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Photography of Trichoptera in flight

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Abstract

Whereas photography of insects at rest is used for a wide variety of purposes, including illustrating publications and aiding their identification, photography of insects in flight is more challenging and little practiced. This paper describes a system that uses a digital single-lens-reflex camera combined with commercial-level flashes (with electronic power settings to give very short exposures) and simple electronics in a rig that can be used to capture high quality images of night-flying insects. With such a rig, hundreds of images of free flying Trichoptera have been obtained. Preliminary observations of night-flying *Athripsodes bergensis* (Leptoceridae) indicate that this system could be used for studying the mechanics of flight, wing beat frequency, aerodynamics, flying speed, aerial activity, and behavioural ecology of night-flying insects in their natural environment.

This paper briefly describes the technique as applied at a site on the banks of the Groot River in the southern Cape region of South Africa between October 2008 and April 2009 and presents a selection of the images obtained.

Key words: Trichoptera, Leptoceridae, flight, photography technique

Introduction

Whereas photography of insects at rest is used for a wide variety of purposes, such as illustrating publications and aiding identification, photography of insects in flight is much more challenging and is not often attempted. In many studies, photographs have been obtained under artificial conditions, for example, tethering the insect glued on a pin or on a string or wire harness (Wooton 1992). Such conditions were obviously prone to result in distortions of natural behaviour and induced abnormal air currents. In the 1970s, valuable pioneering work on capturing photographs of free-flying insects was undertaken by Dalton (1975, 1982) who developed advanced high speed techniques using specially designed equipment. Brackenbury (1995) elucidated the remarkable aerodynamics and mechanics of insects in flight by means of photographs. Significant contributions to our understanding of flight kinematics and wing deformations in Trichoptera have been made with high speed cinematography and flashlights, flat-sheet illumination and laser speckle photography in a wind tunnel (Brodsky & Ivanov 1983, 1984; Ivanov 1985a, 1985b, 1989, 1991; Stocks 2009).

Daylight photography of insects in flight is hampered by the technical demands of requiring an ultra-fast shutter response, which is needed to minimise the delay between initiating the shutter and its full opening to record the image. The response time (shutter delay) of commercially available single-lens-reflex (SLR) camera shutters (whether using film or digital media) usually results in the

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target insect having flown out of the picture frame before the image is captured. Many taxa of Trichoptera are, however, known to have well-defined circadian rhythms that govern the periodicity of adult flight activity (Jackson & Resh 1991). These coordinated rhythms contribute to mating success and to the efficient use of metabolic resources. The times of flight vary with different taxa but are of limited duration, often for an hour or 2 during the hours of darkness, usually shortly after sunset or before sunrise. In the case of species that fly in the dark, the difficulties associated with ultra-fast shutter response can be avoided. This presents an opportunity to use greatly simplified equipment. The technique described in this paper uses unmodified consumer-level flash units and a standard digital SLR camera to produce high quality images of night flying Trichoptera.

A primary objective was to produce good quality images of some of the free-flying insects that are found along rivers arising in the Tsitsikamma mountain range, which runs close to, and is parallel to, the southern Cape coast of South Africa. Rivers in this region harbour a diverse and conservation-worthy assemblage of aquatic macroinvertebrates. The original aim of this project was to obtain images that would assist in promoting stewardship of these rivers and complement research projects being undertaken on the macro-invertebrates of these rivers. However, a further outcome of the photography has been the acquisition of useful information on the flight activity of these insects. A particular target group was the Trichoptera, which are well-represented and abundant in the area.

Valuable information on a number of topics—such as flight mechanics, wing-beat frequency, aerodynamics, flying speed, aerial activity and behavioural ecology—can be obtained by means of in-flight photography of insects in natural conditions, but to the best of our knowledge—after undertaking literature reviews and a search on the web—no such studies have been carried out on Trichoptera.

Methods

Field site

All photographs were taken at a single location on the Groot River (west) near Nature's Valley below the Tsitsikamma Mountains, on the southern Cape Coast (Fig. 1) from October 2008 until mid April 2009. The river at this site, which is a short distance upstream of the tidal prism, flows slowly over a shallow run with stony cobbled substrate into a narrower section of riffles. Upstream of the run there is a large pool about 50 metres long. In this area the river is flanked by well-developed Afro-Montane forest while the bank, in the vicinity where photographs were taken, is lined with rank grasses (Fig. 2).

Technical challenges

To render sharp images of the insects in flight a number of problems were identified and parameters for recording in-flight photography were set:

- The main target species *Athripsodes bergensis* Scott (Leptoceridae) has a wing span ranging between 13 to 17 mm. To render these subjects large enough in the picture frame, macro-photography techniques are required with magnifications approaching 1:1 with a digital SLR camera. As a result, the depth of field (sharpness zone) is very small, only a few millimetres. It is thus desirable to use a small lens aperture (most pictures were taken at f16 or f22).
- Insect flight is relatively fast and erratic, so it is not possible to follow the subject using automatic focus, even with the most sophisticated modern cameras. The use of conventional shutters, even on the fastest digital cameras, is not feasible because of the delay between initiating the shutter release and recording the image on the camera sensor or film of the

camera. The delay (shutter lag) of about 40 to 50 milliseconds, in modern SLR cameras, is sufficient for an insect to fly beyond the picture frame area before recording the image.

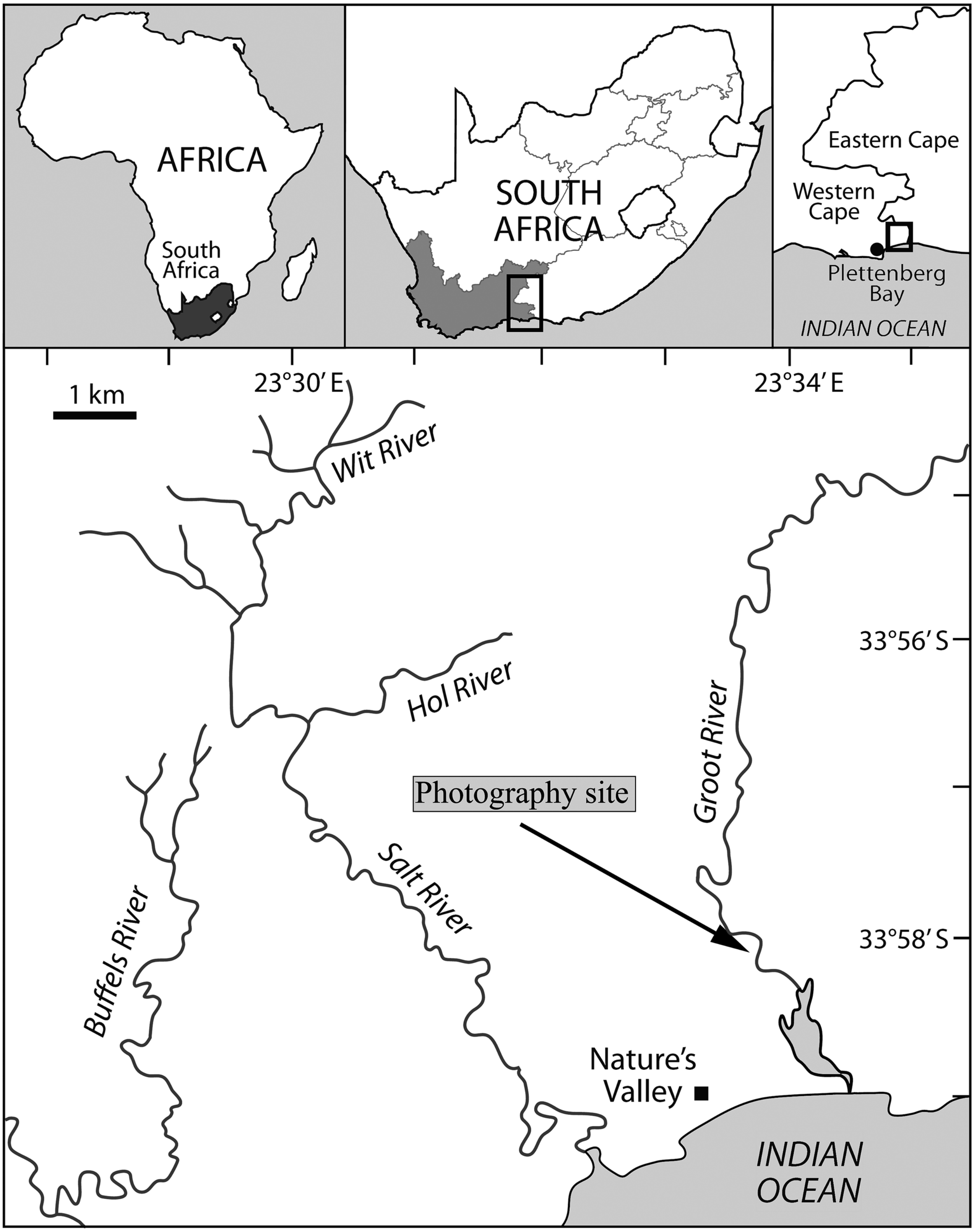

FIGURE 1. Map showing the locality of the site on the Groot River where the photographic research was conducted.

- The amount of light reaching the sensor is considerably reduced because of the magnification required in macro mode. For example, the light intensity at the sensor falls to a quarter of its normal intensity at a magnification of 1:1.
- To minimize graininess or digital noise the use of low ISO ratings (e.g. 200) is desired.
- The combination of short exposure, small aperture (f16–f22) and considerable magnification (close to 1:1) compound each other and necessitate a very intense light source of short duration (of less than 1/20000 sec.).

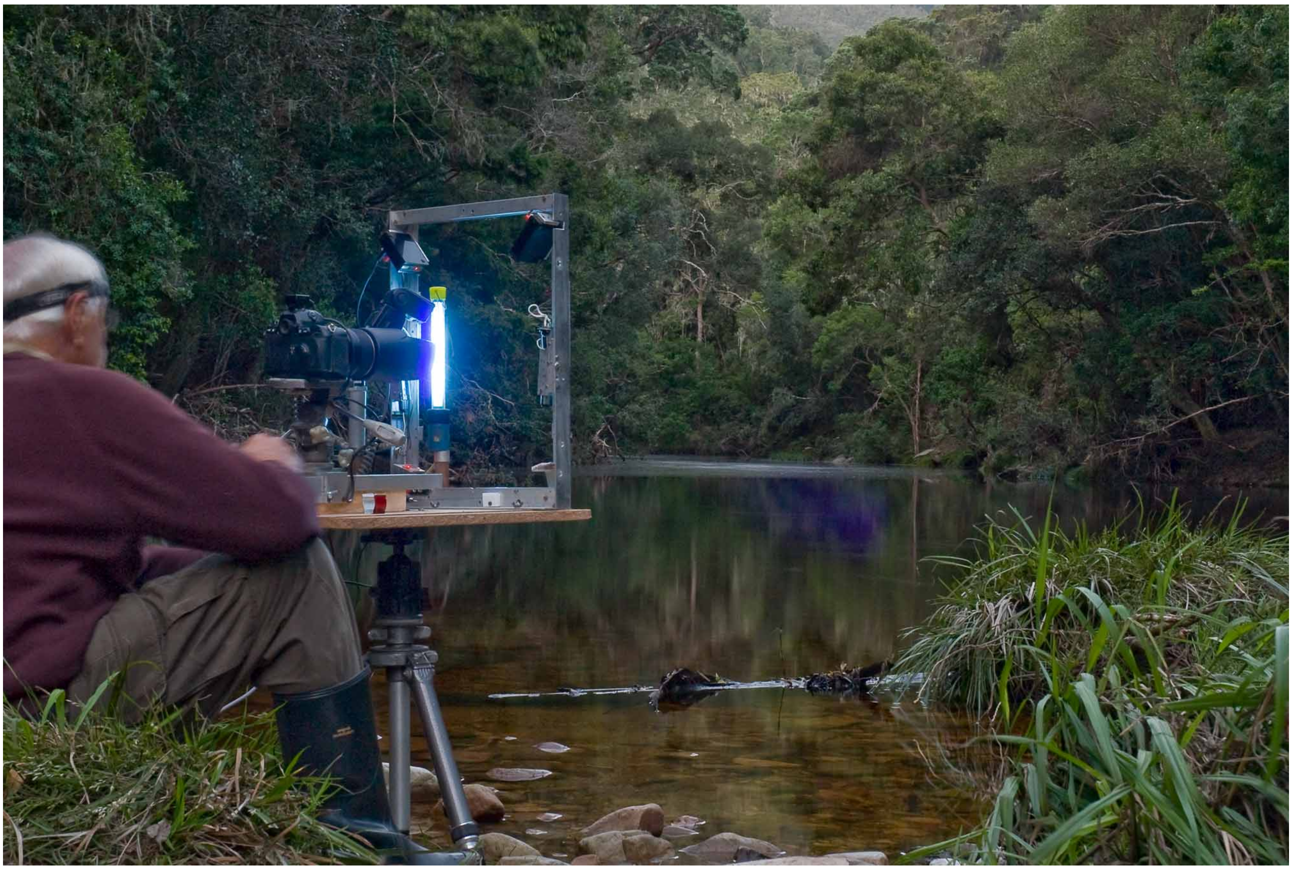

FIGURE 2. An early set-up of the photographic rig on the Groot River near Nature's Valley. At this stage a single UV light was placed vertically to one side. Later it was placed horizontally a little above the image area.

The above challenges can be addressed in the following ways:

Equipment used to set up a pre-focusing system

Instead of attempting to follow insects in flight, the camera (a Nikon D200 with 105mm macro lens) is pre-focused on a fixed point to which the insects are attracted by placing fluorescent lamp units fitted with super-actinic tubes near to this point. Capture of the image is initiated by the insect breaking a pair of laser light beams that intersect at the point where the camera is focused (Fig. 3). To initiate the trip mechanism both laser beams must be broken simultaneously. The width of the laser beam entering each sensor is restricted by placing a sliding device with a range of different sized holes immediately in front of each sensor and selecting a small aperture size (usually about 1 mm in diameter). This improves the sensitivity of the beams for detecting small insect targets.

The photographic set-up used standard laser beam pointers (often used as pointers for presentations) as the triggering beams. Because of the extended periods of operation required, the power supply to these lasers was changed from the normal small button batteries to two externally mounted standard ‘D’ type alkaline batteries. Each light beam sensor used a photo-transistor in a simple electronic circuit made from inexpensive electronic components that are readily available (see circuit diagram in Appendix). The two-sensor circuits are connected in series so that they only initiate the flash when the beams to both sensors are broken at the same time.

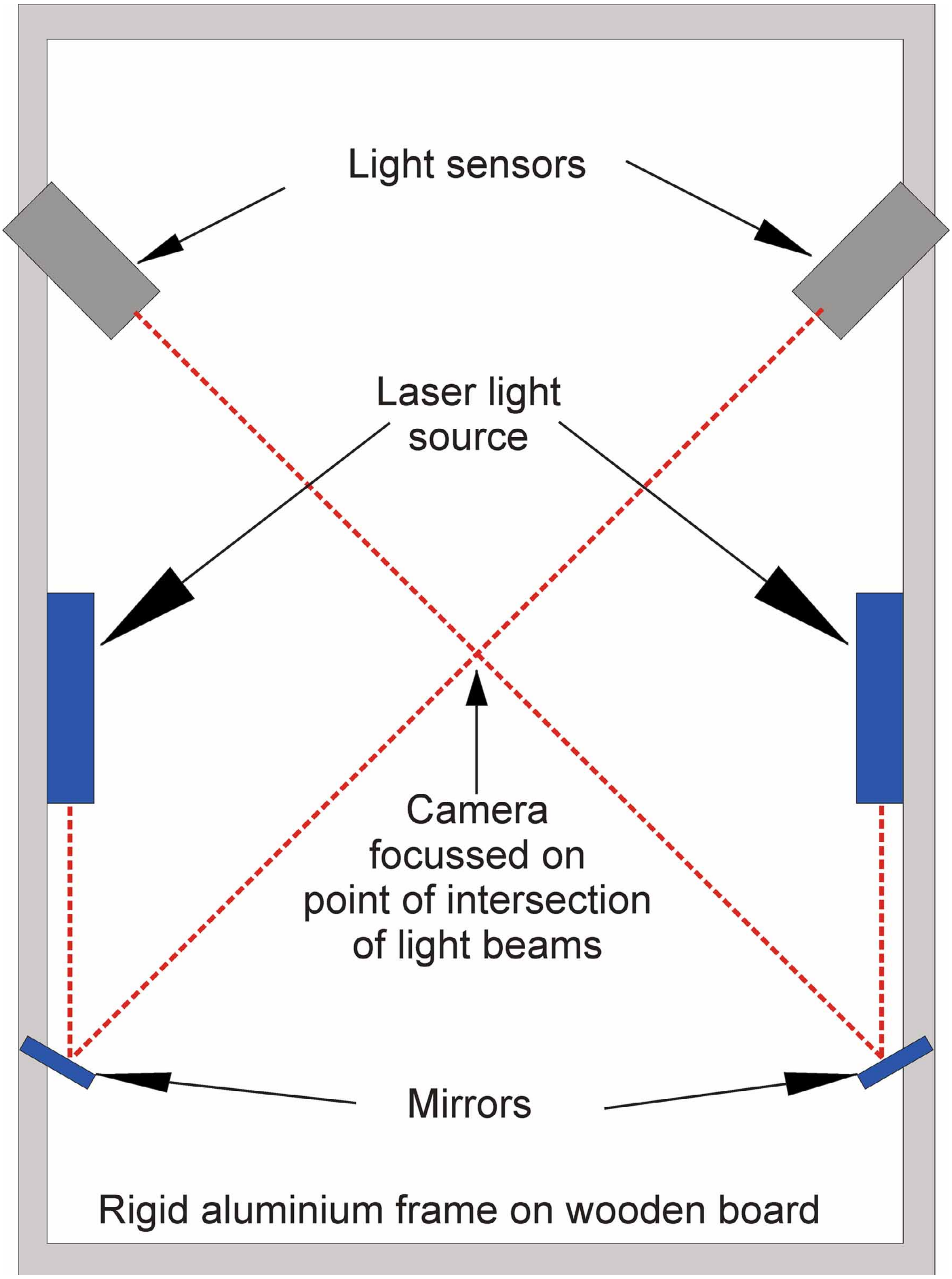

FIGURE 3. Diagram of the laser beam arrangement.

Open shutter system

Since many species of Trichoptera fly after dark, the camera shutter can be held open for extended periods (up to two minutes at a time) without recording background illumination. It is thus possible to fire the flash units directly with the signal from the light beam sensors while the camera shutter is held open manually (shutter set to 'bulb'). After the flash has fired and recorded the image, the shutter is released. There is thus no link between the camera and the flash which fires almost instantaneously (within microseconds) upon breaking the crossed light beams.

Short, high intensity light pulses

A short pulse of light at high intensity is obtained by using standard, commercially-available flash units set manually to a very low power setting, with the flash located close enough to the subject to gain the required light intensity. Modern flash units reduce their light output by reducing the duration of the light flash thereby providing very short exposures suitable for 'freezing' insects in flight. This provides a means of getting a very-short-duration flash without having to resort to specially designed high voltage flash units as was necessary for the early workers like Dalton (1975, 1982). In this study it was possible to obtain usable settings at 1/128 or 1/64 of full power which gave flash durations of 1/41600 (Nikon SB800) or 1/28000 (Nikon SB28) seconds, respectively. To record multiple-exposure flight images for estimating flight speed, the flash unit can be set to repeating flash mode at a chosen flash frequency (e.g., 50 Hz to give 20 millisecond intervals), power setting (e.g., 1/128) and number of flashes (e.g., 10). Such a setting would produce a stroboscope effect of 10 light flashes recorded on a single frame during an exposure of 1/5th of a second (see Figs 4, 5).

FIGURE 4. Flight sequence of *Athripsodes bergensis* taken at 20-millisecond intervals. From such images it is feasible to estimate flying speed.

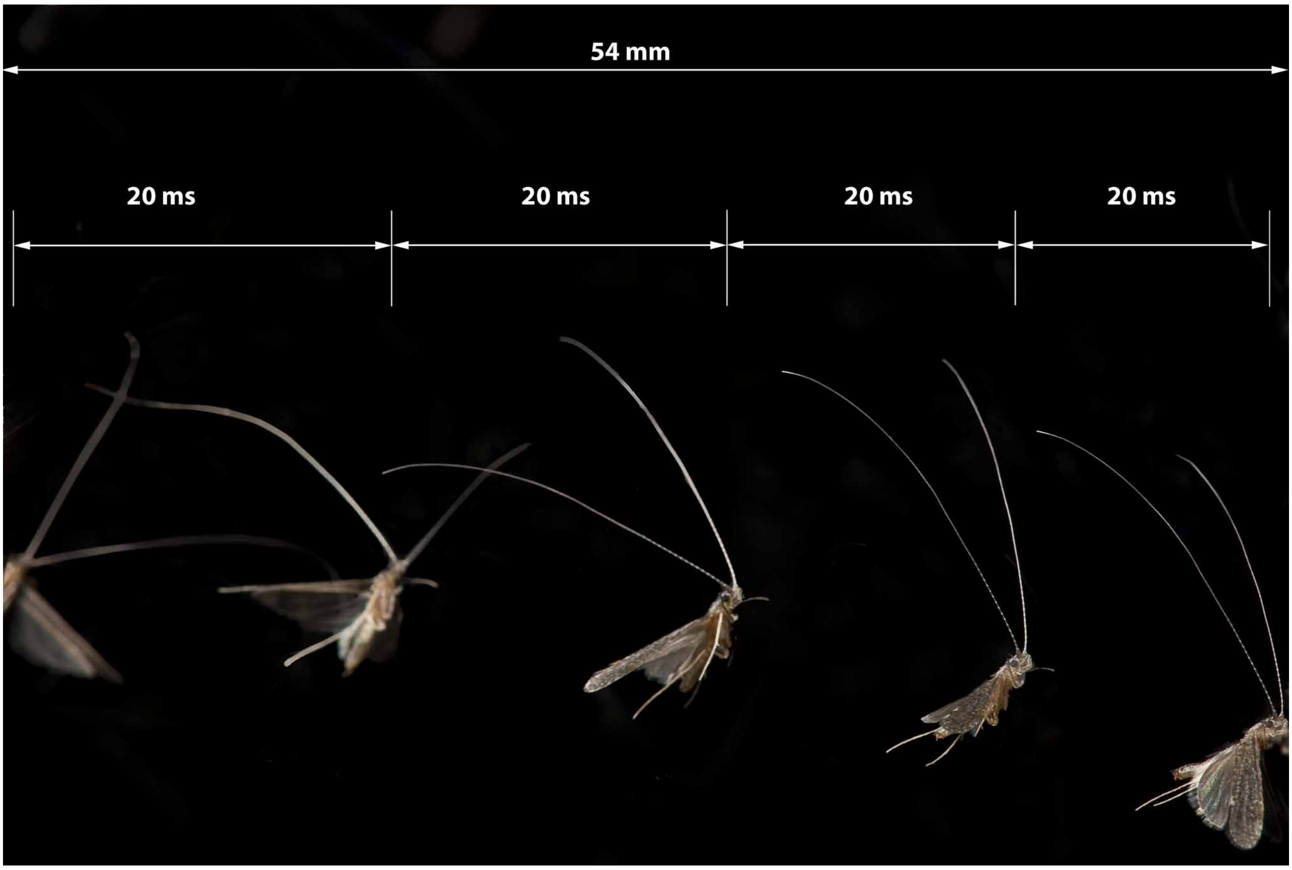

FIGURE 5. Scale bars and flash frequency points inserted, revealing time and distance covered in 80 milliseconds

Rigidly mounted rig and light set up

In order to remain accurately aligned, the array of laser light beams and sensors are mounted on a rigid frame about 330 mm across. Similarly, the camera is rigidly mounted relative to the frame so that it remains stable and focused on the desired spot. The camera auto focus and vibration reduction (image stabilisation) systems are disabled.

Commercially-available, super-actinic fluorescent lights (initially a Philips 12V tube and later two Eurolux FL/T5 were added) are attached to the rigid frame adjacent to the picture area in order to attract the insects towards the point where the camera is focused but outside of the picture frame. The camera lens and photographer are shielded from direct light coming from the tubes by reflectors around the light tubes (Fig. 6).

Field procedures:

After setting up the rig (Fig. 6), mounted on a sturdy tripod at a desired location beside the river, the following procedure was followed:

1. A plywood board is temporarily attached to the frame with a target sheet mounted in the same plane as the intersecting light beams. This target sheet is used for aligning and focusing the camera, and aligning the flash units. These settings remain unchanged throughout a photographic session. The target sheet is marked with a scale in millimetres so that the total size dimension of the captured image at the focal point can be recorded. The size of the photographed insects can be estimated by comparison with the recorded scale image.
2. A photograph of the target screen is taken to record the image dimensions for each photographic session (Fig. 7). Exposure and focus are also checked at this stage.

3. The board, with attached target sheet, is removed.
4. Each laser beam is individually tested to ensure correct functioning. Adjustments are made if necessary.
5. The full system is tested by manually breaking both beams by inserting a finger or thumb through the point of intersection of the laser beams (Fig. 8).
6. Once conditions are suitably dark and sufficient insects have been attracted to the UV light, the camera shutter is held open manually (using the ‘bulb’ setting on camera) and then released immediately after each firing of the flash. The maximum duration of holding the shutter open is usually limited to about 2 minutes in order to avoid gradual fogging by stray ambient light and to avoid the appearance of unwanted ‘noise’ in digital images.
7. After briefly checking the image obtained on the camera’s LCD screen the shutter is again held open to await the next triggering of the beams.

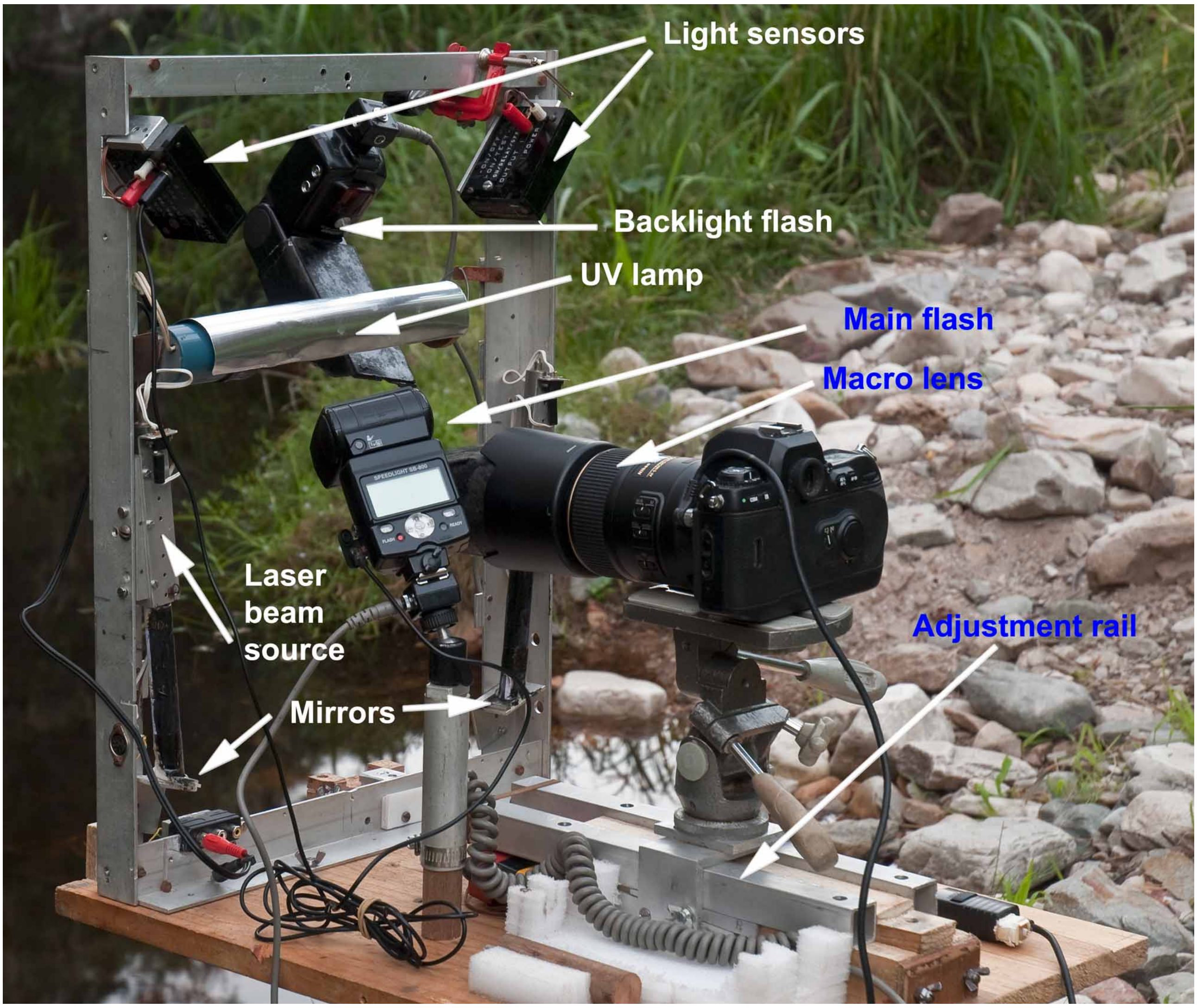

FIGURE 6. Details of insect photography rig set beside the river.

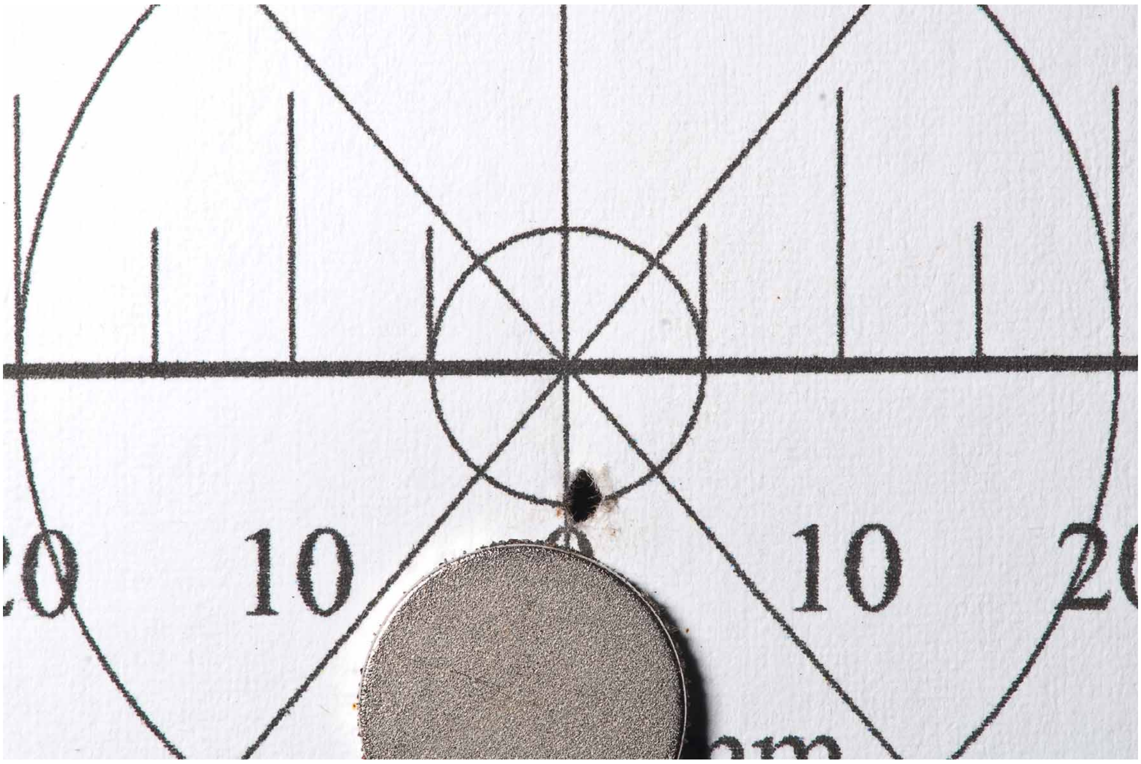

FIGURE 7. Photo of target sheet in situ, providing accurate focus and scale measurement.

FIGURE 8. System test: beams broken by thumb. Here a leptocerid broke the beams at the same time to superimpose its image.

Species identification

Examination of photographs may not provide sufficient detail to positively identify taxa to species level. Ideally, collection of specimens should correspond, in terms of timing and locality, with photographic sessions. Unfortunately, this was not always possible during the present study, but light trap collection of adults at the photographic site provided information of relative abundance and species composition at the site (Table 1). This, together with a comparison of the general appearance and size estimates from photographs with those of species positively-identified from light trap samples, enabled a deductive identification of species in photographs. Where species were recognized as undescribed they were designated the catalogue number allocated to specimens of the species first recorded in the Albany Museum collection.

TABLE 1. Record of relative abundance of Trichoptera collected in light traps set at the Groot River study site between April 2008 and January 2009. TSR472C and SCR258N refer to catalogue entries for undescribed species.

Species recorded %	**09/04/2008**	**07/10/2008**	**21/01/2009**
Athripsodes prionii Scott, 1958	0.2	1.2	
Athripsodes sp. TSR472C		0.9	
Athripsodes bergensis Scott, 1958	99.6	93.2	99.1
Leptecho sp. SCR258N		0.6	
Oecetis modesta (Barnard, 1934)	0.2		0.1
Oecetis sp. SCR164N		0.1	
Oecetis spp. females		0.6	0.1
Thylakion urceolum Barnard, 1934		0.1	0.1
Chimarra ambulans Barnard, 1934		0.4	0.1
Ecnomus thomasseti Mosely, 1932		2.8	
Ecnomus similis Mosely, 1932			0.1
Total numbers	533	673	3027

Results

On the basis of relative abundance of species at the time of collection (Table 1), as well as a comparison of gross morphological features of adults collected in light traps with those illustrated in photographs, it was assumed that all the photographs of Trichoptera illustrated in this paper were of *Athripsodes bergensis*, except for one figure (Fig. 19), identified as *Athripsodes* sp. TSR472C close to *A. schoenobates* (Barnard). More than 1200 flight images have been captured, some of which are illustrated in this paper. The majority of these photographs were of Trichoptera but species from other taxa, such as Ephemeroptera, Diptera and Lepidoptera, were also recorded. Clearly there is no control or choice over which species are recorded, other than by selection of the site, time of day, weather and season. The proportion of pictures of the different species photographed will therefore give an approximate idea of the relative abundance of those attracted to the UV light although, amongst other factors, the size of the insects will influence the abundance of figures because the probability of small insects breaking the beams is lower than it is for larger insects. During 3 separate light trap collecting sessions it was notable that *A. bergensis* was the dominant species representing more than 90% of the Trichoptera collected (Table 1).

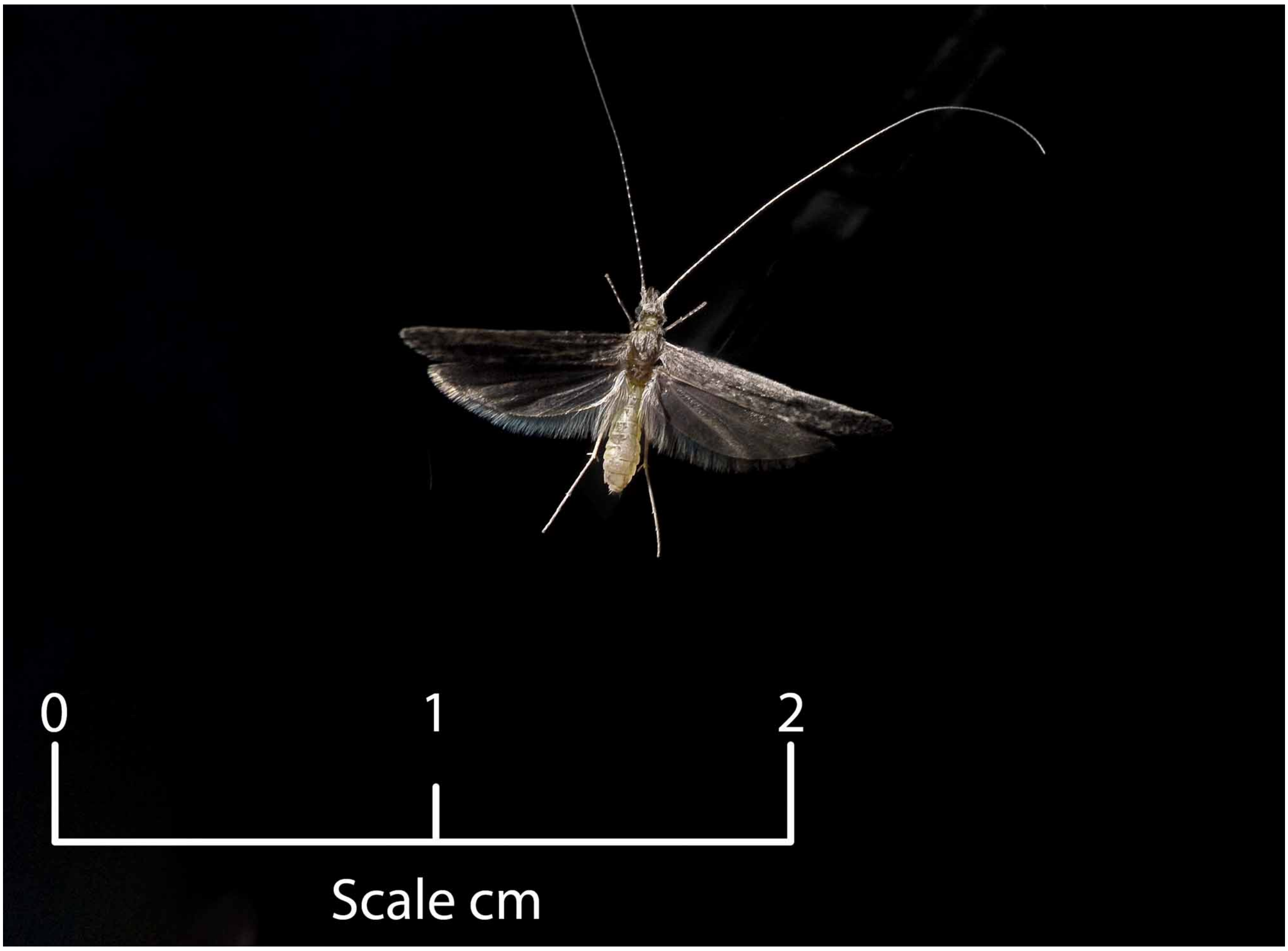

FIGURE 9. The flash is initiated by breaking both laser beams simultaneously, positioning the photographed insect very precisely. Depending on the position and orientation of the insect, it is possible to make accurate measurements of the wingspan and body length, which aid in identification.

Technical observations

While taking these photographs, the flight paths of the insects were unconstrained. As a result the attitude of the subject(s) and picture composition at the point of capture is unpredictable in any one image. However, from among the many random images, a wide variety of attitudes and flight manoeuvres of insects have been captured. The technique has been successful in adequately ‘freezing’ the flight motion and in achieving sharply focused images. Nevertheless, the narrow depth of field remains a limiting factor because of the large magnification used when photographing these small insects. It is often apparent that the body of the insect can be in focus while the extremities (e.g., wing tips) closer to and further from the camera are out of focus. It would be possible to obtain a greater depth of field by selecting smaller apertures and higher ISO settings but this would be at the expense of sharpness since very small apertures (of less than about f16) can result in noticeable loss of detail due to diffraction of light at the diaphragm.

In spite of the above limitations, the photographic technique has been successful in meeting expectations of capturing some high quality images of insects in free flight, although this applies to only a small proportion of the pictures taken.

Technical problems that required correction

A number of technical issues were resolved during the course of this project:

Accurate alignment of laser beam source, mirrors and sensors: This had to be maintained to ensure stable operation. In the event that one beam is non-functional the insects can initiate a picture by breaking the second beam anywhere along its length – the probability that an insect will break the functional beam outside the image area to give a blank image is relatively high. To minimise this problem a number of minor mechanical and electrical refinements were made to improve stability. Also to reduce the chance of insects settling on surfaces that obscure one of the beams (for example, by resting on a mirror or sensor) sections of the beam paths between laser source and mirror (including the mirror itself) were enclosed.

Background images: In early images, the red light of the laser beam was visible in the 'background area' of images and sometimes on the main subject as streaks and shapes ('ghosting') where insects had crossed one or both beams while the camera shutter was being held open (Fig. 10). To resolve this, the high intensity of the laser beams was greatly reduced by using poorly reflective mirror surfaces instead of highly reflective mirrors.

Problems relating to the size and shape of insects: Because of the very long antennae of many of the Trichoptera, the tips of the antennae were often outside the picture frame in many of the early images. To improve this situation the centre of focus of the camera was moved to a point above the point of intersection of the beams.

Lighting: To minimise flare from stray light hitting the camera lens, an additional lens hood was added to the camera lens and a hood was fitted to the backlight flash unit.

Protection from radiation: Reflective covers were placed on the UV light sources to deflect the light forward and away from the rig set-up to protect the eyes of observers against direct radiation and shield the camera lens in order to avoid fogging of images.

Preliminary observations on flight behaviour

The numbers of insects flying peaked between roughly 0.5 and 1.5 hours after sunset. Photography was largely confined to these times. Some of the photographs have been edited to remove confusing, out-of-focus insects flying in the background. The main subject(s) has been left unchanged.

The Trichoptera photographed were remarkably agile, performing loops and spirals (Figs 11, 12, 20–22) and weaving erratically around the light at considerable speed. In spite of dense concentrations of whirling insects at certain times there was little evidence of serious collisions between flying insects (Fig. 11, 12). They appeared to fly faster and with greater agility than the Lepidoptera that were observed at the light. They also appeared to be equally adept when flying upside down (Fig. 13) as when upright. They occasionally also dropped out of the sky head facing downwards with wings folded (Fig. 12).This was possibly to avoid night-flying predators such as bats and nightjars that were sometimes observed flying at the site.

A number of the female *A. bergensis* photographed were carrying large egg masses (Fig. 14). In an image recording unintended multiple exposures, in-flight copulation of *A. bergensis* was also recorded (Fig. 15).

From measurements on three repeat-flash images at 50 Hz flash frequency (see Fig. 5) the speed of flight was estimated to be typically about 0.4 to 1.2 m/sec. and wing beat frequency was estimated apparently at about 5 cycles per sec (but see below). Further measurements are required for a more accurate assessment of these parameters.

FIGURE 10. Initially the red laser beam was too powerful and was visible in the images where insects had crossed one of the beams before setting off the flash.

Fore- and hind wings of *A. bergensis* were observed to beat in phase (Figs 4, 5, 9, 16, 17, 18) which will minimise the drag created by wing-tip vortices (Ivanov 1991, Brackenbury 1995). The coupling of wings is also seen in *Athripsodes* sp. TSR472C (Fig. 19).

The wing motion in horizontal flight has an up and down component as well as a strong horizontal component. During the down beat, the wings move forward and down relative to the insect's body. At the bottom of the down stroke, the forewing tips appear to touch, or nearly touch, each other and reach forward and below the head (Fig. 16). On the up beat the wing tips of the forewing twist and curve to provide continued forward thrust and end up almost touching above the body and to the rear of the abdomen (Fig. 17). This motion, in which the wing tips describe an oval pattern relative to the body, maximises use of energy in flight. The curvature of the wings while in the upstroke and downstroke positions are illustrated (Fig. 18).

FIGURE 11. Erratic flight patterns recorded with the flash set to repeating mode at 50 Hz.

FIGURE 12. *Athripsodes bergensis* falling. Recorded in multi flash exposure at 20 millisecond intervals.

FIGURE 13. *Athripsodes bergensis* flying upside down.

FIGURE 14. Female *Athripsodes bergensis* with egg mass extruding from abdomen.

FIGURE 15. *Athripsodes bergensis in copula*, recorded during unplanned multiple flash exposure.

FIGURE 16. *Athripsodes bergensis* with wings at bottom of downstroke, showing wing tips in front of head.

FIGURE 17. *Athripsodes bergensis* with wing tips at the top of the upstroke, well behind the head.

FIGURE 18. The curvature of the wings of these 2 insects indicate that the wings of the lower insect are on the upstroke and those of the upper are on the downstroke.

FIGURE 19. *Athripsodes* sp. TSR472C (near *A. schoenobates*) showing wing coupling of fore- and hind wings.

Some photographs (Figs 20−22) were taken with continuous light from an incandescent quartz halogen lamp using a 0.6 second exposure together with a short flash burst at the end of the exposure period (rear curtain flash mode). In this mode the flying insect traces its own flight path and pattern with a ‘frozen’ flash image of it at the end of the flight trace. The insect trace appears red because the incandescent light is much redder (colour temperature less than 3000 degrees Kelvin) than the light from the flash (colour temperature c. 5000 degrees Kelvin). By inspection of the pattern traced it is possible to infer the frequency of wing beats more accurately than is possible with the stroboscope setting. Unfortunately, in the pictures illustrated (Fig. 20-22), none of the recorded images had a complete flight trace and the insects may have been out of the picture for part of the exposure duration of 600 milliseconds used during this study. Nevertheless the counts of completed wing beat cycles were in the order of 25 or more. This would indicate a wing beat frequency of not less than 42 Hz (i.e., 25/0.6). These estimates indicate that the wing beat assessment of about 5 Hz based on pictures produced by using stroboscopic flashes must be erroneous. The higher frequency seen in the incandescent images suggests that the error can be attributed to 'missed' wing beats within the 20 millisecond intervals between stroboscopic flashes. If it is assumed that one completed beat has been missed and that the wing has advanced about 20% of a cycle between each flash (as might be plausible from inspection of Figs 4, 5 for example) the actual wing beat frequency would then be 60 cycles per second (1.2 cycles in 20 milliseconds = 1.2 x 1000/20 Hz). If 2 cycles were missed, the frequency could be 110 Hz (2.2 x 50) and 160 Hz if 3 were missed. Such estimates are subject to a further assumption that the wing beat position between a few successive images can be used to deduce the proportion of a cycle completed between flashes. However the incandescent images also suggest that the upstroke of the wings is completed faster than the down stroke and the deductions of wing beat frequency from the stroboscopic images, which depict down stroke only, require adjustment for this factor which has not been determined at this stage.

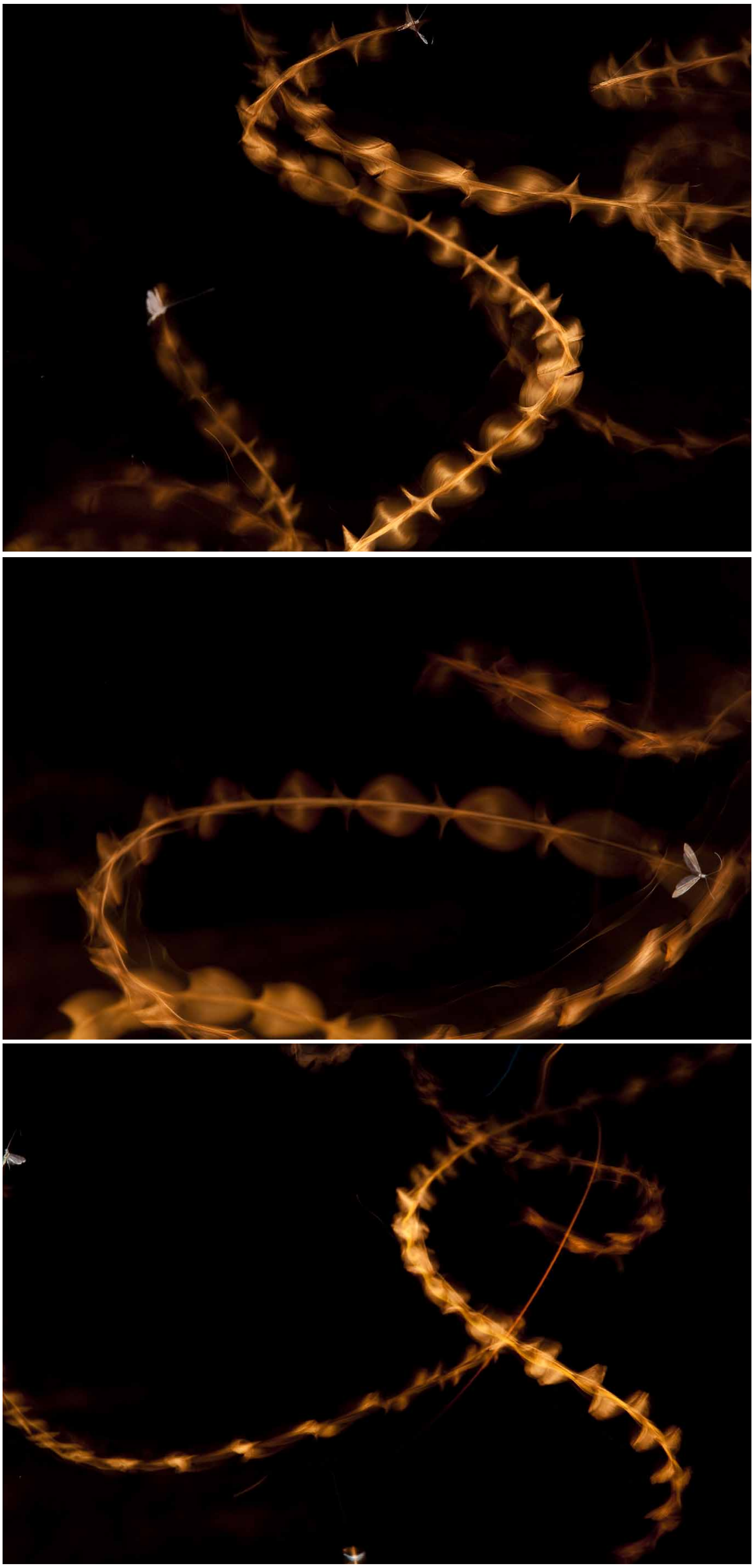

FIGURE 20–22. Caddisfly flight photographed under continuous incandescent light over 0.6-second exposure, ended by a flash. Insects trace their own flight paths.

Discussion

Possible modifications to the design and future options

Further investigations indicate a number of options that can be considered to improve the photographic setup described above. These include an upgraded sensor system (based on infra-red beams) that positively eliminates unintended multiple exposures as seen in Fig. 15. The infra-red beams also eliminate unwanted illumination occasionally seen when using laser beams and also avoid the need for reducing the laser intensity by means of partially reflecting mirrors.

The above options need to be investigated to improve the set up described in this paper. A recently-developed electronic system, the STOP SHOT Electronic flash Trigger system (Cognisys, 2009), that is now commercially advertised, could also be considered. It includes the improvement of features discussed above. Although the authors have not tested this commercial system, it could provide a convenient option for researchers wishing to use the techniques described in this paper. Whichever electronic circuitry is selected, it should be checked for compatibility with the flash units to which it will be connected.

This paper is mainly about the methods, but some interesting preliminary observations were made and are reported. There is much room for improvement, but the techniques offer a relatively inexpensive means for studying *in situ* nocturnal insect flight behaviour. This provides further opportunities for research in flight dynamics, behavioural ecology, and even systematics and evolution by evaluating how flight influences mating behaviour.

Acknowledgements

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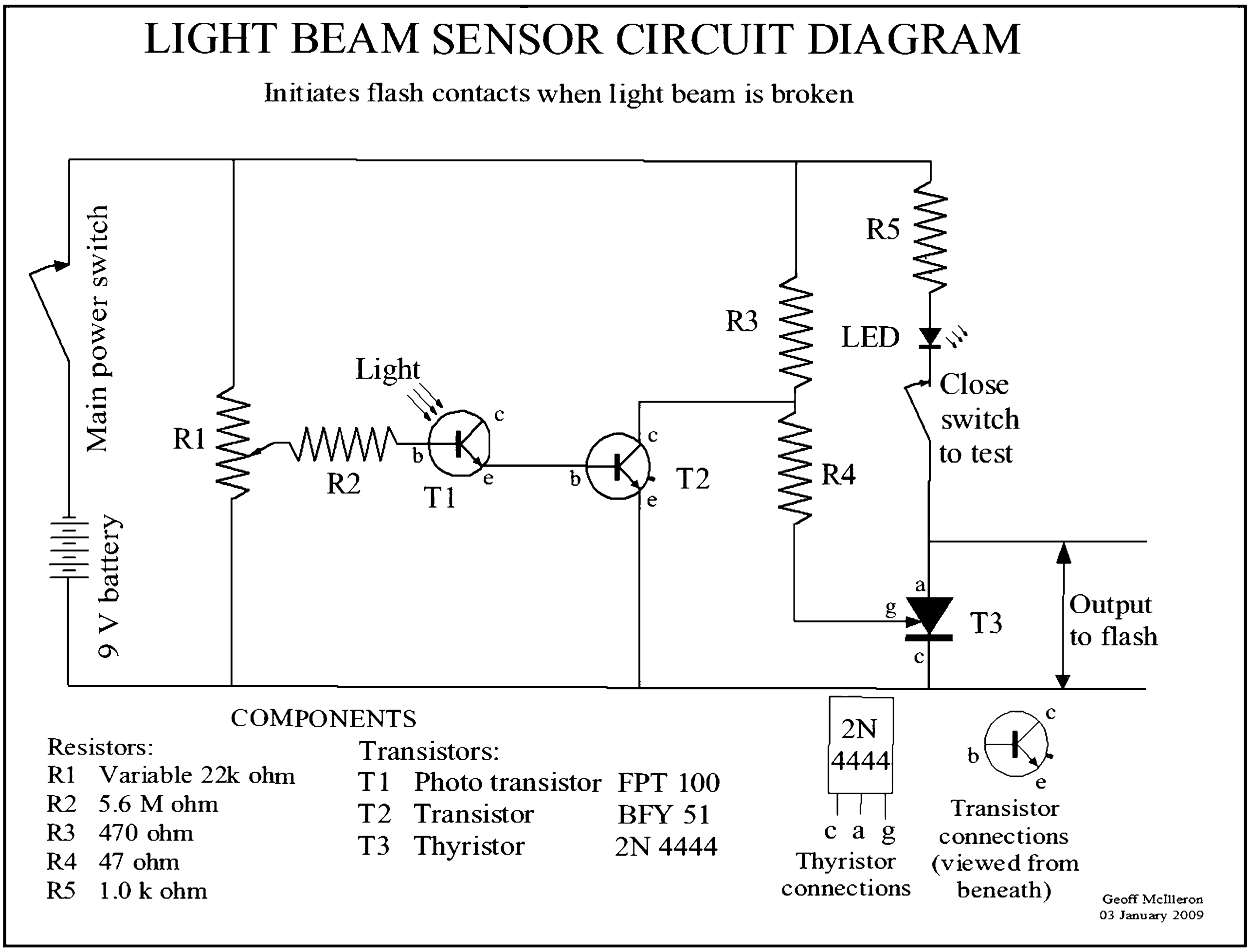
In view of the interest expressed by delegates to the conference in using the photographic techniques presented in this paper, the authors are prepared to construct and supply, at an agreed price, a limited number of complete kits (excluding cameras and flash units) to interested conference delegates. The kits for photographing insects in flight will be based on considerably improved designs which are now in regular use by the authors. If delegates wish to follow-up on this offer, they may enquire of one of the authors directly using the e-mail addresses indicated in the paper. In order to help in procuring the right quantities of needed materials, the authors would appreciate responses from interested delegates within 3 months of the date of this memorandum.



APPENDIX FIGURE 1. Circuit diagram of sensor used for detecting light beam interruptions. Two such sensors, one for each beam, were connected in series to initiate the flash. With this series arrangement, separate batteries are required for each sensor.