. The trial used unbaited traps in a randomized blocks design with 4 trap types per block with 13 sequential replicates. The other traps tested were the STD trap with an all plastic back (as in experiment 8), and the STD trap with an all netting back. Mean catches in the Vavoua trap were 7.6 *Stomoxys* (mostly *S. calcitrans*) and 23.9 non-biting Muscinae per day. All new designs caught significantly more flies than the Vavoua trap, with no significant differences among the three designs. As in experiment 9, the Edge design performed best (3.1× the catch in a Vavoua trap for *Stomoxys*, 2.3× for non-biting Muscinae).

Modifications to the trap interior

To improve the Edge design, solid panels were added to the body interior or the upper cone to minimize escapes by directing flies already inside the trap away from the front entrance, as in the logic used to refine the F3 trap in Zimbabwe (Flint, 1985). In experiment 10, six versions of the Edge trap were compared at Nguruman in a thrice-replicated 8 × 8 Latin square during the rainy season in April 1995. The M3 trap was included to investigate the efficacy of multiple entrances, a low cone and interior shelves. The trap variations (fig. 3) were: Edge, as in experiment 9 with a blue front and black/netting back; Reverse, with a black front and a blue/netting back; Horizontal Shelf, with a black shelf extending horizontally half-way into the body of the trap (as in the blue shelf used in the Epsilon trap); Vertical Shelf, with a black shelf as a partition in the middle of the trap extending up into the cone (as in many traps for riverine tsetse); Black Cone, with the front panel of the cone replaced with black (to entice flies to move up and forward); and Blue Cone, with the two rear panels of the cone replaced with blue (to entice flies to move up and backward).

As only traps with interior shelves (Horizontal Shelf, M3) performed well for all flies, this feature was focused on in experiment 11, a thrice-replicated 8 × 8 Latin square conducted at Nguruman in early May 1995 during rainy weather. Seven versions of the Edge trap were tested with different transparent/opaque interior panels. The objective was to achieve a bias towards entry versus escape, e.g. by making it difficult for flies to orient towards the entrance once inside the trap body. The trap variations (fig. 4) were: Horizontal Shelf, with a black shelf as in experiment 10; Horizontal Net, the same trap with the shelf made of

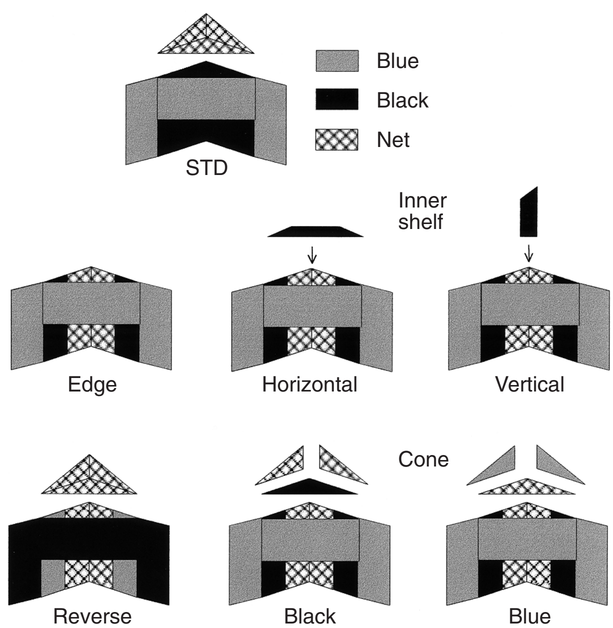

Fig. 3. Variations on the Edge trap in experiment 10. The cone is not shown in the first tier of three traps.

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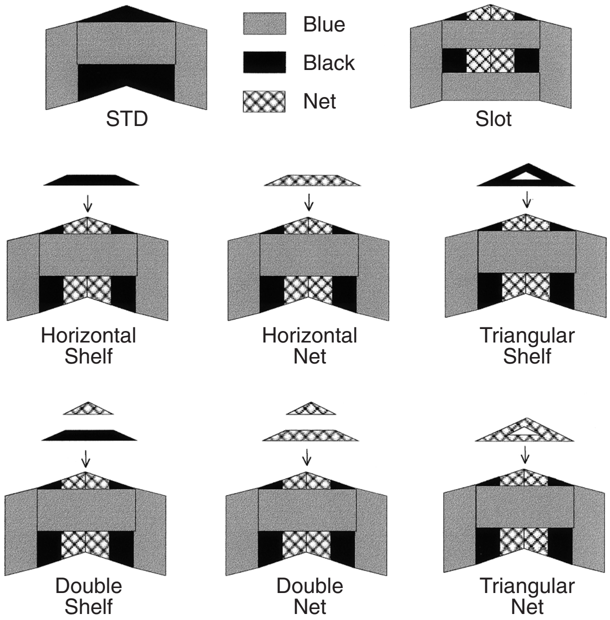

Fig. 4. Variations on the Edge trap in experiment 11. The cones are omitted.

netting; Double Shelf, the Horizontal Shelf trap with a second horizontal netting shelf at the back at the bottom of the cone; Double Net, the Horizontal Net trap with a second top netting shelf; Triangular Shelf, with a black horizontal 15-cm wide shelf on all three sides (as in the M3); Triangular Net, the same trap with the shelf made of netting; and Slot, with no interior baffles but with the entrance moved up by 22.5 cm by dividing the front blue shelf into top and bottom sections.

Lastly, the best version of the Edge trap with good efficiency for all groups of flies (Horizontal Net) was tested in three colours at Nguruman against four efficient conventional traps in late May 1995. Experiment 12 was a thrice-replicated 8 × 8 Latin square conducted at the annual peak in fly density during dry weather, just after the rainy season. For convenience, the Horizontal Net trap will now be referred to as the Nzi-I (Nzi-Initial, nzi is the Swahili word for fly). The colour variations were red or blue substitutions for the black (Nzi-I Blue, Nzi-I Red). The conventional traps were the Biconical, NG2G, Vavoua and M3.

In experiment 10, all six versions of the Edge trap caught significantly more Stomoxyinae and *G. longipennis* than the STD trap, with no significant differences in the catch of tabanids (table 4). The version with a horizontal black shelf caught about twice as many *G. pallidipes* as the STD trap; other modifications to the trap layout were not effective for this species. The M3 trap, with a horizontal inner shelf along all sides, also performed well. In experiment 11, all four versions of the Edge trap with single or double horizontal shelves in either black or netting caught significantly more Stomoxyinae, *G. longipennis* and *G. pallidipes* than the STD trap, with no significant differences in the catch of tabanids (table 4). The Horizontal Net version was uniformly best for all groups of flies; it caught a phenomenal 8.7× as many Stomoxyinae as the STD trap.

Table 4. Catch indices for traps in experiments 10–12 relative to the STD trap.

Expt	Trap details	*Glossina pallidipes*	*G. longipennis*	Tabanidae	Stomoxyinae
10	Effect of adding inner black partitions, reversing the blue and the black, or adding solid panels to the cone in the Edge trap as in fig. 3				
	Edge	1.02	**1.90***	0.87	**2.87***
	Horizontal Shelf	**1.89***	**2.99***	0.85	**2.61***
	Vertical Shelf	1.23	**1.69***	0.89	**2.84***
	Reverse	0.85	**1.82***	1.05	**3.00***
	Black	**0.65***	**1.52***	0.78	**2.43***
	Blue	**0.48***	**2.15***	0.94	**2.33***
11	Comparisons of various inner partitions in black or netting relative to the optimal Horizontal Shelf version of the Edge trap as in fig. 4				
	Horizontal Net	**1.72***	**3.01***	1.28	**8.68***
	Double Net	**1.41***	**2.51***	0.82	**6.15***
	Double Shelf	**1.74***	**2.10***	0.79	**3.28***
	Horizontal Shelf	**1.73***	**2.32***	0.86	**2.44***
	Slot	**0.58***	**1.52***	0.97	**2.13***
	Triangular Net	**0.74***	**1.56***	0.75	1.42
	Triangular Shelf	1.20	**1.73***	**0.70***	1.07
12	Comparison of blue and red substitutions for black in the back of the trap in the optimal version of the Edge trap (Nzi-I = Horizontal Net version above)				
	Nzi-I	1.62	**2.79***	1.12	ND
	Nzi-I Red	1.31	**2.49***	1.15	ND
	Nzi-I Blue	1.21	1.41	1.27	ND
	Conventional traps				
10	M3	**1.92***	**2.36***	0.81	**3.29***
12	M3	1.25	1.64	**0.49***	ND
	NG2G	1.26	1.61	**0.74***	ND
	Vavoua	**0.55***	0.74	**0.18***	ND
	Biconical	**0.32***	0.78	**0.26***	ND

Expt, experiment; ND, no data presented for Stomoxyinae in experiment 12 due to very low catches. Catches that differed significantly from those in the STD trap are marked in bold face with an asterisk ($P < 0.05$, *SNK* test). No conventional trap was used in experiment 11.

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Experiment 12 was conducted at very high densities of *G. pallidipes* (maximum catch of 5304 flies per day in the Nzi-I) and modest densities of tabanids (maximum catch of 51 in the Nzi-I, 97% of which were *A. agrestis*). Tabanidae were at low density in the previous three experiments when critical design options were being tested. Stomoxyinae were, unfortunately, at low density when this experiment was conducted. Results were straightforward in that the Nzi-I trap performed best for all groups of flies, either numerically or statistically (table 4). The Nzi-I trap caught significantly more *G. longipennis* than the STD trap, and also caught significantly more *G. longipennis* and Tabanidae than any of the conventional traps. Except for a drop in the catch of *G. longipennis* with a blue back, use of coloured back panels in place of black did not have an appreciable effect on these patterns.

Series 2: validation and optimization of the Nzi trap

A second series of 11 experiments was started in June 1995 to validate the design decisions leading to the development of the Nzi-I trap. Hence, the Nzi-I was now used as an experimental standard in place of the solid blue/black triangular trap (STD). The overall objective was to validate its performance against many species in diverse environments relative to the 'best' conventional traps. These comparisons were done in a selective manner, targeting seasonal peaks in density in various areas of Kenya. This was deemed necessary as key final decisions on the ideal trap format (experiments 9–12) were mostly based on the behaviour of common species at Nguruman: the tsetse *G. pallidipes* and *G. longipennis*, the tabanid *A. agrestis*, and the stable flies *S. n. bilineatus* and *S. n. niger*. A few variations in format (colour, size, cloth types, etc.) were tested to establish whether certain minor options would be more effective.

Performance against stable flies

An important application of a useful trap would be the control of biting flies near confined livestock. Experiment 13 therefore targeted peridomestic *Stomoxys* at the ICIPE large animal facility in June 1995. As in experiment 12, blue and red substitutions for the black back of the Nzi-I trap were tested against the Nzi-I and the Vavoua trap. The trial used unbaited traps in a randomized blocks design with 4 trap types per block with 9 sequential replicates. No odour baits were used on the assumption that octenol would not increase catches near animals (Mihok *et al*., 1995). The Nzi-I trap and the red version were then retested against the Vavoua in experiment 14 in a thrice-replicated 3 × 3 Latin square in Nairobi Park in July. Octenol was used as an odour bait in order to increase the catch of certain species (Mihok *et al*., 1996a). Experiment 15 was then set up in a Nairobi garden to compare cotton and polyester versions of the Nzi-I using a new trap fabric introduced by Vestergaard Frandsen A/S (VF, Kolding, Denmark) for tsetse control (Colour 16 or Blue 589, and its matching black polyester). The traps were baited with octenol and compared in paired blocks with 8 replicates.

An unbaited Nzi-I trap caught more *S. calcitrans*, *S. n. niger* and *S. n. bilineatus* in a peridomestic setting than any other trap in experiment 13, with a highly significant increase in catch relative to the Vavoua trap for both *S. niger* subspecies (about 7–8× the catch, table 5). Red- and blue-backed versions of the Nzi-I trap caught fewer stable flies and non-biting Muscinae than the black-backed version, but differences were mostly not significant. When baited with octenol in experiment 14, the Nzi-I trap also caught significantly more, or statistically equal numbers, of seven taxa of *Stomoxys* relative to the Vavoua trap, again with a very large increase in catch for the dominant fly *S. niger bilineatus* (5×). None of the wild *Stomoxys* in Nairobi Park were caught in significantly different numbers in the red-backed version of the Nzi-I trap relative to the black version. The Vavoua trap caught about 50% more non-biting Muscinae than the Nzi-I trap in both settings, but this difference was not significant. In experiment 15, the polyester version of the Nzi-I trap performed as well as the cotton version for all groups of flies.

Performance against tabanids and tsetse

During Series 1, tabanids other than *A. agrestis* were often not present in large numbers when trap designs were being changed based on increases in the catch of tsetse or *Stomoxys*. Hence, a few trials were conducted focusing on diverse tabanids to validate some of the design options incorporated in the Nzi-I. In experiment 16 at Kirimun in June 1995, previous trials were first repeated with coloured Nzi-I traps in an attempt to catch the tabanid typical of desert areas after seasonal rains (the genus *Philoliche* Wiedemann, (Dirie *et al*., 1989)). This experiment also targeted *G. longipennis,* which appeared to be responding to red in many experiments at Nguruman. The experiment was a 5 × 5 Latin square in duplicate testing the Nzi-I, Nzi-I Blue, Nzi-I Red, STD and Vavoua traps.

Results are not reported in detail as the seasonal peak of tabanids occurred before the experiment was conducted (average of only 0.4 *Philoliche* caught per trap per day, with a maximum catch of 4). All trap comparisons for *Philoliche* and for other tabanids were not significant. Catches of *G. longipennis* were also low in this dry habitat (appendix 2), but sufficient for statistical inference. As found in many trials at Nguruman with traps including red, the red version of the Nzi-I caught the highest numbers of *G. longipennis* (1.92× the STD trap, versus the Nzi-I at 1.54× the STD trap, Nzi-I Blue at 0.99×, Vavoua at 1.00×). As before, catch differences among traps were marginally not significant ($P = 0.10$).

An exploratory trial (experiment 17, 8 × 8 Latin square with no replication) was then conducted at Nguruman in August to provide guidance on further tests of minor variations in trap format. An optimal tabanid trap was included for reference (the Canopy), in the event that tabanids were at high numbers. The treatments (fig. 5) were: Nzi-I; Nzi-I Black, with the blue front replaced with black, i.e. an all-black version; Nzi-I Reverse, with the blue and black reversed; Nzi-I No Wings, with the two blue wings removed; Nzi-I Black Shelf, with the front vertical blue shelf replaced with black; Nzi-I Net Shelf, with the front blue vertical shelf replaced with netting; STD, the blue/black triangular trap from Series 1; and STD Horizontal Net, with a horizontal shelf made of white netting as in the shelf in the Nzi-I.

This trial was conducted at high densities of both tsetse and non-biting Muscinae, but at low densities of Tabanidae and Stomoxyinae (appendix 2). The Nzi-I trap caught more flies of almost every kind than all other traps (from 2–10× the catch), but with mostly non-significant (*NS*) differences among the trap types (power was low with only one replicate). The two traps showing potential for certain species were the Nzi-I Black and the STD Horizontal Net. The Nzi-I Black caught 1.34× as many non-biting Muscinae

Table 5. Results of experiments 13–15 targeting different species of Stomoxyinae in Nairobi, Kenya.

Expt 13. Comparison of coloured versions of the Nzi-I in a peridomestic setting using unbaited traps

Species	*S. calcitrans*	*S. niger niger*	*S. niger bilineatus*	Non-biting Muscinae
Mean Nzi-I catch	45.6	57.0	13.8	19.8
Probability* *df*=3,24	$P = 0.18$	$P << 0.001$	$P << 0.001$	$P = 0.005$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{ab}
Nzi-I Red	0.67^{a}	0.85^{a}	0.64^{a}	0.60^{b}
Nzi-I Blue	0.54^{a}	0.32^{b}	0.50^{a}	0.51^{b}
Vavoua	0.65^{a}	0.14^{c}	0.12^{b}	1.61^{a}

Expt 14. Comparison of coloured versions of the Nzi-I in a forest using octenol-baited traps

Species	*S. calcitrans*	*S. niger niger*	*S. niger bilineatus*	Non-biting Muscinae
Mean Nzi-I catch	1.7	5.0	194.1	10.4
Probability* *df*=2,14	$P = 0.52$	$P = 0.69$	$P = 0.03$	$P = 0.10$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
Nzi-I Red	0.82^{a}	1.15^{a}	0.54^{ab}	0.74^{a}
Vavoua	0.65^{a}	0.82^{a}	0.21^{b}	1.48^{a}

Species	*S. taeniatus*	*S. taeniatus f. brunnipes* Grünberg	*S. varipes* Bezzi	*S. inornatus* Grünberg
Mean Nzi-I catch	51.3	26.3	24.9	4.0
Probability* *df*=2,14	$P < 0.05$	$P < 0.01$	$P = 0.35$	$P = 0.22$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
Nzi-I Red	0.66^{ab}	0.50^{ab}	1.12^{a}	0.37^{a}
Vavoua	0.32^{b}	0.25^{b}	0.62^{a}	0.58^{a}

Expt 15. Comparison with a polyester version in a residential garden using octenol-baited traps

Species	*S. calcitrans*	*S. niger niger*	*S. niger bilineatus*	Non-biting Muscinae
Mean Nzi-I catch	4.8	45.6	7.6	5.9
Probability* *df*=1,13	$P = 0.61$	$P = 0.81$	$P = 0.55$	$P = 0.68$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
Nzi-I Polyester	1.13^{a}	0.91^{a}	1.29^{a}	0.86^{a}

* Probability from Analysis of Variance that the means across all trap types are equal. Superscript letters denote significant differences among means ($P < 0.05$, *SNK* test).

as the Nzi-I (*NS*, $P > 0.05$, SNK test), with no worse than a 20% reduction in the catch of any other kind of fly. The STD Horizontal Net caught 1.5× as many *G. pallidipes* as the Nzi-I (*NS*), but at the expense of 0.5× the catch of *G. longipennis* (*NS*). The STD Horizontal Net trap was a surprisingly poor trap for Muscidae (catch of zero Stomoxyinae, and a 10-fold reduction in non-biting Muscinae relative to the Nzi-I).

The Nzi-I was then compared with the Nzi-I Black, Canopy, Vavoua, STD and STD Horizontal Net traps in experiment 18 in a thrice-replicated 6 × 6 Latin square. This experiment was conducted in August in the dense thickets of Ruma Park in the Lambwe Valley, an area with reliably high densities of Tabanidae. *Glossina pallidipes* was present, but it was at extremely low density due to ongoing control operations with insecticide-impregnated targets. A similar experiment (no. 19) was then conducted in peridomestic habitats along the shores of Lake Victoria near Mbita Point in an area with the riverine tsetse *G. f. fuscipes*. The same experimental design was used, but the Nzi-I Black Shelf was substituted for the Canopy trap, and a standard polythene sachet of phenols/octenol (Torr *et al.*, 1995) was used in place of cow urine/octenol dispensed in bottles (acetone was still used).

Experiment 18 in Ruma Park yielded the second highest numbers of Tabanidae in the entire suite of experiments (1218 captured in 108 trap-days). It was also unique in that the

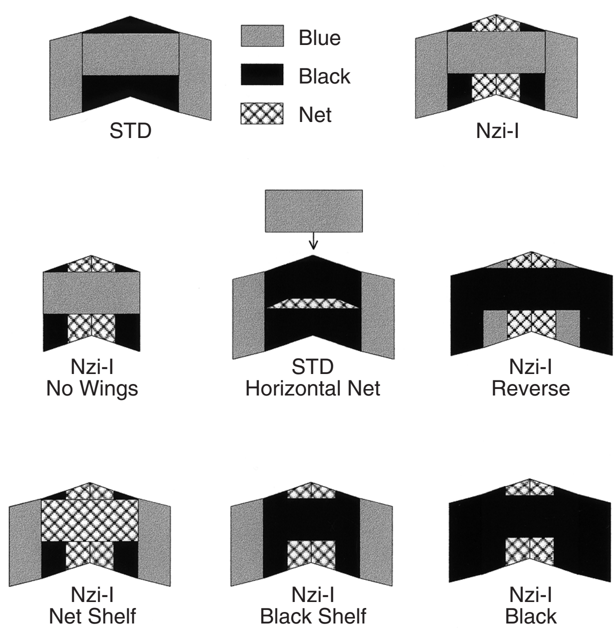

Fig. 5. Variations on the Nzi-I trap in experiment 17. The cones are omitted.

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tabanid fauna consisted mainly of *Tabanus* spp.; in experiments at Nguruman the catch was always dominated by *A. agrestis*. At Ruma Park, the Nzi-I caught significantly more tabanids than all other traps, except for the Canopy trap. As trends were the same for all species, results are summarized only for two genera accounting for 95% of the catch (table 6). Catches of *Tabanus* consisted of 77% *T. taeniola*, 18% *T. thoracinus* Palisot de Beauvois, 4% *T. gratus* Loew, and 1% *T. par* Walker. *Haematopota* Meigen were not identified to species. *Ancala africana* Gray, *Euancala maculatissima* Macquart and *Atylotus agrestis* were also caught. *Haematobosca* Bezzi (small Stomoxyinae) were captured for the first time in sufficient numbers for statistical analysis. Vavoua traps caught unusually high numbers of *Haematobosca* (mean of 10.6, maximum of 195) relative to all other traps (table 6). The Nzi-I was second best with a maximum catch of 9. At Mbita Point, only 65 tabanids were caught in total (mostly *Chrysops* Meigen and *Haematopota*), and hence no further useful information was gathered. *Glossina f. fuscipes* was present in sufficient numbers for statistical inference. The Vavoua trap was the best trap for this riverine tsetse, catching 2.4× as many flies as the Nzi-I trap (table 6).

To conclude validation of Nzi-I trap performance against diverse species of tsetse and biting flies, experiment 20 was conducted in November (rainy season) at Shimba Hills Reserve on the Kenya coast. The Nzi-I (made from Jinja blue/black cotton) was compared with traps made from three light-weight, experimental polyesters produced by VF for tsetse traps (appendix 1): Lucky Uganda (colour 17, shiny royal blue); Art Con (colour 18, partially-texturized pure blue); and Art Sed (colour 19, partially-texturized pure blue). Each prototype blue polyester had a matching black polyester. This thrice-replicated 8 × 8 Latin square experiment included optimal conventional traps for *G. pallidipes* and *G. brevipalpis* (Siamese, designed specifically for this area), *G. austeni* (Sticky-cross) and tabanids (Canopy, Écran-piège). The Siamese trap was modified slightly from the published version based on unpublished experiments of the original authour (C. Kyorku). It was made to a trapezoidal rather than a cuboidal shape and had a slightly taller cone with a shorter black interior partition (not extending into the cone). Unlike other experiments where conventional traps were made from Jinja cotton, the Écran-piège was not fabricated locally; it was made in Burkina Faso from West African polyester-cotton.

The catch in the cotton Nzi-I trap was statistically equivalent to the catch in the best traps (table 6) for each major group of flies (*G. brevipalpis*: Siamese and Écran-piège; *G. pallidipes*: Siamese and Canopy; Tabanidae: all traps except Sticky-cross; *Haematobosca*: all traps except Sticky-cross). Catches of both tsetse species were very high, and useful information was again obtained for the small Stomoxyinae *Haematobosca* (captures of up to 458 flies, mostly *H. latifrons* Malloch, appendix 2). Nine species of tabanids were captured, with most of the catch consisting of *Haematopota* spp. (73%), *T. taeniola* (13%) and *T. insignis* Loew (7%). Only 104 *G. austeni* were captured in 192 trap-days. The Sticky-cross trap caught the most *G. austeni* (average of 1.8 versus 0.9 in the next best trap, the Siamese). Substitutions of blue and black polyester for cotton significantly decreased the catch of the two common tsetse species by a factor of about 2–4×. Reductions in the catch of Tabanidae and *Haematobosca* were not significant. Catches in the subset of polyester Nzi-I traps were statistically homogeneous for all groups of flies.

Table 6. Results of experiments 18–20 targeting Tabanidae and diverse species of tsetse near Lake Victoria and at the Kenya coast.

Expt 18/19. Comparison of traps in the Lambwe Valley in dense thicket in Ruma Park (18) and in peridomestic habitats along the shores of Lake Victoria at Mbita Point (19)

	Tabanidae Ruma Park		Stomoxyinae Ruma Park	Glossinidae Mbita Point
Species	*Tabanus* spp.	*Haematopota* spp.	*Haematobosca* spp.	*Glossina f. fuscipes*
Mean Nzi-I catch	16.1	1.8	1.5	2.3
Probability* *df*=5,80	$P << 0.001$	$P = 0.11$	$P << 0.001$	$P = 0.004$
Indices of relative catch				
Nzi-I	1.00[a]	1.00[a]	1.00[b]	1.00[b]
Nzi-I Black Shelf	ND	ND	ND	0.97[b]
Canopy	0.83[a]	0.76[ab]	0.70[b]	ND
Nzi-I Black	0.42[b]	0.77[ab]	1.10[b]	1.20[b]
STD	0.32[bc]	0.84[ab]	1.01[b]	1.57[ab]
Vavoua	0.22[c]	0.82[ab]	7.14[a]	2.40[a]
STD Horizontal Net	0.20[c]	0.61[b]	0.70[b]	1.50[ab]

Expt 20. Comparison of traps at the Kenya coast in forest at Shimba Hills Reserve

Species	*Glossina brevipalpis*	*Glossina pallidipes*	Tabanidae	*Haematobosca* spp.
Mean Nzi-I catch	27.5	314.1	2.1	7.4
Probability* *df*=7,154	$P << 0.001$	$P << 0.001$	$P < 0.01$	$P < 0.01$
Indices of relative catch				
Nzi-I	1.00[a]	1.00[a]	1.00[ab]	1.00[ab]
Siamese	0.91[a]	1.01[a]	1.17[ab]	1.56[a]
Écran-piège	0.62[ab]	0.58[b]	0.87[ab]	1.10[ab]
Canopy	0.45[bc]	1.12[a]	1.39[a]	1.33[ab]
Art Sed	0.38[bc]	0.34[c]	0.81[ab]	1.03[ab]
Sticky-cross	0.36[bc]	0.14[d]	0.76[b]	0.45[b]
Art Con	0.32[bc]	0.43[bc]	0.80[ab]	0.52[ab]
Lucky Uganda	0.23[c]	0.35[c]	0.92[ab]	0.55[ab]

ND, trap not used in experiment. * Probability from Analysis of Variance that the means across all trap types are equal. Superscript letters denote significant differences among means ($P < 0.05$, *SNK* test).

Making traps more efficient

During trap development, field experiments with electrocuting nets and sticky panels revealed that some species were landing on the outside of Nzi-I traps in large numbers, but were often not being caught (Ndegwa & Mihok, 1999). Hence, two experiments were conducted with the objective of improving the balance between trap attractiveness and efficiency (Green, 1986). In experiment 21, flies were discouraged from landing on outside surfaces (as in experiment 8) by attaching unattractive materials (Allan *et al*., 1987; Gibson & Torr, 1999) to the outer blue and black surfaces on the back of the trap. These manipulations maintained an attractive front entrance (blue) and interior landing area (black), while keeping the outer back surfaces unattractive. The objective was to produce a 'push-pull' effect in flies investigating and/or circling at close range. The four materials were canary yellow, and relatively narrow black and white stripes (Gibson, 1992) in three variations (horizontal linear stripes, with a diametre of 8 mm white and 4 mm black, vertical linear stripes, and imitation zebra stripes). This trial was conducted in the rainy season in October in a Nairobi garden. Materials were attached in random sequence in blocks of 5 treatments with 6 sequential replicates. The control was the Nzi-I.

Additions of horizontal stripes to traps were investigated next in an area with both tsetse and biting flies (Nguruman). In experiment 22, the Nzi-I was compared to the same trap with stripes covering all of the outside blue and black surfaces on the back (Stripes Full), or just covering the bottom 45 cm (Stripes Low) or just the top 45 cm (Stripes High). Two other variations were also tested: a trap with a white netting floor (Net Floor, to prevent escape at the bottom) and a trap with one wing folded back onto the black cloth (Folded Wing, to reduce the attractive outside surface area of the trap).

In experiment 21, all traps caught statistically equivalent numbers of *S. calcitrans*, *S. n. niger*, *S. n. bilineatus* and non-biting Muscinae, with no evidence for an improvement in catch resulting from the treatments (table 7). If anything, catches were lower. As horizontal stripes resulted in the lowest apparent reduction in catch, this manipulation was chosen for more detailed investigation in an area with more fly diversity. At Nguruman, catches of Stomoxyinae were low due to the onset of the dry season, but good catches were obtained for both tsetse species and for non-biting Muscinae, with some data also generated for Tabanidae (96% of which were *A. agrestis*). But, as before, all trap modifications resulted in only non-significant, minor variations in catch, for all groups of flies (table 7).

Table 7. Results of modifications to the Nzi-I trap in experiments 21–23 at Nairobi and at Nguruman.

Expt 21. Effect of attaching panels of unattractive materials to the back outside surfaces of the Nzi-I trap in a Nairobi garden

Species	*S. calcitrans*	*S. niger niger*	*S. niger bilineatus*	Non-biting Muscinae
Mean Nzi-I catch	19.0	23.2	6.0	14.7
Probability* *df*=4,29	$P = 0.29$	$P = 0.37$	$P = 0.58$	$P = 0.17$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
Horizontal Stripes	0.92^{a}	0.97^{a}	1.02^{a}	0.68^{a}
Canary yellow	0.79^{a}	0.74^{a}	0.58^{a}	0.74^{a}
Vertical Stripes	0.61^{a}	0.54^{a}	0.63^{a}	0.82^{a}
Zebra Stripes	0.49^{a}	0.39^{a}	0.59^{a}	0.58^{a}

Expt 22. Effect of attaching panels of horizontal stripes to the back outside surfaces of traps at Nguruman, along with two other minor variations in trap format

Species	*Glossina pallidipes*	*Glossina longipennis*	Tabanidae	Non-biting Muscinae
Mean Nzi-I catch	173.8	11.7	2.1	35.3
Probability* *df*=5,80	$P = 0.04$	$P = 0.54$	$P = 0.40$	$P = 0.17$
Indices of relative catch				
Nzi-I	1.00^{a}	1.00^{a}	1.00^{a}	1.00^{a}
Stripes High	1.05^{a}	1.07^{a}	1.12^{a}	1.13^{a}
Net Floor	1.01^{a}	0.95^{a}	0.92^{a}	0.82^{a}
Stripes Low	0.79^{a}	1.09^{a}	0.98^{a}	0.97^{a}
Horizontal Stripes	0.69^{a}	1.09^{a}	0.80^{a}	1.16^{a}
Folded Wing	0.68^{a}	1.29^{a}	0.93^{a}	1.82^{a}

Expt 23. Comparison of cotton and polyester versions of the Nzi-I trap, along with size modifications

Species	*Glossina pallidipes*	*Glossina longipennis*	Tabanidae	Non-biting Muscinae
Mean Nzi-I catch	266.7	16.5	17.4	55.6
Probability* *df*=6,114	$P = 0.07$	$P = 0.01$	$P = 0.01$	$P << 0.001$
Indices of relative catch				
Opaque cotton drill	1.46^{a}	0.73^{b}	1.63^{a}	1.44^{ab}
Large (150 cm)	1.20^{ab}	1.69^{a}	0.98^{b}	1.83^{a}
Medium (120 cm)	1.20^{ab}	1.28^{ab}	1.01^{b}	1.12^{bc}
Polyester pure blue	1.13^{ab}	1.03^{b}	1.28^{ab}	1.19^{bc}
VF Net	1.10^{ab}	1.14^{b}	1.09^{b}	1.16^{a}
Nzi-I	1.00^{ab}	1.00^{b}	1.00^{b}	1.00^{bc}
Polyester royal blue	0.94^{ab}	1.02^{b}	0.99^{b}	0.77^{c}

* Probability from Analysis of Variance that the means across all trap types are equal. Superscript letters denote significant differences among means ($P < 0.05$, *SNK* test).

The Nzi trap

A final thrice-replicated 7 × 7 Latin square experiment had the objective of optimizing practical details of trap construction, particularly fabric choices (appendix 1). It was conducted at Nguruman during the dry season in January 1996. As in previous experiments, the standard Nzi-I trap was made to a 90 cm size out of semi-opaque blue (darker dye lot, colour 1b) and black (colour 0) Jinja cotton, and local white polyester netting (material 2). Variations consisted of the following: two larger versions made from the same materials (Medium 120 cm, Large 150 cm); a 90-cm version made with texturized netting (VF Net, material 25); a 90-cm version made from heavier-weight cotton (Opaque Cotton Drill, material 26); and two 90-cm versions made from identical fully-texturized, semi-opaque, nearly-matt polyesters from VF. The two polyester traps differed from each other only in terms of a red tint in one blue fabric (Polyester Royal Blue, colour 23 versus Polyester Pure Blue, colour 24); the black portions were of matching polyesters.

High catches were obtained for both tsetse species, Tabanidae (98% of which were *A. agrestis*), and non-biting Muscinae; very few Stomoxyinae were captured. There was only minor variation in catches among most trap types, with few statistically significant patterns (table 7). The large version (150 cm) caught significantly more *G. longipennis* and non-biting Muscinae than the Nzi-I (90 cm), and the opaque cotton drill version caught significantly more *A. agrestis* than the Nzi-I (semi-opaque Jinja cotton). Traps made from the matt polyesters performed well for all species, and in particular for *G. pallidipes*. This was in sharp contrast to the poor performance of shiny or partially-texturized polyesters in experiment 20 at Shimba Hills (table 6). Traps made from royal blue polyester (with a reddish tint) caught almost exactly the same number of *G. longipennis* as traps made from a similar pure blue polyester (without a reddish tint).

Based on this last experiment, a standard format for the Nzi trap is defined in figs 6 and 7. The trap should be made to a 1-m format from opaque Phthalogen Blue and black cotton drill (or a similar well-texturized fabric without a shiny finish), with the remaining parts made from transparent white netting, or an equivalent, highly-transparent, non-shiny material. Further details of trap construction are provided at the web site http://informatics.icipe.org/nzi.

Discussion

Optimization of trap format

The development of the Nzi trap was facilitated by a break with conventional wisdom (Vale, 1993) when clear plastic was substituted for the black 'target' area of the standard trap in experiment 8. This modification created a transparent enclosure to intercept flies passing through the front entrance. The trap now had only blue panels to attract

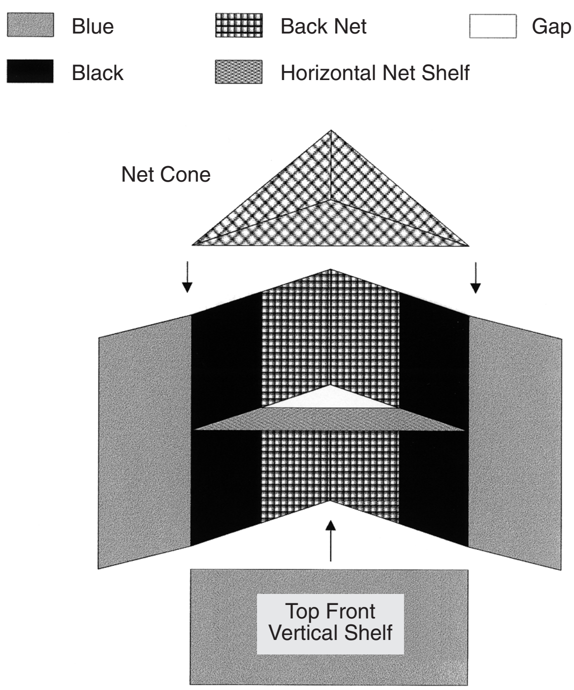

Fig. 6. Schematic view of the Nzi trap with the front blue top vertical shelf removed for clarity. The body is in the shape of an equilateral triangle flanked by two blue wings at the front. The sides are half black towards the front and half netting towards the back. A trapezoidal netting shelf extends horizontally from the bottom of the front shelf to the midpoint of the sides, leaving a gap at the back through which insects can fly up into the cone. The cone is a tetrahedron of netting.

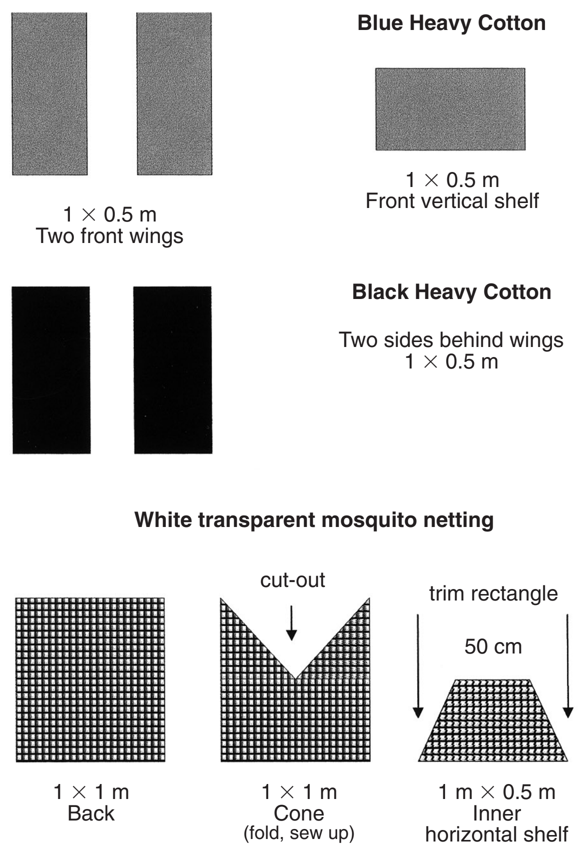

Fig. 7. Schematic diagram of the material requirements for the Nzi trap. Pieces are most easily cut from material that is 1 m in width. The trap requires 1 m^2 of black, 1.5 m^2 of blue, and 2.5 m^2 of netting.

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flies, with no major visual cue to direct flies into the body. This change resulted in greatly improved catches of Stomoxyinae, but at the expense of reduced catches of *G. pallidipes*. This was likely to be the result of a weaker attractive stimulus, combined with the absence of an interior landing area (Torr, 1989; Vale, 1993). Traps that are both attractive and efficient for tsetse (F3, Epsilon, NG2G) contain large quantities of blue fabric to attract flies, combined with smaller black panels to induce landing (Green, 1986). In contrast, the original target for savannah tsetse was based on a large black panel (to both attract flies and induce landing) flanked by transparent netting (to intercept circling flies). This balance between attraction and interception has been a critical factor in target design for many species (Green, 1994; Kappmeier & Nevill, 1999). Similar principles have rarely been incorporated in traps, other than in Malaise traps.

The main obstacle to exploiting this finding was the need to achieve a balance between attraction and enhanced entry for all kinds of flies. This was achieved partially with the Edge design by replacing only half of the black area with netting. To improve on this interim design, a feature common to efficient tsetse traps was exploited: the use of inner partitions. For example, in traps for riverine tsetse, black inner panels are used to provide both interception surfaces and enhanced contrast/opacity to direct flies into the bright areas of the cone. In traps for savannah tsetse (F3, Epsilon), blue/black landing areas are framed by a horizontal blue shelf at the mid-front of the trap. This shelf partitions the trap body and reduces escape. Multiple entrances with inner shelves and sloping panels are also used in traps such as the M3, the S3 (Ndegwa & Mihok, 1999) and the H-trap (Kappmeier & Nevill, 2000). Direct contrasts in experiments 10 and 11 confirmed the overall importance of inner partitions, with many options producing similar results. The final one chosen for the Nzi trap (a horizontal shelf in netting) was chosen for simplicity. It also happened to produce the highest catch of all species. Similar targeted modifications to conventional tsetse traps could provide a basis for further improvements.

Visual ecology

Traps incorporating colours other than blue rarely performed well; catches were mostly lower, or did not change significantly relative to conventional traps. Hence, experiments were formulated mainly to investigate evidence for a relationship between trap effectiveness and the colour red (Green & Flint, 1986). Considerable literature exists on both the physiological and ecological responses of both tsetse and biting flies to colour, contrast, etc. (Allan *et al*., 1987). The literature on tsetse is comprehensive (Gibson & Torr, 1999), but the literature on biting flies is somewhat selective. It consists largely of studies of two key species: *S. calcitrans* and *Tabanus nigrovittatus* Macquart in North America.

In the present study, many species were sampled under diverse conditions in Africa, confirming the efficacy of traps based on blue-black geometric shapes. The only unexpected result was a trend for increased catches of the *fusca* tsetse *G. longipennis* with red. This trend was consistent, although not always significant, in initial experiments conducted with polyester/cotton blends. Hence, increased catches could have resulted from features of the fabrics themselves, rather than visible colour, e.g. higher ultraviolet reflectance (Green, 1993b), or a smoother, shiny texture (polarization of light). Use of an exact material match in all later experiments (medium red Jinja cotton) failed to validate this trend for all-red and red-blue traps in three experiments (5, 7, 8), although some increases in catch were still obtained. No evidence, statistical or otherwise, for a response to red was found in many trials with the savannah tsetse *G. pallidipes*, nor in the single relevant trial with another *fusca* tsetse, *G. brevipalpis*. Lastly, when a more efficient trap was used in the second series of experiments (Nzi-I), there was no evidence that *G. longipennis* (or any other species) could detect red in trials with carefully-matched cotton or polyester fabrics. These last experiments appear definitive, and agree with existing data on the spectral sensitivity of visual pigments in tsetse and other biting flies (Agee & Patterson, 1983; Green & Cosens, 1983; Allan *et al*., 1991). However, some residual uncertainty remains for *G. longipennis*. This species is active mainly at sunset (Kyorku & Brady, 1994), and hence it could have a unique response to red light, given the complexity of innate patterns observed in other tsetse (Green, 1993a). To validate such a response in the field will require more sophisticated experiments, as with nocturnal mosquitoes (Gibson, 1995).

A second finding of practical importance was the response of many species to features of synthetic fabrics that are not apparent to the human eye. Synthetics or blends are often used to make tsetse traps and targets, especially in West Africa in wetter climates, as they are durable and colour-fast, and they also retain insecticides well (Laveissière *et al*., 1987a,b). Most synthetics have a fine weave, and hence are shiny, reflecting polarized light. Many blue synthetics in tsetse traps also have a shoulder of reflectance in the ultraviolet, whereas blue cottons reflect little in this region. The tsetse retina is responsive to both of these subtle features (Green & Cosens, 1983; Hardie *et al*., 1989), as presumably are the retinas of other biting flies (Agee & Patterson, 1983; Allan *et al*., 1991; Smith & Butler, 1991).

The response of certain species to inconspicuous features of fabrics was evident in the trial of prototype polyester fabrics from Vestergaard Frandsen A/S at Shimba Hills National Reserve. Polyester Nzi-I traps with excellent colour matches to Phthalogen Blue (i.e. nearly identical dominant wavelengths) caught low numbers of *G. pallidipes* and *G. brevipalpis* relative to cotton traps (experiment 20, table 6). Adjustments to these fabrics by the manufacturer (particularly full rather than partial texturization), resulted in a large improvement in catch in the last experiment. Equitable results with matt blue and royal blue polyesters relative to cotton drill were obtained for *G. pallidipes* and *G. longipennis*, and for one tabanid (*A. agrestis*, table 7). Unfortunately, stable flies were not present in sufficient numbers for statistical inference. In the only relevant trial of another prototype polyester (experiment 15, table 5), catches of mostly *S. niger niger* were not affected by the use of a shiny fabric, with moderate ultraviolet reflectance. This result might be expected, given that the cosmopolitan species *S. calcitrans* is sampled well with traps made from translucent, ultraviolet-reflective panels (Agee & Patterson, 1983). In unpublished experiments, results from different environments around the world have not been as easy to interpret. Catches of some savannah tsetse and many species of biting flies have often been lower when traps have been made from ‘optimized’, matt polyester fabrics. These results will be discussed in a future publication.

Species specificity

The objective to develop a trap with minimal species bias was largely achieved with the Nzi design. Although other traps sometimes performed as well as the Nzi for certain species, the Nzi was the only trap consistently catching a variety of species in all three groups: tsetse, stable flies and tabanids. From these experiments, the best time to both sample and kill tsetse and biting flies appears to be during or just after the rainy season. Trap performance is likely to vary across seasons, but this aspect was not examined explicitly in the experiments reported here.

For tsetse, the Nzi represents a useful improvement for the *fusca* group, catching about twice as many *G. longipennis* as the NG2G trap (Brightwell *et al*., 1991), and as many *G. brevipalpis* as the Siamese (Kyorku *et al*., 1995) and the H-trap (Kappmeier & Nevill, 2000). For the important savannah tsetse *G. pallidipes*, the Nzi performed as well as other traps for this species. The only potential deficiency for tsetse appears to be for the riverine group, based on the few results obtained for *G. fuscipes*. Riverine tsetse are typically sampled with specific traps designed for this purpose, e.g. the biconical, pyramidal or Vavoua. Unfortunately, these more open styles are extremely poor for tabanids and most other tsetse.

The most significant aspect of the Nzi trap is its ability to catch Stomoxyinae, while simultaneously catching high numbers of both tsetse and tabanids. This combination is not found in any conventional trap, as shown in the many experiments reported here. Prior to this study, the Vavoua appeared to be the best trap for sampling stable flies, particularly genera other than *Stomoxys* (Mihok *et al*., 1996a). Here, the Nzi was demonstrated to be a much better trap for Stomoxyinae, although it may not be optimal for some very small flies such as *Haematobosca*. Significantly, the Nzi is an excellent trap for the two most common species in Africa: *S. niger niger* and *S. niger bilineatus*. In definitive experiments at high density with both unbaited and octenol-baited traps, catches of these species were up to 5–8× those in Vavoua traps (table 5). Catches of *S. calcitrans*, and many other *Stomoxys*, were also uniformly higher in the Nzi trap.

A further practical aspect of the trap is its ability to catch tabanids, without having to resort to the use of specialized traps designed for this purpose, e.g. the Manitoba, Canopy or the Malaise. These large traps are efficient for tabanids, but are extremely prone to theft, especially if they incorporate hanging balls as targets or decoys (Bracken & Thorsteinson, 1965). In this study, the Nzi trap caught 20+ species of Tabanidae in a few habitats in just one country. Some tabanids almost never caught in traps, e.g. *Philoliche* (Phelps & Holloway, 1992), were caught in modest numbers. Although tabanids were often not abundant in the dry habitats typical of tsetse, high catches of widespread species such as *A. agrestis* and *T. taeniola* were obtained. Over many seasons and in many localities, Nzi traps caught numerically or statistically more tabanids than any other trap, in nearly every comparison. In two final experiments, the Nzi caught statistically equivalent numbers of tabanids relative to the Canopy trap (table 6). These results have since been confirmed with more robust studies at higher densities in other countries (unpublished data). The trap has also been used for faunal surveys of tabanids in Chad and the Ivory Coast (Acapovi *et al*., 2002; A.A. Doutoum, A. Delafosse, P. Elsen & S. Amsler-Delafosse, unpublished).

The overall goal of this study was not only to develop an efficient trap for tsetse and biting flies, but to develop a simple, non-technical and economical trap, amenable to community use. The Nzi meets the objective of simplicity well. It can be sewn from basic geometric shapes and does not require special accessories, other than a few external poles and wires. The trap is non-technical in that it can be hand-made, erected and maintained after minimal instruction, making it ideal for public use. The Nzi format can also be modified in many ways (the focus of some exploratory trials) and still remain effective. Lastly, the trap is economical. In 1997, production of 300 traps in Kenya using local labour and foot-pedal sewing machines cost US$7–9 per trap (capital, labour, materials), depending largely on the prices of cloth and netting.

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Appendix 1

Characteristics of the materials used to make traps.

Colour	Material	Code	Fabric notes	Experiment	Ultraviolet %	Peak wave-length	CIE 1931 Colour indices				
							Dominant wavelength	Y	x	y	Purity
Standard black	Cotton	0	Mount Kenya Textiles	1–23	3.2	–	–	2.9	0.306	0.315	–
Standard blue	Cotton	1a	Mount Kenya Textiles	1–22	9.4	466	478	8.8	0.173	0.181	65
Standard blue	Cotton	1b	New lot, slightly darker	23	6.0	462	478	6.6	0.183	0.196	60
Standard netting	Polyester	2	White, local	1–23	(74.2)	–	–	(83.9)	0.316	0.331	–
Dark red	Poly/cot	3	Chinese, imported	1–4	4.9	790	680	5.9	0.505	0.298	44
Bright red	Poly/cot	4	Chinese, imported	2	6.8	762	615	9.5	0.544	0.320	62
Dark bluish purple	Poly/cot	5	Chinese, imported	1	7.0	440	565_{c}	4.1	0.267	0.194	40
Dark reddish purple	Poly/cot	6	Chinese, imported	1,2	7.3	790	495_{c}	6.0	0.410	0.283	32
Dark reddish purple	Poly/cot	7	Near match to no. 6	3	6.2	790	494_{c}	5.0	0.442	0.291	34
Dark green	Poly/cot	8	Chinese, imported	1,2	6.9	492	495	6.1	0.246	0.339	23
Bright turquoise	Poly/cot	9	Chinese, imported	1–3	16.4	478	487	25.4	0.200	0.279	44
Bright violet	Cotton	10	Local Jinja	8	22.9	432	476	17.0	0.250	0.249	30
Dark bluish purple	Cotton	11	Local Jinja	8	12.3	411	563_{c}	5.1	0.273	0.193	43
Bright turquoise	Cotton	12	Local match to no. 9	8	20.2	477	486	21.7	0.211	0.275	40
Light green	Cotton	13	Local Jinja	8	12.6	500	502	21.5	0.247	0.372	22
Transparent plastic	Plastic	14	Local (250 µm thick)	8	(87.7)	–	–	(86.1)	0.314	0.330	–
Medium red	Cotton	15	Local Jinja	5–8, 12–16	5.2	672	620	8.6	0.536	0.313	59
Shiny pure blue	Polyester	16	VF Brilliant Blue 589	15	14.2	462	480	10.1	0.198	0.224	50
Shiny royal blue	Polyester	17	VF Lucky Uganda	20	20.0	414	472	6.6	0.212	0.191	51
50% Texturized blue	Polyester	18	VF Art Con	20	16.5	458	477	10.0	0.192	0.197	56
50% Texturized blue	Polyester	19	VF Art Sed	20	17.6	455	478	8.4	0.200	0.212	51
Canary yellow	Cotton	20	Local Jinja	21	8.2	–	572	55.4	0.404	0.477	71
Zebra stripes	Cotton	21	Local	21	19.3	–	–	34.2	0.308	0.321	–
Black/white stripes	Cotton	22	Local	21,22	15.1	–	–	27.6	0.305	0.318	–
Matt royal blue	Polyester	23	VF Pongee 1	23	28.1	438	472	7.6	0.191	0.167	62
Matt pure blue	Polyester	24	VF Pongee 2	23	20.7	466	479	10.5	0.189	0.209	56
Texturized netting	Polyester	25	VF Code 3 March 1996	23	(74.2)	–	–	(82.1)	0.312	0.328	–
Opaque pure blue	Cotton	26	Ethiopian, heavy drill	23	14.9	450	478	11.4	0.179	0.187	63

Notes: CIE 1931 colour indices are explained in the methods section. Transmittance data are reported in brackets for the two nettings and the plastic (2, 14, 25). Ultraviolet % is the mean reflectance or (transmittance) between 370 and 399 nm.

Appendix 2

Summary of experiments with backtransformed mean and maximum catches in flies per trap per day for the standard trap in each series.

Details of experiment				Backtransformed catches in the Standard Trap						
Expt	Area	Month	Conventional fly traps compared	Stastistic for standard catch	*Glossina pallidipes*	*Fusca* tsetse	Other tsetse	Tabanidae	Stomo-xyinae	Non-biting Muscinae
Series 1: Standard trap is STD (triangular trap with blue front and black back, fig. 1)										
1	Nguruman	November	Vavoua	STD Trap Mean	3.7	8.3		3.6		10.6
				Maximum	94	36		10		57
2	Nguruman	December	Siamese	STD Trap Mean	18.2	16.4		5.8		16.4
				Maximum	101	74		20		51
3	Nguruman	January	NG2G	STD Trap Mean	6.8	5.6		22.2		17.3
				Maximum	19	41		115		96
4	Lambwe	February	Siamese	STD Trap Mean	3.2			4.8		4.7
	Valley		NG2G	Maximum	14			17		273
5	Nguruman	May	None	STD Trap Mean	137.1	27.2		7.5	5.0	35.7
				Maximum	798	72		44	76	147
6	Nguruman	June	NG2G, Vavoua	STD Trap Mean	95.9	22.6		5.2	6.9	22.8
			Manitoba	Maximum	2832	150		27	67	135
7	Shimba Hills	October	Vavoua	STD Trap Mean	90.0	4.9	1.8			
				Maximum	647	26	9			
8	Nguruman	December	Epsilon	STD Trap Mean	66.5	10.0		1.8	6.3	5.9
			(modified)	Maximum	494	160		14	418	95
9	Nguruman	January	Vavoua	STD Trap Mean	117.5	8.9		1.8	2.3	6.7
				Maximum	500	70		11	1117	119
10	Nguruman	April	M3	STD Trap Mean	129.7	6.2		1.8	3.9	8.7
				Maximum	553	42		13	220	27
11	Nguruman	May	None	STD Trap Mean	133.3	4.4		1.6	4.6	4.3
				Maximum	389	31		4	30	15
12	Nguruman	May	M3, NG2G	STD Trap Mean	359.7	3.7		6.5	2.8	8.0
			Biconical, Vavoua	Maximum	1932	12		51	12	33

Series 2: Standard trap is Nzi-I (Nzi 'Initial', 90 cm size, made with blue and black Jinja cotton and white polyester netting)										
13	ICIPE	June	Vavoua	Nzi-I Trap Mean					124.5	19.8
				Maximum					344	42
14	Nairobi Park	July	Vavoua	Nzi-I Trap Mean					317.7	10.4
				Maximum					2709	94
15	Nairobi Garden	August	None	Nzi-I Trap Mean					58.7	5.9
				Maximum					402	18
16	Maralal	June	Vavoua	Nzi-I Trap Mean		3.5				
				Maximum		26				
17	Nguruman	August	Canopy	Nzi-I Trap Mean	484.2	31.5		2.8	2.8	77.8
				Maximum	840	111		4	11	222
18	Lambwe Valley	August	Canopy	Nzi-I Trap Mean				18.1	8.1	10.2
			Vavoua, STD	Maximum				141	239	145
19	Mbita Point	September	Vavoua	Nzi-I Trap Mean			2.3		6.9	19.0
			STD	Maximum			7		75	125
20	Shimba Hills	November	Canopy, Siamese	Nzi-I Trap Mean	314.1	27.5	1.2	2.1	7.4	9.0
			Écran piège	Maximum	1205	133	2	12	458	47
			Sticky-cross							
21	Nairobi Garden	November	None	Nzi-I Trap Mean					48.6	14.7
				Maximum					147	23
22	Nguruman	December	None	Nzi-I Trap Mean	173.8	11.7		2.1	1.4	35.3
				Maximum	950	47		7	2	177
23	Nguruman	January	None	Nzi-I Trap Mean	266.7	16.5		17.4	1.5	55.6
				Maximum	1545	95		69	5	142

Fusca tsetse: *G. longipennis* at Nguruman, *G. brevipalpis* at Shimba Hills, Other tsetse: *G. austeni* at Shimba Hills, *G. f. fuscipes* at Lambwe Valley.

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